6. Nutritional value of insects for human consumption

6.1 NUTRITIONAL COMPOSITION

The nutritional values of edible insects are highly variable, not least because of the wide variety of species. Even within the same group of edible insect species, values may differ depending on the metamorphic stage of the insect (in particular, for species with a complete metamorphosis – known as holometabolous species – such as ants, bees and beetles), and their habitat and diet. Like most foods, preparation and processing methods (e.g. drying, boiling or frying) applied before consumption will also influence nutritional composition. A few scattered studies analyse the nutritional value of edible insects; however, these data are not always comparable due to the above-mentioned variations between insects and because of the varying methodologies employed to analyse the compounds. Moreover, where commonly consumed, insects comprise only a part of local diets. For example, in certain African communities insects form 5–10 percent of the protein consumed (Ayieko and Oriaro, 2008). Nevertheless, because of their nutritional value they are still a highly significant food source for human populations. Attempts are now being made to compile data on the nutritional value of insects (Box 6.1).

This chapter looks at nutritional aspects of insects for human consumption, while Chapter 8 touches on insects in relation to animal nutrition. The main components of insects are protein, fat and fibre; nutritional values are expressed in this chapter as dietary energy, proteins, fatty acids, fibres, dietary minerals and vitamins.

BOX 6.1

The FAO/INFOODS food composition database for biodiversity

The International Network of Food Data Systems (INFOODS), established in 1984, aims to stimulate and coordinate efforts to improve the quality and worldwide availability of food analysis data and to ensure that all people in different parts of the world can obtain adequate and reliable food composition data. INFOODS and FAO are collecting data on food composition and consumption at many levels (e.g. variety, cultivar and breed), and on wild and underused foods in order to promote biodiversity. The first version of the INFOODS Food Composition Database for Biodiversity, comprising analytical data from published and unpublished literature, was launched on 15 December 2010 and now includes the nutritional values of certain edible insects. To be included, nutritional values must be expressed as a 100 g edible portion on a fresh weight basis (FAO, 2012f).

Rumpold and Schlüter (2013) compiled nutrient compositions for 236 edible insects, as published in the literature (based on dry matter). Although significant variation was found in the data, many edible insects provide satisfactory amounts of energy and protein, meet amino acid requirements for humans, are high in monounsaturated and/or polyunsaturated fatty acids, and are rich in micronutrients such as copper, iron, magnesium, manganese, phosphorous, selenium and zinc, as well as riboflavin, pantothenic acid, biotin and, in some cases, folic acid.

6.1.1 Dietary energy

Ramos Elorduy *et al.* (1997) analysed 78 insect species from Oaxaca state, Mexico, and determined that caloric content was 293–762 kilocalories per 100 g of dry matter. For example, the gross energy (which is normally higher than metabolizable energy) of the migratory locust (*Locusta migratoria*) was in the range 598–816 kJ per 100 g fresh weight (recalculated from dry matter), depending on the insect's diet (Oonincx and van der Poel, 2011). Table 6.1 presents energy values expressed in kilocalories per 100 g fresh weight of selected wild and farmed insects worldwide.

TABLE 6.1
Examples of energy content of differently processed insect species, by region

Location	Common name	Scientific name	Energy content (kcal/100 g fresh weight)
Australia	Australian plague locust, raw	*Chortoicetes terminifera*	499
Australia	Green (weaver) ant, raw	*Oecophylla smaragdina*	1 272
Canada, Quebec	Red-legged grasshopper, whole, raw	*Melanoplus femurrubrum*	160
United States, Illinois	Yellow mealworm, larva, raw	*Tenebrio molitor*	206
United States, Illinois	Yellow mealworm, adult, raw	*Tenebrio molitor*	138
Ivory Coast	Termite, adult, dewinged, dried, flour	*Macrotermes subhyalinus*	535
Mexico, Veracruz State	Leaf-cutter ant, adult, raw	*Atta mexicana*	404
Mexico, Hidalgo State	Honey ant, adult, raw	*Myrmecocystus melliger*	116
Thailand	Field cricket, raw	*Gryllus bimaculatus*	120
Thailand	Giant water bug, raw	*Lethocerus indicus*	165
Thailand	Rice grasshopper, raw	*Oxya japonica*	149
Thailand	Grasshopper, raw	*Cyrtacanthacris tatarica*	89
Thailand	Domesticated silkworm, pupa, raw	*Bombyx mori*	94
The Netherlands	Migratory locust, adult, raw	*Locusta migratoria*	179

Source: FAO, 2012f.

6.1.2 Protein

General information about proteins and various amino acids, as well as protein quality, are provided in Box 6.2.

BOX 6.2
Proteins and amino acids ("food chemistry")

Proteins are organic compounds consisting of amino acids. They are important elements of food nutrition but also contribute to its physical and sensory properties. The nutritive value depends on several factors: **protein content**, which varies widely among all foods; **protein quality**, which depends on the kind of amino acids present (essential or non-essential) and whether the quality complies with human needs; and **protein digestibility**, which refers to the digestibility of the amino acids present in the food.

Amino acids are the building blocks required for the biosynthesis of all proteins through human metabolism to ensure proper growth, development and maintenance.

Essential amino acids are indispensable because the body cannot synthesize them and so must obtain them through food. Eight amino acids are classified as essential: phenylalanine, valine, threonine, tryptophan, isoleucine, methionine, leucine and lysine.

Xiaoming *et al.* (2010) evaluated the protein content of 100 species from a number of insect orders. Table 6.2 shows that protein content was in the range 13–77 percent of dry matter and that there was large variation between and within insect orders.

TABLE 6.2
Crude protein content, by insect order

Insect order	Stage	Range (% protein)
Coleoptera	Adults and larvae	23 – 66
Lepidoptera	Pupae and larvae	14 – 68
Hemiptera	Adults and larvae	42 – 74
Homoptera	Adults, larvae and eggs	45 – 57
Hymenoptera	Adults, pupae, larvae and eggs	13 – 77
Odonata	Adults and naiad	46 – 65
Orthoptera	Adults and nymph	23 – 65

Source: Xiaoming *et al.*, 2010.

Bukkens (1997) showed that the mopane caterpillar had lower protein content when dry-roasted than when dried (48 and 57 percent, respectively). The same was true for termites: protein content was 20 percent in raw termites and 32 percent and 37 percent of fresh weight when fried and smoked, respectively (the difference due to varying water content). Protein content is high in insects and therefore using insects as food can help increase dietary quality when including animal source proteins.

TABLE 6.3
Comparison of average protein content among insects, reptiles, fish and mammals

Animal group	Species and common name	Edible product	Protein content (g/100 g fresh weight)
Insects (raw)	Locusts and grasshoppers: *Locusta migratoria, Acridium melanorhodon, Ruspolia differens*	larva	14–18
	Locusts and grasshoppers: *Locusta migratoria, Acridium melanorhodon, Ruspolia differens*	Adult	13–28
	Sphenarium purpurascens (chapulines – Mexico)	Adult	35–48
	Silkworm (*Bombyx mori*)	Caterpillar	10–17
	Palmworm beetles: *Rhynchophorus palmarum, R. phoenicis, Callipogon barbatus*	Larva	7–36
	Yellow mealworm (*Tenebrio molitor*)	Larva	14–25
	Crickets	Adult	8–25
	Termites	Adult	13–28
Cattle		Beef (raw)	19–26
Reptiles (cooked)	Turtles: *Chelodina rugosa, Chelonia depressa*	Flesh	25–27
		Intestine	18
		Liver	11
		Heart	17–23
		Liver	12-27
Fish (raw)	Finfish	Tilapia	16–19
		Mackerel	16–28
		Catfish	17–28
	Crustaceans	Lobster	17–19
		Prawn (Malaysia)	16–19
		Shrimp	13–27
	Molluscs	Cuttlefish, squid	15–18

Source: FAO, 2012f.

The protein content of insects also varies strongly by species. As shown in Table 6.3, some insects compare favourably with mammals, reptiles and fish.

Protein content also depends on the feed (e.g. vegetables, grains or waste). Grasshoppers in Nigeria that are fed with bran, which contains high levels of essential fatty acids, have almost double the protein content of those fed on maize. The protein content of insects also depends on the metamorphosis stage (Ademolu *et al.*, 2010): adults usually have higher protein content than instars (Table 6.4).

TABLE 6.4
Variation in insect protein along subsequent metamorphosis phases of the variegated grasshopper, *Zonocerus variegatus* (raw), Ogun state, Nigeria

Insect stage	Gram protein/100 g fresh weight
Instar:	
First	18.3
Second	14.4
Third	16.8
Fourth	15.5
Fifth	14.6
Sixth	16.1
Adult	21.4

Source: Ademolu, Idowu and Olatunde, 2010.

In Mexico, the protein content of 78 evaluated species ranged from 15 percent to 81 percent of dry matter and protein digestibility ranged from 76 percent to 98 percent (Ramos Elorduy *et al.*, 1997). Comparable studies have been conducted on single species, such as the mopane caterpillar (Headings and Rahnema, 2002) and the field cricket *Gryllus testaceus* (Wang *et al.*, 2004). Bukkens (2005) analysed the protein content of 17 caterpillar species of the family Saturniidae (of which the mopane caterpillar is a member) and found protein content in the range 52–80 percent of dry matter.

6.1.3 Amino acids

Cereal proteins that are key staples in diets around the world are often low in lysine and, in some cases, lack the amino acids tryptophan (e.g. maize) and threonine. In some insect species, these amino acids are very well represented (Bukkens, 2005). For example, several caterpillars of the Saturniidae family, palm weevil larvae and aquatic insects have amino acid scores for lysine higher than 100 mg amino acid per 100 g crude protein. Yet in order to make recommendations regarding the use of edible insects as food enrichments in diets, it is important to look at traditional diets in their entirety, and in particular at staple foods, and to compare their nutritional quality against that of edible insects locally available in the region. In the Democratic Republic of the Congo, for example, lysine-rich caterpillars complement lysine-poor staple proteins. Likewise, people in Papua New Guinea eat tubers that are poor in lysine and leucine but compensate for this nutritional gap by eating palm weevil larvae. The tubers provide tryptophan and aromatic amino acids, which are limited in palm weevils (Bukkens, 2005). In countries in Africa where maize is a staple food – such as Angola, Kenya, Nigeria and Zimbabwe – there are occasionally widespread tryptophan and lysine deficiencies; supplementing diets with termite species like *Macrotermes bellicosus* (Angola) should be a relatively easy step, as they already form accepted parts of traditional diets. Not all termite species are suitable, however: *Macrotermes subhyalinus*, for example, is not rich in these amino acids (Sogbesan and Ugwumba, 2008).

6.1.4 Fat content

Fat is the most energy-dense macronutrient in food. It consists of triglycerides, which all have a glycerol molecule and three fatty acids in their molecular makeup. Box 6.3 provides information on saturated, unsaturated and essential fatty acids.

BOX 6.3

Fatty acids

Saturated fatty acids. In general, saturated fatty acids have a higher melting point than unsaturated fatty acids and are solid at room temperature. They are often found in animal products and tropical oils (e.g. palm and coconut oil).

Unsaturated fatty acids. These consist of mono-unsaturated fatty acids and polyunsaturated fatty acids and are generally liquid at room temperature. Unsaturated fats consist of at least one double bond, and yield slightly less energy during metabolism. They are mostly present in vegetable oils, nuts and seafood. Unsaturated fatty acids are considered better for human health than saturated fat.

Essential fatty acids. These cannot be synthesized by the human body, which means that they must be obtained from the diet. They include some omega-3 fatty acids (e.g. α-linolenic acid) and some omega-6 fatty acids (e.g. linoleic acid).

An example of an edible insect species with high fat content (38 percent of dry weight) is Australia's witchetty grub (Box 6.4). These are very rich in oleic acid, which is an omega-9 mono-unsaturated fatty acid (Naughton, Odea and Sinclair, 1986).

BOX 6.4

Witchetty grub

Witchetty (also spelt witjuti) grubs refer to the large, white, wood-eating larvae of several moths (Cossidae and Hepialidae) and beetles (Cerambycidae) found in Australia. However, the term applies mostly to the larva of the cossid moth, *Xyleutes* species, which can be found 60 cm below ground feeding on the roots of river red gums (*Eucalyptus camaldulensis*). The grub is the most important insect food of the desert and was a staple in the diets of Aboriginal women and children. Edible either raw or lightly cooked in hot ashes, they are sought by Aborigines as a high-protein, high-fat food. The raw witchetty grub tastes like almonds; when cooked, the skin becomes crisp like roast chicken and the inside becomes light yellow in colour.

Edible insects are a considerable source of fat. Womeni *et al.* (2009) investigated the content and composition of oils extracted from several insects (see Table 6.5). Their oils are rich in polyunsaturated fatty acids and frequently contain the essential linoleic and α-linolenic acids. The nutritional importance of these two essential fatty acids is well recognized, mainly for the healthy development of children and infants (Michaelsen *et al.*, 2009). Greater attention has been paid to the potential deficient intake of these omega-3 and omega-6 fatty acids in recent times, and insects could play an important role, in particular in landlocked developing countries with lower access to fish food sources, by supplying these essential fatty acids to local diets (N. Roos, personal communication, 2012). The fatty acid composition of insects appears to be influenced by the plants on which they feed (Bukkens, 2005). The presence of unsaturated fatty acids will also give rise to rapid oxidation of insect food products during processing, causing them to go rancid quickly.

TABLE 6.5
Fat content and randomly selected fatty acids of several edible insect species consumed in Cameroon

Edible insect species	Fat content (% of dry matter)	Composition of main fatty acids (% of oil content)	SFA, MUFA or PUFA1
African palm weevil (*Rhynchophorus phoenicis*)	54%	Palmitoleic acid (38%)	MUFA
		Linoleic acid (45%)	PUFA
Edible grasshopper (*Ruspolia differens*)	67%	Palmitoleic acid (28%)	MUFA
		Linoleic acid (46%)	PUFA
		α-Linolenic acid (16%)	PUFA
Variegated grasshopper (*Zonocerus variegates*)	9%	Palmitoleic acid (24%)	MUFA
		Oleic acid (11%)	MUFA
		Linoleic acid (21%)	PUFA
		α-Linolenic acid (15%)	PUFA
		γ-Linolenic acid (23%)	PUFA
Termites (*Macrotermes* sp.)	49%	Palmitic acid (30%)	SFA
		Oleic acid (48%)	MUFA
		Stearic acid (9%)	SFA
Saturniid caterpillar (*Imbrasia* sp.)	24%	Palmitic acid (8%)	SFA
		Oleic acid (9%)	MUFA
		Linoleic acid (7%)	PUFA
		α-Linolenic acid (38%)	PUFA

Note: 1SFA – saturated fatty acids; MUFA and PUFA – mono and poly unsaturated fatty acids.
Source: Womeni *et al.*, 2009.

6.1.5 Micronutrients

Micronutrients – including minerals and vitamins – play an important role in the nutritional value of food. Micronutrient deficiencies, which are commonplace in many developing countries, can have major adverse health consequences, contributing to impairments in growth, immune function, mental and physical development and reproductive outcomes that cannot always be reversed by nutrition interventions (FAO, 2011c). In insects, metamorphic stage and diet highly influence nutritional value, making all-encompassing statements on the micronutrient content of insect species of little value. Moreover, the mineral and vitamin contents of edible insects described in the literature are highly variable across species and orders. Consumption of the entire insect body generally elevates nutritional content. A study on small fish, for example, suggested that consuming the whole organism – including all tissues – is a better source of minerals and vitamins than the consumption of fish fillets. In much the same way, consuming the entire insect is expected to provide higher micronutrient content than eating individual insect parts (N. Roos, personal communication, 2012).

6.1.6 Minerals

Minerals play an important part in biological processes. The recommended dietary allowance (RDA) and adequate intake are generally used to quantify suggested daily intake of minerals. Table 6.6 compares the RDA of minerals for a 25-year-old male with those provided by the mopane caterpillar. From the table, it is clear that the mopane caterpillar – like many edible insects – is an excellent source of iron. Most edible insects boast equal or higher iron contents than beef (Bukkens, 2005). Beef has an iron content of 6 mg per 100 g of dry weight, while the iron content of the mopane capterpillar, for example, is 31–77 mg per 100 g. The iron content of locusts (*Locusta migratoria*) varies between 8 and 20 mg per 100 g of dry weight, depending on their diet (Oonincx *et al.*, 2010).

Edible insects are undeniably rich sources of iron and their inclusion in the daily diet could improve iron status and help prevent anaemia in developing countries. WHO has flagged iron deficiency as the world's most common and widespread nutritional disorder. In developing countries, one in two pregnant women and about 40 percent of preschool children are believed to be anaemic. Health consequences include poor pregnancy outcomes, impaired physical and cognitive development, increased risk of morbidity in children and reduced work productivity in adults. Anaemia is a preventable deficiency but contributes to 20 percent of all maternal deaths. Given the high iron content of several insect species, further evaluation of more edible insect species is warranted (FAO/WHO, 2001b).

Zinc deficiency is another core public health problem, especially for child and maternal health. Zinc deficiencies can lead to growth retardation, delayed sexual and bone maturation, skin lesions, diarrhea, alopecia, impaired appetite and increased susceptibility to infections mediated via defects in the immune system (FAO/WHO, 2001b). In general, most insects are believed to be good sources of zinc. Beef averages 12.5 mg per 100 g of dry weight, while the palm weevil larvae (*Rhynchophorus phoenicis*), for example, contains 26.5 mg per 100 g (Bukkens, 2005).

TABLE 6.6

Recommended intake of essential minerals per day compared with the mopane caterpillar (*Imbrasia belina*)

Mineral	Intake recommendation for 25-year-old males (mg per day)*	Mopane caterpillar (mg per 100 g dry weight)
Potassium	4 700	1 032
Chloride	2 300	–
Sodium	1 500	1 024
Calcium	1 000	174
Phosphorus	700	543
Magnesium	400	160
Zinc	11	14
Iron	8	31
Manganese	2.3	3.95
Copper	0.9	0.91
Iodine	0.15	–
Selenium	0.055	–
Molybdenum	0.045	–

Note: * Dietary reference intakes (DRIs): recommended dietary allowances and adequate intakes, minerals, Food and Nutrition Board, Institute of Medicine, National Academies.

Source: Bukkens, 2005.

6.1.7 Vitamins

Vitamins essential for stimulating metabolic processes and enhancing immune system functions are present in most edible insects. Bukkens (2005) showed for a whole range of insects that thiamine (also known as vitamin B1, an essential vitamin that acts principally as a co-enzyme to metabolize carbohydrate into energy) ranged from 0.1 mg to 4 mg per 100 g of dry matter. Riboflavin (also known as vitamin B2, whose principle function is metabolism) ranged from 0.11 to 8.9 mg per 100 mg. By comparison, wholemeal bread provides 0.16 mg and 0.19 mg per 100 g of B1 and B2, respectively. Vitamin B12 occurs only in food of animal origin and is well represented in mealworm larvae, *Tenebrio molitor* (0.47 µg per 100 g) and house crickets, *Acheta domesticus* (5.4 µg per 100 g in adults and 8.7 µg per 100 g in nymphs). Nevertheless, many species have very low levels of vitamin B12, which is why more research is needed to identify edible insects rich in B vitamins (Bukkens, 2005; Finke, 2002).

Retinol and β-carotene (vitamin A) have been detected in some caterpillars, including *Imbrasia* (=*Nudaurelia*) *oyemensis*, *I. truncata* and *I. epimethea*; values ranged from 32 µg to 48 µg per 100 g and 6.8 µg to 8.2 µg per 100 g of dry matter for retinol and β-carotene, respectively. The levels of these vitamins were less than 20 µg per 100 g and less than 100 µg per 100 g in yellow mealworm larvae, superworms and house crickets (Finke, 2002; Bukkens, 2005; Oonincx and Poel, 2011). Generally, insects are not the best source of vitamin A (D. Oonincx, personal communication, 2012). Vitamin E featured in the palm weevil larvae, for example, which boasts 35 mg and 9 mg per 100 g of α-tocopherol and β+γ tocopherol, respectively; the daily recommended intake is 15 mg (Bukkens, 2005). The vitamin E content in ground and freeze-dried silkworm powder (*Bombyx mori*) is also relatively high, at 9.65 mg per 100 g (Tong, Yiu and Liu, 2011).

6.1.8 Fibre content

Insects contain significant amounts of fibre, as measured by crude fibre, acid detergent fibre and neutral detergent fibre. The most common form of fibre in insects is chitin, an insoluble fibre derived from the exoskeleton. A significant amount of data is available on the fibre content of insects, but it has been produced by various methods and is not easily comparable (H. Klunder, personal communication, 2012). Finke (2007) estimated the chitin content of insect species raised commercially as food for insectivores, and found it to range from 2.7 mg to 49.8 mg per kg (fresh) and from 11.6 mg to 137.2 mg per kg (dry matter).

Chitin, the main component of the exoskeleton of an insect, is a long-chain polymer of N-acetyl glucosamine – a derivative of glucose. Chitin is much like the polysaccharide cellulose found in plants, which is largely believed to be indigestible by humans, although chitinase has been found in human gastric juices (Paoletti *et al.*, 2007). Chitin has also been associated with defence against parasitic infections and some allergic conditions. The above study, carried out among Italians, showed an absence of chitinase activity in 20 percent of cases. Chitinase activity is more prevalent in tropical countries where insects are regularly consumed; there may be a lower rate of chitinase activity in Western countries due to the absence of chitin in the diet. Some argue that chitin acts like a dietetic fibre (Muzzarelli *et al.*, 2001), and this could imply a high-fibre content in edible insects, especially species with hard exoskeletons (Bukkens, 2005).

6.2 BEEF VERSUS INSECTS: AN EXAMPLE OF THE MEALWORM

Finke (2002) explored the nutritional value of several insect species, including the yellow mealworm (*Tenebrio molitor*). The larvae of the beetle have been mentioned as a promising option for mass rearing in Western countries because the species is endemic in temperate climates and easy to farm on a large scale, it has a short life cycle, and farming expertise is already available, particularly in the pet food industry. In the study by Finke (2002), insects were fasted for 24 hours to void their intestinal tract. The following conclusions were made (on a dry weight basis except for moisture and energy):

- **Macronutrient composition.** The fat content of beef is higher than that of mealworm larvae. Beef has slightly lower moisture content than mealworms and is marginally higher in protein and metabolizable energy.
- **Amino-acids.** Beef is higher in a.o. glutamic acid, lysine and methionine and lower in a.o. isoleucine, leucine, valine, tyrosine and alanine, compared with mealworms.
- **Fatty acids:** Beef contains more palmitoleic, palmitic and stearic acid than mealworms, but far higher values in essential linoleic acids were present in mealworms. Howard and Stanley-Samuelson (1990) analysed the phospholipid fatty acid composition of the adult *T. molitor* and found that over 80 percent of these fatty acids consisted of palmitic, stearic, oleic and linoleic acids. Finke (2002) found the same fatty acids in high amounts in *T. molitor* larvae. Polyunsaturated fatty acids are mostly found as phospholipids (Howard and Stanley-Samuelson, 1990).

- **Minerals.** Mealworms contain comparable values of copper, sodium, potassium, iron, zinc and selenium.
- **Vitamins.** Mealworms have generally higher vitamin content than beef, with the exception of vitamin B12.

TABLE 6.7
Average approximate analysis of selected *Tenebrio molitor* and beef as a percentage of dry matter except for moisture content

	T. molitor[1]	Beef
Moisture (% of fresh weight)	61.9	52.3
Protein	49.1	55.0
Fat	35.2	41.0
Metabolizable energy (kcal/kg)	2 056	2 820

Notes: [1] Mean body mass 0.13 g. Data presented based on a single analysis.
Source: Adapted from Finke, 2002, and USDA, 2012, by D. Oonincx.

TABLE 6.8
Average amino acid content of *Tenebrio molitor* and beef (amounts in g/kg dry matter unless stated otherwise)

Amino acid	*T. molitor* g/kg dry matter	Beef g/kg dry matter
Essential		
Isoleucine	24.7	16
Leucine	52.2	42
Lysine	26.8	45
Methionine	6.3	16
Phenylalanine	17.3	24
Threonine	20.2	25
Tryptophan	3.9	–
Valine	28.9	20
Semi-essential		
Arginine	25.5	33
Histidine	15.5	20
Methionine + cysteine	10.5	22
Tyrosine	36.0	22
Non-essential		
Alanine	40.4	30
Aspartic acid	40.0	52
Cysteine	4.2	5.9
Glycine	27.3	24
Glutamic acid	55.4	90
Proline	34.1	28
Serine	25.2	27
Taurine (mg/kg)	210	–

Source: Adapted from Finke, 2002, and USDA, 2012, by D. Oonincx.

The extent to which generalizations can be made about the nutrient content of *T. molitor*, presented in tables 6.7, 6.8 and 6.9, is limited, since data were from a single study and insect growth and development and nutritional composition depend on the specific diet of the insect (Davis and Sosulski, 1974; Anderson, 2000; Finke, 2002). *Tenebrio molitor* larvae, for example, need a dietary carbohydrate concentration of at

TABLE 6.9
Fatty acid content of *Tenebrio molitor* and beef on a dry matter basis

Fatty acid	Saturation	*T. molitor*[1]	Beef
Essential			
Linoleic	Omega-6 polyunsaturated	91.3	10.2
Linolenic	Omega-3 polyunsaturated	3.7	3.9
Arachidonic	Omega-6 polyunsaturated	–	0.63
Non-essential			
Capric	Saturated	–	1.05
Lauric	Saturated	< 0.5	1.05
Myristic	Saturated	7.6	13
Pentadecanoic	Saturated	< 0.5	–
Palmitic	Saturated	60.1	99
Palmitoleic	Omega-7 monounsaturated	9.2	17
Heptadecanoic	Saturated	< 0.5	–
Heptadecenoic	Omega-7 monounsaturated	0.8	–
Stearic	Saturated	10.2	48
Oleic	Omega-9 monounsaturated	141.5	159
Arachidic	Saturated	0.8	–
Eiconenoic	Omega-9 monounsaturated	–	0.63
Others		0.5	–

Notes: Hyphens indicate values that are not available. Values with inequalities indicate the detection limit of the assay; contents were lower than this limit. [1] Data based on a single analysis.

Source: Adapted from Finke, 2002, and USDA, 2012, by D. Oonincx.

least 40 percent to develop, and optimal growth is reached when the insect is grown on diets containing 70 percent carbohydrates (Behmer, 2006). Additionally, larvae grow and develop faster when a water source is available than when reared on dry food only (Urs and Hopkins, 1973a). Larvae reared in the presence of moisture are, moreover, heavier; this difference in weight is due not to higher water content but to a higher fat content because although insects can be fed on low-value organic waste streams it will affect their nutritional values, resulting in values lower than shown in tables 6.8 and 6.9.

6.3 INSECTS AS PART OF DIETS

6.3.1 The role of insects in food regimens: traditional diets

Traditional foods are those accepted by a community – through habit and tradition – to be desirable and appropriate sources of food. Traditional foods are accessible locally and within a given natural environment from farming or wild harvesting and constitute important elements in dietary regimens worldwide.

> The food systems of indigenous people show the important role of a diversified diet based on local plant and animal species and traditional food for health and well-being. In most cases, the increase of processed and commercial food items over time results in a decrease in the quality of the diet. Countries, communities or cultures that maintain their own traditional food systems are better able to conserve local food specialties with a corresponding diversity of crops and animal breeds. They are also more likely to show a lower prevalence of diet-related diseases (FAO, 2009b).

People in Africa, Asia and Latin America eat insects as regular parts of their diets. They may do so not only because conventional meats such as beef, fish and chicken are unavailable and insects therefore are vital sources of protein, but also because insects are considered important food items, often delicacies.

The problem is not simply convincing the West to consume insects, but also making sure that traditional practices of eating edible insects do not disappear as food regimens westernize. In countries where edible insects constitute regular elements in traditional diets, the shift towards Western foods constitutes a real threat to entomophagy. To counter this, efforts are being made to merge the traditional practice of insect eating with more popular foods. In Mexico, for example, it is not uncommon to find tortillas enriched with yellow mealworms, a traditional source of protein (Aguilar-Miranda *et al.*, 2002) (Box 6.5).

BOX 6.5

Don Bugito: creative and traditional Mexican food cart

Monica Martinez is a 36-year-old artist. Using art as a means, she wants to convince people to consider insects as a viable food source. This is the driving factor behind Don Bugito – launched in 2011 – a street food cart project which sells edible insect treats that are healthy for both people and the planet at street parties, festivals and food fairs. Inspired by prehispanic and contemporary Mexican cuisine, Don Bugito features a creative and traditional use of edible insects, grown organically and naturally in California, where Martinez is based. "San Francisco's foodie culture and its large Asian and Latino communities – whose cuisines already include edible insects – make the city a natural testing ground," says the artist. The cart features familiar Mexican ingredients – soft, blue corn tortillas, chilies and cheeses – along with protein-rich insects also found in prehispanic fare. The plump larvae of the wax moth fill tacos, along with peppers and a mint-cilantro salsa (Campbell, 2011). Martinez serves additional toasted crickets and, for dessert, caramelized mealworms on top of Mexican vanilla ice cream.

Source: Sweet, 2011.

6.3.2 How important are edible insects for protein intake in traditional diets?

The importance of edible insects on a global scale is difficult to estimate. Statistics and information are scarce and only available from a few, very specific studies. Nevertheless, such studies can provide an idea of how important edible insects are in various food systems and offer insights into the possibilities for developing the sector at a global scale.

Among indigenous peoples, insect gathering can be an important activity for food acquisition (see Chapter 3). A co-study of the Centre for Indigenous Peoples' Nutrition and Environment and FAO evaluated the nutritional and cultural importance of various traditional food items of 12 indigenous communities[11] from different parts of the world (see Table 6.11) (Kuhnlein, Erasmus and Spigelski, 2009). It found that the nutritional importance of insects in the Ingano community in Columbia was particularly significant. For example, the mojojoy larvae of May beetles and June beetles, which are both eaten in the Ingano community, are particularly rich in fat. Hormigas (Formicidae ants) also provide important sources of energy, and can be collected year round. The community described the attributes of the insects as follows:

- **Hormigas** (Formicidae ants). They are nutritious, very popular, improve growth, strengthen immune defences and provide proteins, vitamins and minerals.
- **Mojojoy** (May or June beetles). They are nutritious, improve growth and act as a medicine for pulmonary affections, their fat helps prevent pulmonary problems, and they provide proteins, vitamins and minerals.

[11] Ainu (Japan), Awajun (Peru), Baffin Inuit (Canada), Bhil (India), Dalit (India), Gwich'in (Canada), Igbo (Nigeria), Ingano (Colombia), Karen (Thailand), Maasai (Kenya), Nuxalk (Canada) and Pohnpei (Federated States of Micronesia).

Leaf-eating and litter-feeding invertebrates provide many Amerindian groups with important, underappreciated food sources. In the Amazon Basin, at least 32 Amerindian groups use terrestrial invertebrates as food (Paoletti *et al.*, 2000). The consumption of invertebrates provides significant amounts of animal protein (see Table 6.10), especially during lean times when fish and game are scarce. The Guajibo, for example, who live at the savannah border (at Alcabala Guajibo, Amazonas, Venezuela) rely mostly on insects, especially grasshoppers and larvae of the palm weevil *Rhynchophorus palmarum*. During the rainy season (July to August) over 60 percent of their animal protein is derived from insects. By selecting these small invertebrates, Amerindians choose their animal food from food webs in the rainforest that have the highest energy flow and which constitute the greatest renewable stock of readily available nutrients. The consumption of leaf-eating and litter-feeding invertebrates by forest-dwelling peoples as a means of acquiring protein, fat and vitamins offers a new perspective for the development of sustainable animal food production.

TABLE 6.10
Annual consumption of invertebrates in the Tukanoan village of Iapu (Rio Papuri, Vaupes, Columbia), composed of about 100 people

Name	Mean fresh weight consumed (kg/year)	Percentage of total number of invertebrates consumed
Atta soldiers and queens (three species)	100	29.3
Syntermes soldiers (three species)	133	39.0
Caterpillars (five species)	96	28.1
Vespidae larvae and pupae (three species)	2	0.60
Melaponinae larvae and pupae (one species)	1.5	0.44
Rhynchophorus palmarum larva	6	1.7
Beetle larvae boring on wood and dead wood (four species[1])	2.5	0.73

Note: [1] Four species (Scarabaeidae, Buprestidae, Cerambycidae, Passalidae).
Source: Paoletti *et al.*, 2000.

A mid-twentieth century study in the southwest of the Democratic Republic of the Congo found that animal protein was obtained from large game, crickets and grasshoppers during the dry season and largely from caterpillars during the rainy season (see also Chapter 2) (Adriaens, 1951). Fish, rodents, reptiles and various insect larvae were eaten year-round. The estimated production of dried caterpillars in the district of Kwango between 1954 and 1958 was nearly 300 tonnes per year. Moreover, in six provinces of the Democratic Republic of the Congo, insects constituted an average of 10 percent of the animal protein in daily diets (up to 15–22 percent in western provinces), with fish and game meat the two primary sources of protein, at 47 percent and 30 percent, respectively (Gomez, Halut and Collin, 1961). More recently, it was found that in the city of Kananga in the country's southwest, 28 percent of the inhabitants ate insects, mainly termites, caterpillars and beetle larvae, at an average of 2.4 kg of insects per month (Kitsa, 1989). Only palm beetle larvae and soldier termites (20 percent of the edible insect species), however, were available in markets throughout the year, while the remainder, in particular caterpillars and flying termites, were only seasonally available (December to April).

Food consumption data on wild, underused, indigenous and traditional plant and animal foods, however, remain limited and fragmented (FAO, 2010c). As the importance of food biodiversity becomes increasingly acknowledged, more research needs to be directed towards the consumption and composition of a wide variety of foods, including insects. Specifically, research is needed on the nutritional composition of wild, underused, indigenous and traditional insects and food biodiversity more generally, and data need to be compiled in accessible databases. To this end, an international network for data on food biodiversity was set up in 2010 within the INFOODS network (Box 6.1).

TABLE 6.11
Traditional food items of four indigenous communities from different parts of the world: the Awajun (Peru), the Ingano (Colombia), the Karen (Thailand) and the Igbo (Nigeria)

Insects as traditional foods	English name	Local name
Awajun, Peru		
Coleoptera	Palm weevil larvae	Bukin
Hymenoptera (*Brachygastra* spp.)	Wasp larvae	Ete téji
Hymenoptera (Formicidae)	Ant	Maya
Ingano, Colombia		
Hymenoptera: *Atta* spp.	Leaf-cutting ant	Hormiga arriera
Coleoptera	Beetle	Mojojoy
Karen, Thailand		
Orthoptera: Gryllidae (*Gryllus bimaculatus*)	Field cricket	Xer-lai-zu-wa
Igbo, Nigeria		
Coleoptera	Beetle	Ebe
Isoptera: Termitidae (2 spp.)	Termite	Aku-mkpu, aku-mbe
Coleoptera: Curculionoidea (3 spp.)	Palm weevil larvae (palm, raffia palm)	Akpa-nkwu, akpa-ngwo, nzam
Orthoptera: Gryllidae	Cricket	Abuzu
Orthoptera: Acrididae	Locust	Wewe, igurube

Source: Kuhnlein, Erasmus and Spigelski, 2009.

6.4 SUSTAINABLE DIETS

> Sustainable diets are those diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally accepted, accessible, economically fair and affordable; nutritional adequate, safe and healthy; while optimizing natural and human resources. (FAO, 2010b)

The need to feed a growing global population inevitably places continuous pressure on crop production, which in turn contributes further to the degradation of natural resources (FAO, 2009a). Difficulties arising from climate change, moreover, are set to compound present problems in production. Currently, FAO activities on sustainable diets explore linkages and synergies among food biodiversity, nutrition, food composition, food production, agriculture, urban agriculture (the Food for the Cities programme) and sustainability. The underlying objective is to improve food and nutritional security and provide more ecologically sound food recommendations to consumers and policymakers, including clarifying what is meant by an environmentally sustainable food system (FAO, 2009b). Edible insects as food fit comfortably within this environmentally sound scenario (see Chapter 5) and, by extension, ought to be considered prime candidates as both food staples and supplements, as well as more generally for their role in sustainable diets.

6.5 EDIBLE INSECTS IN EMERGENCY RELIEF PROGRAMMES

According to the UN's Standing Committee on Nutrition, the largest single contributor to disease is malnutrition. In emergency situations, disease can often contribute to or be a direct result of malnutrition. This not only involves sustaining the *quantity* of food people get, but also the *quality* of food. Not enough (or too much) food, the wrong types of food, and the body's response to a wide range of infections that result in the malabsorption of nutrients or the inability to use nutrients properly to maintain health are all factors influencing malnutrition. From a clinical point of view, malnutrition is characterized by the inadequate or excess intake of protein, energy and micronutrients such as vitamins. This definition also includes the frequent infections and disorders that are the result of an inadequate diet (WHO, 2013).

In areas where food insecurity is salient – 70 countries around the world – fortified blended food products (FBFs) are typically distributed to the most vulnerable peoples. FBFs are blends of partially precooked and milled cereals, such as soya, beans and pulses, fortified with micronutrients. Special adaptations may contain vegetable oil or milk powder. Corn soya blend is the main blended food distributed by the UN's World Food Programme, although wheat soya blend is also used. FBFs are largely designed to provide protein and micronutrient supplements in food assistance programmes. They are also commonly used in World Food Programme Supplementary Feeding and Mother and Child Health programmes (Pérez-Expósito and Klein, 2009).

The problem, however, is that the principal ingredients of FBFs (such as soy) are generally not part of traditional diets, nor, in many countries, are they locally available crops, making them ill-suited from nutritional, social and ecological points of view, particularly within the framework of sustainable diets (FAO, 2010b). Considering the protein and micronutrient content of many edible insects, their minimal ecological impact, their availability and, above all, their cultural appropriateness in a large majority of developing countries where food insecurity is a primary concern, their use in FBFs ought to be considered.

BOX 6.6

WinFood: alleviating childhood malnutrition by improved use of traditional foods

WinFood, a project funded by the Consultative Research Committee for Development Research and Danida in Denmark, aims to develop nutritionally improved foods for infants and young children, based on the improved use of traditional foods. Farmed vegetables, fruit and animal-source foods are nutritious but expensive, and consumption is limited in this target group. An unbalanced diet with too few non-staple foods, moreover, leads to the inadequate intake of iron, zinc and vitamin A in particular and is a major cause of childhood malnutrition. The idea of WinFood is to contribute to alleviating child malnutrition by focusing on traditional food systems based on semidomesticated or wild indigenous plant or animal foods (such as fruits, roots, small fish, snails, frogs and insects) and on traditional processing practices such as fermentation, germination and the soaking of staple and non-staple foods.

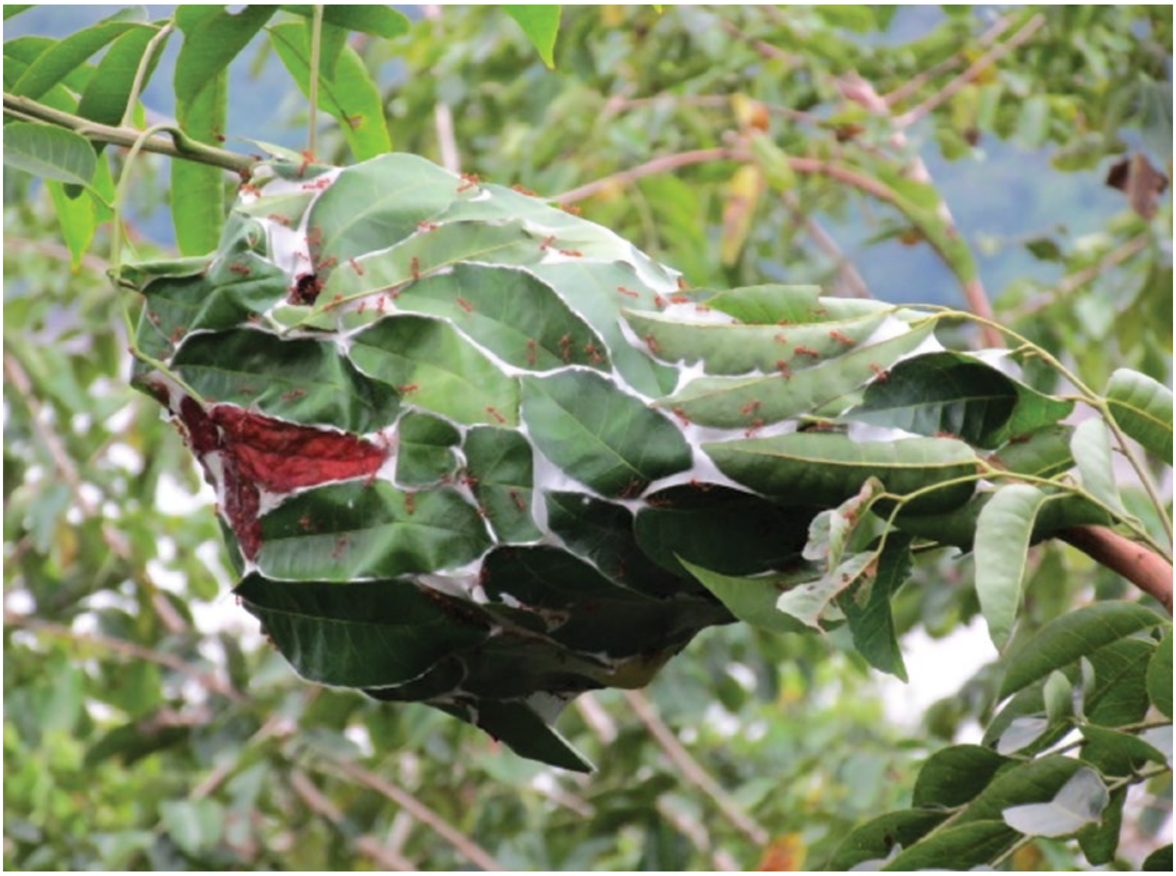
The WinFood concept is being developed through parallel studies in Cambodia and Kenya, two countries with very different cultural and ecological settings. Based on the results, generic guidelines for a WinFood strategy will be developed for implementation at the household level or through local small and medium-sized enterprises.

Edible insects – as traditional local foods in both Cambodia and Kenya – play an important role because they are locally available and are important sources of zinc and iron. For this reason, two WinFood products have been developed:

- WinFood Cambodia, which consists of rice, fish and spiders (*Haplopelma albostriatum*), among other food items;
- WinFood Kenya, which typically includes amaranth grain, maize, fish and termites (*Macrotermes subhyalinus*).

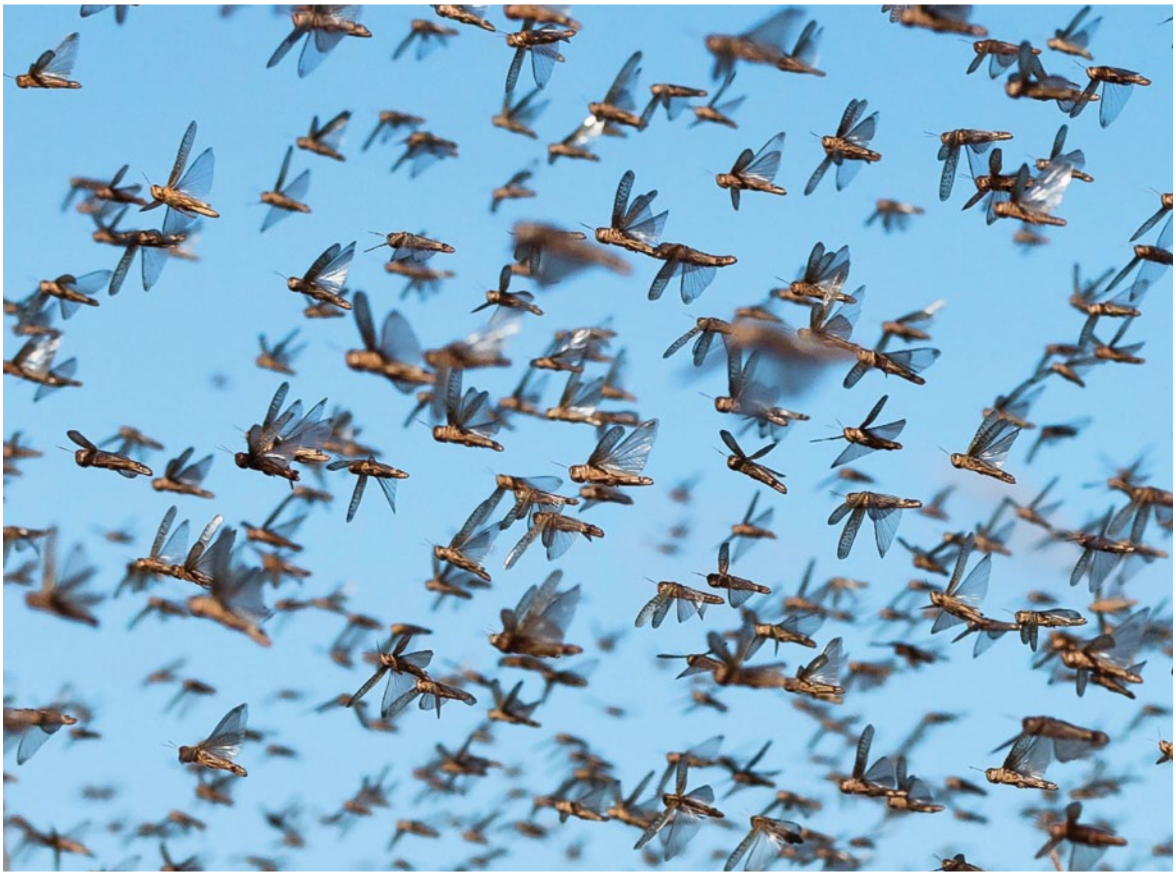
While results are promising, the lack of food standards for edible insects remains a major obstacle to further development (see chapters 10 and 14).

Source: N. Roos, personal communication, 2012.



Weaver ants

Cochineal on Opuntia cactus, La Palma, Canary Islands



FAO/YASUYOSHI CHIBA

A dense swarm of locusts as seen during spraying operations, Madagascar

ARNOLD VAN HUIS

Termite mound

JOOST VAN ITTERBEECK

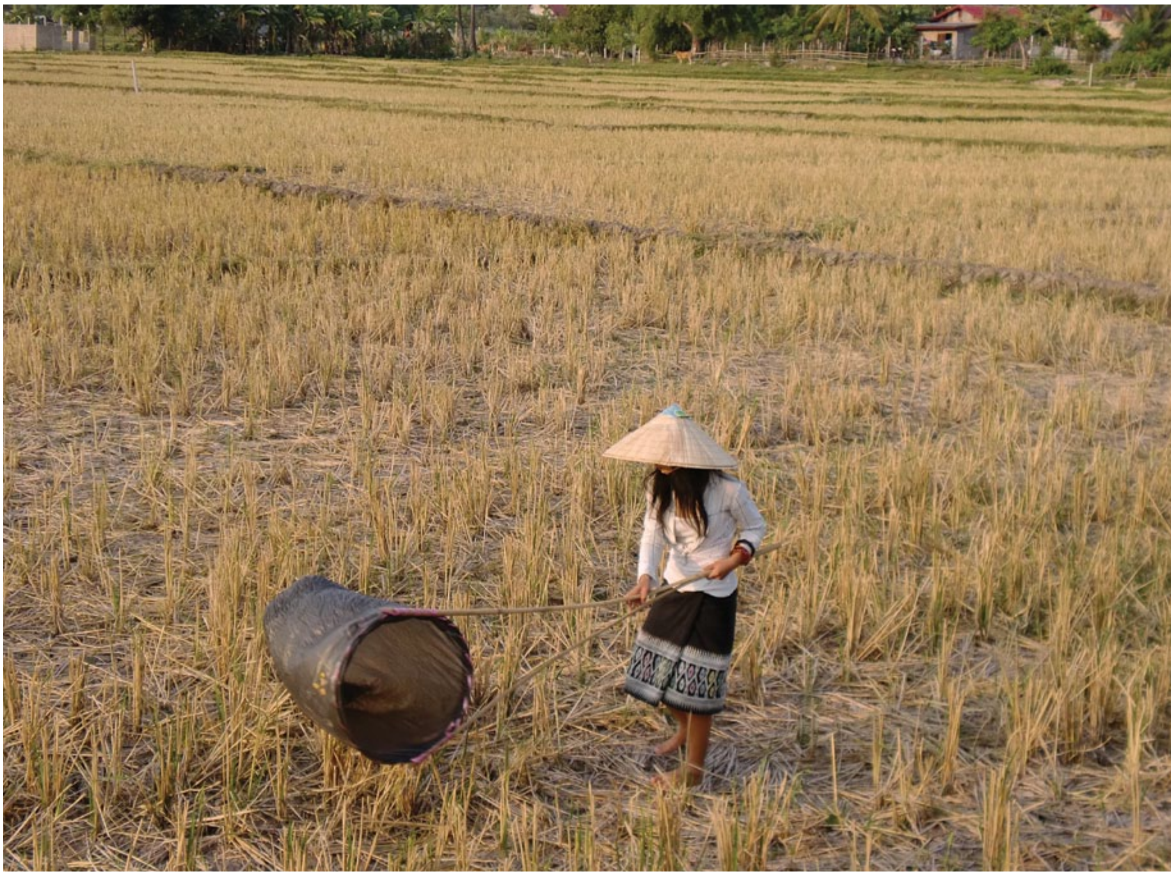
Harvesting weaver ant larvae and pupae in Laos


ARNOLD VAN HUIS

Cricket trapping, Laos


PAUL VANTOMME

Seperating mealworms from chaff, the Netherlands


HARMKE KLUNDER

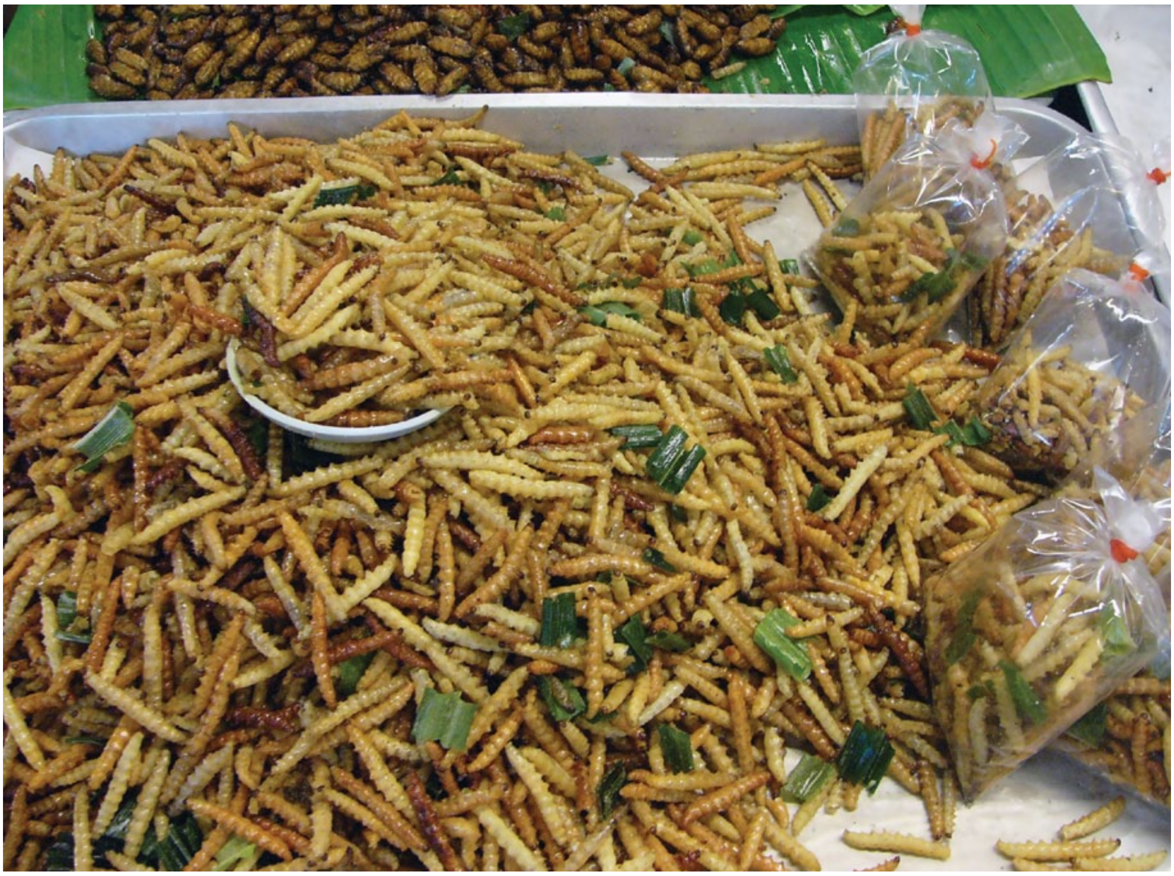
A woman harvests grasshoppers in Laos

LAUREN HEATON

Developing feed for aquaculture systems from Black solider fly larvae

MARCUS HARRISON

Shield bug snacks

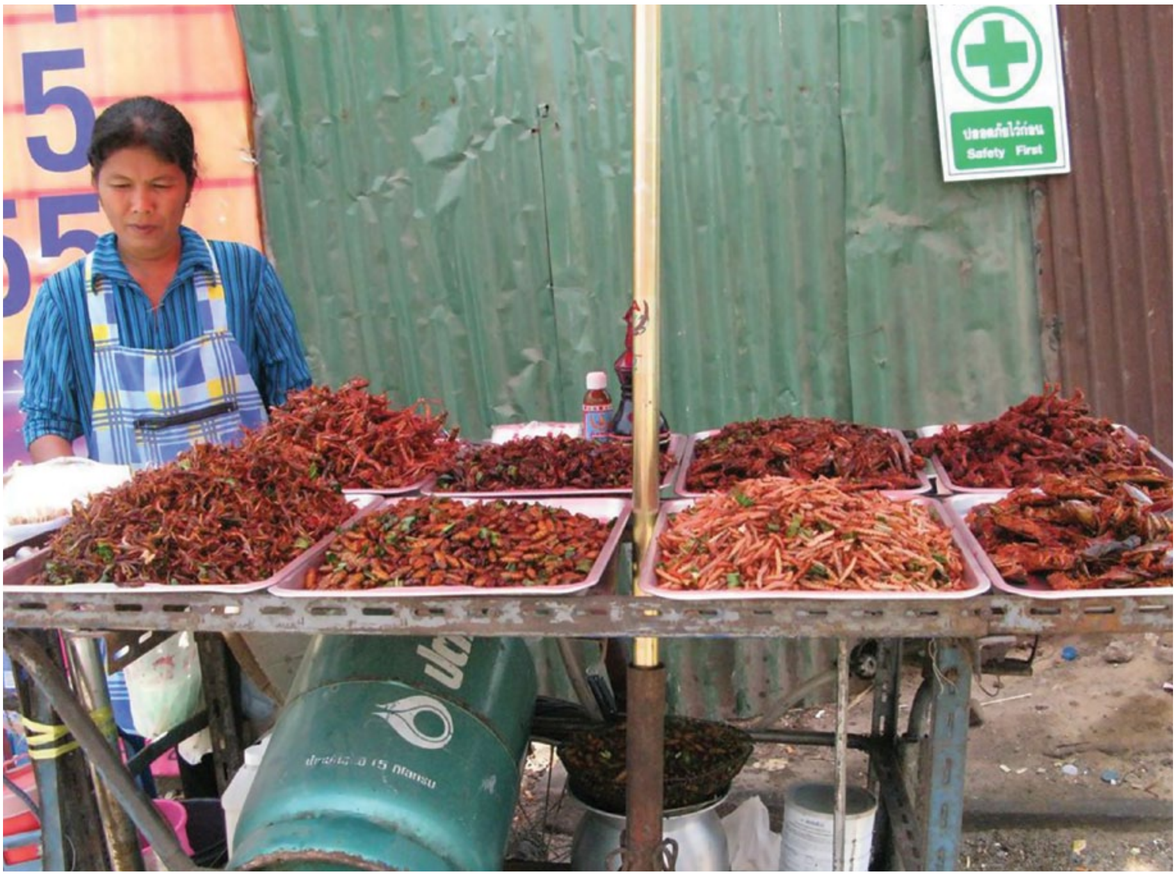


FAO - PATRICK DURST

Bamboo borers cooked and prepared for sale at a local market in Chaing Mai, Thailand

BENJAMIN HARINK

Inside a Japanese ornamental bug store

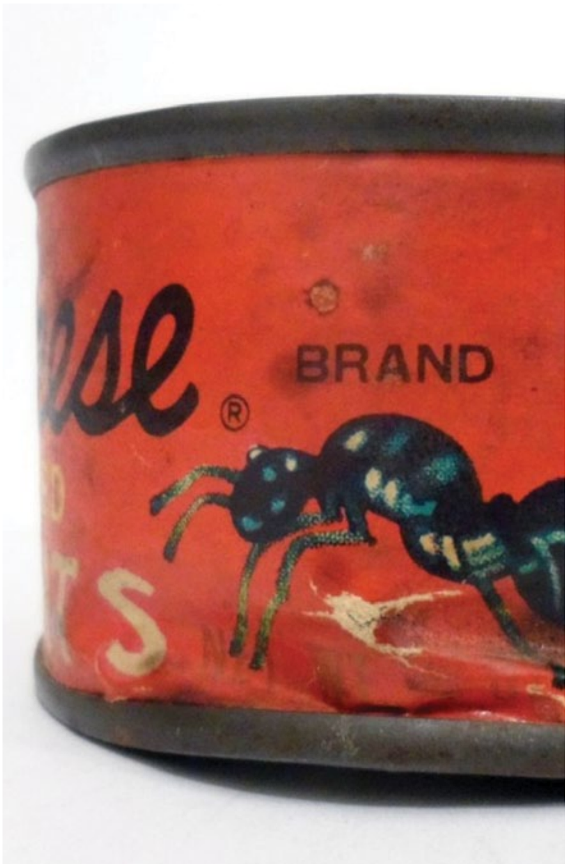


DAWN STARIN

A variety of insects for sale as street food in Bangkok, Thailand


FRANK SHULZ

Chapulines vendors in Oaxaca, Mexico

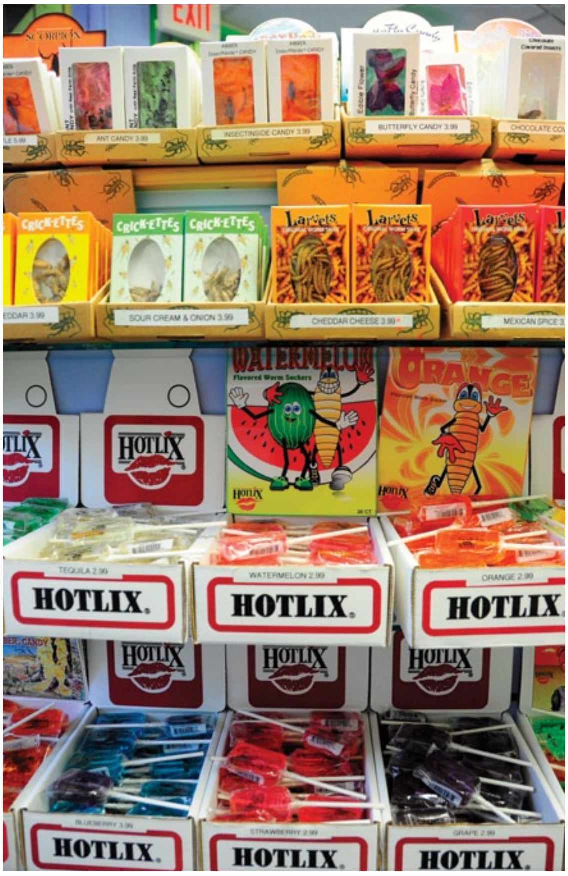


DAVID SKINNER

Antique chocolate covered ant tin, USA


FAO/GIULIO NAPOLITANO

Caterpillars for sale in Kinshasa, Democratic Republic of the Congo



AFTON HALLORAN

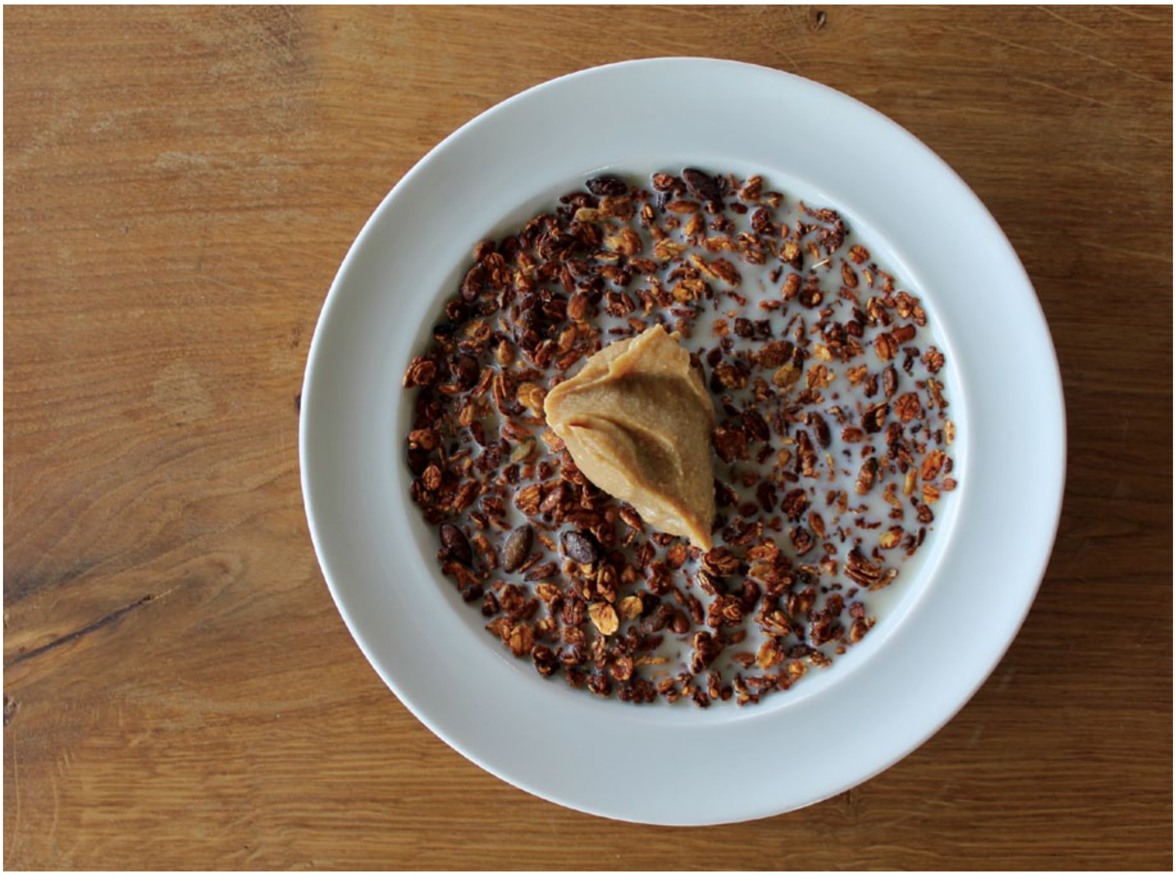
Insect snacks and candies for sale, Canada


MICHAEL FULLER

Scorpions for sale, China

AGRIPROTEIN

Feeding trials with magmeal made from the common housefly



JOSH EVANS

Bee larvae granola with bee larvae yoghurt, Nordic Food Lab, Copenhagen