Insects as Food

15

Geetanjali Mishra and Omkar

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15.1 Introduction

Conservative estimates indicate that world population is likely to reach nine billion by the year 2050. This increase in population would further place an untenable strain on the land owing to the need for increased agricultural production as well as housing and other basic amenities. As the increase in population continues unabated, the biggest question facing the world is how to feed these growing numbers adequately in the years to come. The possibility of increasing agricultural production is also seriously curtailed due to the limitation of available land suitable for it. The other option of venturing to the increased consumption of non-vegetarian food is fraught with even greater damage to the ecosystem. Under the current global food system, 30% of ice-free land is used for rearing large livestock, and the increasing population would require us to at least double it. This would in turn lead to soil degradation due to overgrazing, erosion and compaction, water pollution due to run off and augmentation of greenhouse gas emissions through production of methane gases and ammonia wastes. What other options for increasing food production to feed the many hungry mouths in the near future then lie with us?

Insects have been an important component of human diet across time and land zones. Holt (1885) mentions that instances and examples of insect consumption can be found from each and every part of the human-inhabited globe across different eras of human civilization. Historically, human food records show that like their

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Omkar (ed.), *Industrial Entomology*, DOI 10.1007/978-981-10-3304-9_15

closest primate relatives, human diets have been largely omnivorous ranging from leafy matter, roots, fruits and nuts to animals including insects. In view of the gatherer lifestyle of early man, it seems highly likely that gathering of not only fruits, nuts, roots, etc. but also insects could have been a component of the early life as well as diet of human populations.

What is however interesting is that a large number of historical records as well as text book accounts, while mentioning that ancient man hunted, gathered and scavenged a large variety of food items, have consistently failed to mention insects as one of them (Diamond 1991; Jones et al. 1992; Ingold 1994). Bodenheimer (1951) mentioned that the ignorance by scholars of such a major diet source for early man as well as in many cultures is baffling, despite the mention of such instances in the accounts of a number of travellers, naturalists and anthropologists. It is worth wondering, whether this complete ignorance of well-established facts has to do with the largely Western world squeamishness with insect consumption. Being exceptions to the trend, Bodenheimer (1951) and Defoliart (2012) have contributed extensively in discussing the importance of edible insects historically and also in detailing the many insect species that are consumed as food by the native populations in Australia, Africa, Asia and Americas, particularly the tropics.

While the ubiquity of insects as food is well recognized and accepted in many parts of the world, yet, a large part of the populace is affected by the Western affliction of disgust for consumption of insects or entomophagy. Western countries per se look down upon the consumption of insects leading to an outlook that has led to their reduced and rather infrequent consumption as well as restricted discussions in the programmes of international organizations and donor agencies that deal with food security issues (http://www.fao.org/forestry/edibleinsects/65424/en/). This is also a reason for lack of promotion of entomophagy (DeFoliart 1999; Yen 2009).

Bequaert (1921) and Bodenheimer (1951) can be credited with providing an overview of entomophagic practices the world over, with the latter making extensive listings of the various insects consumed as food. However, while these workers played a major role in recognizing entomophagy as an acceptable food practice the world over, they did not encourage its adoption in the non-entomophagy world. It was in particular that DeFoliart, who first as an editor of the *Food Insects Newsletter* (DeFoliart et al. 2009) and then via an online biography (DeFoliart 2012), focussed the attention of the masses on the massive potential, nutritional content and ecosustainability of insects. Reviews on entomophagy practices in different regions (Cherry 1991; Ramos-Elorduy et al. 2002; van Huis 2003; Yhoung-Aree and Viwatpanich 2005) as well as on the nutritional aspects of entomophagy (Bukkens 1997) have been published. Around 1900 insect species are consumed across the globe and the number continues to increase (http://www.ent.wur.nl/UK/Edible+insects/Worldwide+species+list/). The FAO branch of the UN has taken active steps since the beginning of this decade for assessing the role as well as potential of insects in providing food security to both humans and their livestock (http://www.fao.org/forestry/edibleinsects/74848/en/).

This review explores the entomophagic practices across the globe as well as whether insects should be actively considered as a sustainable and viable food resource for the massive human as well as animal population of the near future.

15.1.1 Entomophagic Practices Across the Globe

A huge number as well as variety of insects is consumed across the globe. Below is an overview of regions from where maximum incidence of entomophagy has been investigated and published.

15.1.1.1 Africa

Amongst a huge variety of insects consumed, caterpillars and termites (winged sexuals) are the most extensively consumed insects in Africa.

Out of a minimum of 22 families, more than 65 species of insects are consumed as food in Congo (Gomez et al. 1961). Of the total animal protein produced in Congo, insects account for a total of 10%. Similarly, they account for 30% of game, 47% for fishing, only 1% for fish culture, 10% for grazing animals and 2% for poultry (Gomez et al. 1961). In some districts of Congo, insect diets make up 37% of the total animal protein diet. Of the 30+ insect species consumed in Kwango and Kwilu districts of Congo, *Cirina forda* along with two more saturniid larvae are a major export component. In Southern Congo, at least 35 species of caterpillars are consumed (Malaisse and Parent 1980). Dried caterpillars of 23 species (including 17 Saturniidae) on analysis revealed that crude protein content accounted for 63.5% per 100 g, with iron levels being 335% of the daily intake.

In Angola, the commonly consumed termite, *Macrotermes subhyalinus*, and palm weevil larva, *Rhynchophorus phoenicis*, were found to have a high calorific value, 613 and 561 kcal/100 g, respectively, and the latter along with saturniid caterpillar, *Usta terpsichore*, had high levels of zinc, thiamine and riboflavin (Oliveira et al. 1976).

Most Nigerians have consumed or heard of consumption of insects, with usually the rural populations being more ready to admit the occurrence of such entomophagic practices versus the "educated elite". It was first recommended by Fasoranti and Ajiboye (1993) that malnutrition in Nigeria could be resolved through entomophagy. They also stated the necessity of the mass multiplication of insects versus exploitation of the natural sources for a continued and sustained supply. Mass rearing is also essential since the fast-occurring losses of natural habitats could constrain the availability of a food source. In case of *Anaphe venata*, the reduction of its host plant, *Triplochiton scleroxylon*, owing to excessive deforestation led to a drastic reduction in its availability in Nigeria (Ashiru 1988). These larvae are an extremely good source of fat (Ashiru 1988), having 611 kcal/100 g, but are also responsible for seasonal ataxia syndrome (Adamolekun 1993).

Entomophagy has been found not only to reduce the incidence of malnutrition but also to preserve biodiversity. The opening of national parks and sanctuaries to the local populations for harvesting of insects for food consumption has led to the decrease in poaching incidences in Malawi (Munthali and Mughogho 1992). This programme began in 1990, and it has been found that using gross margin analysis, insect collection and beekeeping (within parks) produced twice or more profits than many agricultural crops (Munthali and Mughogho 1992). What was also interesting was that these enterprises did not compete for labour with the other agricultural activities, leading to added advantage of higher earnings in the absence of labour conflicts. This was also the underlying reason behind low poaching incidences and could be a worthwhile step to consider and emulate for wildlife conservation.

During November–February, when food sources run low in Zambia, insects form a major source of nutrients, in comparison to the other available fruits and fresh mushrooms, containing only 2 g and 1 g protein, respectively. Silow's (1976) fieldwork recognized and acknowledged the importance of caterpillars as food in Zambia. Caterpillars are consumed as roasted snacks or as meat in porridge as main meals. The Mbunda tribe consumes 31 insects and markets 7. Most Zambian tribes find the meat of termites (*Macrotermes*) more delectable than meat of animals, birds and fishes.

More than 60 species of insects belonging to 15 families of 6 orders are consumed in Zambia. Honeybees from multiple genera produce multiple nutritional as well as commercial products (Mbata 1995). Honey not only is a food but also a liquor source for the people of Zambia. Wax is used in candle making and for conditioning the stretched skins on traditional drums. The immature stages (larvae and pupae) are consumed in multiple forms, viz. raw, boiled, roasted and fried. White (1961) notes that it is sacrilege and highly offending to interfere with a persons' marked hives in the Luvale tribe of Zambia. Not only honeybees but also caterpillars from Saturniidae family, locally known as *mumpa* (Bemba term), are highly treasured by people in Zambia and are a major animal protein source in areas of abundance (Holden 1991). Rich pickings (of about 20 l/day) for a week can garner a price that is equal to or more than a month's salary for a general worker in Zambia.

At least 40 species of insects belonging to 25 genera, 14 families and 7 orders are used as foods in Zimbabwe. Insects gathered from the wild are used as relish on the daily stiff cereal porridge consumed in rural diets. Insects are one of the cheapest sources of protein found here and play a major role in averting kwashiorkor (Chavunduka 1975). Fresh caterpillars are used as relishes and else their dried version as consumed. The marked decline in insect availability is not strongly correlated with the decline in their food trees, indicating over exploitation as a cause. *Gonimbrasia belina* an important food item has price similar to fresh beef. Winged termites are also consumed as raw, grilled or fried post removal of wings. *Brachytrupes membranaceus* (Fig. 15.1) is the most commonly consumed cricket and has witnessed an increase in its populations because of its adaptability to new agroecosystems (Wilson 1989) and has turned into a significant pest. McGregor (1991) also remarked on the abundant sale of these crickets in urban markets. Up to a 100 crickets can usually be collected in a day with women and children contributing to it (Gelfland 1971).

15.1.1.2 Asia and Oceania

In India, in northeastern India, pupa of wild silkworms, especially the Eri silkworm, *Samia ricini*, is considered a food connoisseur item (Chowdhury 1982). Ericulture being a cottage industry also results in cocoons as byproducts. In Manipur, insect consumption forms the cheapest source of protein (Gope and Prasad 1983) and should thus be encouraged.

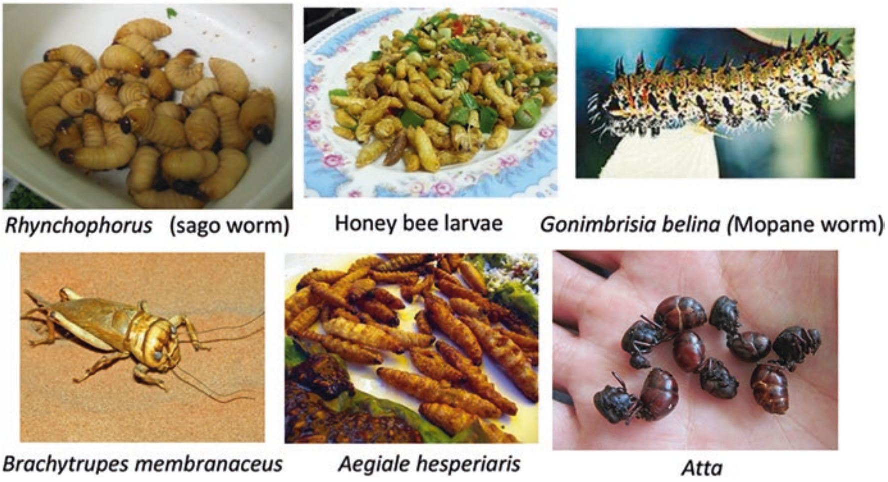

Fig. 15.1 Some much loved edible insects

Sungpuag and Puwastien (1983) found that in Ubon, Thailand, 20–60 g of insects are consumed per day. The Ministry of Public Health of Thailand has, in 1987, published a booklet highlighting six insect species that should be consumed to battle malnutrition in rural areas. At least 80 species of insects from 35 families are consumed in Thailand with details available from identification, collection to preparation and marketing (Vara-asavapati et al. 1975). Many insects, such as wasps, bamboo caterpillars, crickets and locusts, are considered as gourmet delicacies and now grace the finest restaurants (Yhoung-Aree et al. 1997). The Thai government has been hugely responsible for promulgating insect consumption, particularly during times of insect abundance such as locust plagues. Thai farmers began collecting grasshoppers/locusts as food in 1983 (Expat World 1992), and the price increased from 12 cents per kg in 1983 to \$2.80 per kg in 1992, with earnings from locusts being double that of agricultural produce.

In China, usage of insects as food has been highlighted in different time frames (Luo 1997). Mass production of two insects, viz. ant *Polyrhachis vicina* (Zhang et al. 2008) and larvae of *Musca domestica vicina*, for edible consumption is being attempted. Sale of ant and related food items sustain an almost \$100 million economy (Kantha 1994).

Ricefield grasshoppers (*Oxya yezoensis* and *Oxya japonica*), stir fried and seasoned, form one of the most preferred foods of Japanese society, both in earlier and modern times. These grasshoppers, which had once nearly disappeared due to excess pesticide use, have now reappeared as luxury items (Mitsuhashi 1997). “Hachinoko”, bee or wasp larvae, is consumed raw, boiled in soy sauce or overboiled rice, is another delicacy in Japan and subject to the modernity of present day times is even available canned. Canned wasps weighing 65 g were selling for 1000 yen (= \$8.00) in 1988. The late Emperor Hirohito was especially fond of the wasp-rice dish, which he is purported to have polished off even in the event of lack of

Fig. 15.2 Traditional and modern gastronomic delights made from insects

appetite following surgery (Mitsuhashi 1997). Larval Trichoptera, which are aquatic insects inhabiting gravel river beds and also known as "zazamushi", are also consumed in large quantities in Japan. Mitsuhashi (1997) has provided updated information on annual prices and processed quantities of edible species in Japan.

Papua New Guinea is also home to a number of edible insect species, chief amongst which is the sago grub, *Rhynchophorus ferrugineus papuanus* (Fig. 15.1). It is not only widely available and highly relished but it is also usually the centre of attraction of grub festivals. Connoisseurs advertise its texture as tender and taste as sweet with nutty overtones. Even the Europeans, who are reluctant consumers of insects, are fond of these grubs (Mercer 1993). They form a good 30 % of the protein intake and are a good nutrient source of fat, iron and zinc. These insects are found in the rotting pith of sago palms Mercer (1994). The production of these insects is environmentally efficient and a major source of rural income.

A similarly efficient system is the harvesting of cerambycid grub, *Hoplocerambyx severus*, from *Anisoptera polyandra* logs in Papua New Guinea (Mercer 1994). The population is so dense that almost 100 grubs can be gathered from a single log in less than a quarter of an hour.

Aborigines of Australia are voracious consumers of a number of insects, such as witchetty grubs (Cossidae), bogong moth (Noctuidae) and bardee larva (Cerambycidae), honeypot ants and honey and brood of the stingless bees. These food items have recently caught the fancy of high-end restaurants and are making their appearance on "couture" dishes (*Christian Science Monitor*, 1991; Fig. 15.2). Witchetty grubs are believed to be a gourmet's delight when lightly roasted in hot ashes (Tindale 1966).

15.1.1.3 Latin America

Leafcutter ants (*Atta* spp.), palm weevil larvae (*Rhynchophorus* spp.) and bee and wasp brood (Apidae and Vespidae) are highly recommended for their taste and flavour not only amongst the indigenous tribe of Latin America but also the outsiders. Palm weevil, *R. palmarum*, is believed to have immense mass production and marketing potential (DeFoliart 1993) and has been "semi-cultivated" by native people in many countries of the world. The fungus-feeding *Atta* ants are widely preferred edible items in South America (DeFoliart 1997). They also have ecological impact in the rain forest, since its consumption of a cultured fungus has let them tap into a limitless supply of cellulose (Hodgson 1955).

In South America, edible insects are commonplace in rural as well as urban markets. They sometimes are so much in demand that sometimes the price of certain insects, such as immature stages of the ants, *Liometopum apiculatum* and *Liometopum occidentale* var. *luctuosum* (escamoles), has gone up to 1000 pesos per kilogram (in 1981). Current rates for these insect larvae and also for white maguey worms (Fig. 15.1) are $25 per plate in many restaurants. Digging out these underground ant nests, which are regarded as private property, is hard work. Post harvesting of nests, the nest is covered with dried grass, or fresh weeds, in order to maintain an environment suitable for survival and regrowth of the colony (Ramos-Elorduy et al. 1989). Escamole hunting can lead to ant season income being higher than annual incomes in rural areas (de Conconi 1982).

Stingless bees (*Melipona, Scaptotrigona*, *Trigona*) are cultivated for honey as well as brood in small clay jars kept near the walls of houses and in small hollowed trunks (de Conconi 1982). Wasp brood enclosed in combs is usually sold (de Conconi 1982). These nests are first collected from nature when they have just begun (foundation combs) and hung in roofs of farm homes and barns till they reach the desired size, which may in case of *Polybia occidentalis bohemani* reach up to 1 m.

"Ahuahutle" or Mexican caviar-producing aquatic hemipterans (five species of Corixidae, one species of Notonectidae) are reared in alkaline lakes and have been for centuries farmed (de Conconi 1982). Oviposition traplines made of shore grass are used to trap bugs as well as their eggs every 3 weeks. The harvest of this delicacy has been affected by the pollution in lakes, but still it is traditionally harvested. Stuffed in tortillas and tamales, it forms a local delicacy served by restaurants. It is also exported to Germany and Great Britain as fish and bird feed (Ramos-Elorduy and Pino 1990).

Larva of the giant skipper butterfly, *Aegiale hesperiaris* (white agave or maguey worm), as well of *Comadia redtenbacheri* (pink worm of the maguey, the red agave worm) found on agave cactus, is much in demand in Mexico, the United States, Canada, France and Japan in fresh as well as canned form (Ramos-Elorduy and Pino 1990). The latter is consumed fried, as fillings in tortilla, in rice or tomato soup or in roasted and ground form (Ramos-Elorduy and Pino 1990).

In Mexico, more than 20 species of grasshoppers and locusts are sold and consumed widely (deConconi 1982). Their preparation involves cooking with onion, garlic and chilli powder and take the taste of the ingredients that they are cooked with.

Alate leafcutter ants (*Atta* spp.; Fig. 15.2), known as hormigas culonas or big-bottomed ants, are a national delicacy in Colombia and at par in gastronomic value with Russian caviar or French truffles. It has been stated that toasted ants are the crème de la crème of Colombian cookery. There is a huge literature available on the *Atta* ants in Brazil (Kevan and Bye 1991).

Insects of 22 genera belonging to seven orders are used as a food source by tribes along the Colombia-Venezuela border region. Though abundance was not a criterion for entomophagy, the decrease in game and aversion to consuming recently domesticated animals had led to an increase in entomophagy (Ruddle 1973). On the other hand, Dufour (1987) found that the most important insects in the diet of Tukanoans are the ones whose aggregations are large and predictable in nature.

15.1.2 Why Eat Insects?

15.1.2.1 Alternative Protein Sources

Increased wealth and better financial status has led to an increase in the global food demand (Msangi and Rosegrant 2011), particularly that of meat (Tillman et al. 2011). An increase in wealth is expected to lead to a rise in per capita consumption by 9% in countries belonging to the higher-income bracket and by 50% in China by the year 2000. This would lead to an increase in the demand for livestock feed by 48 and 158%, in higher-income countries and China, respectively (Msangi and Rosegrant 2011). It has been reported that each kilogram increase in production of animal protein requires a corresponding sixfold increase in plant protein (Pimentel and Pimentel 2003; Trostle 2008).

This along with the rapidly increasing human population will lead to an untenable strain on the agricultural sector, and the earth will not be able to sustain. This would also cause a global escalation in prices of agricultural crops, which will peter down to that of animal protein, with a predicted 30% rise in 50 years (2000–2050; Nelson et al. 2009). The same study also indicates that climate change would further aggravate the situation, causing an additional 18–21% rise in prices. The need for more biofuels in conjunction with decrease in agricultural productivity would further fuel up the situation. As it is, the rate of increase in productivity of land is slowly reaching a plateau (Alston et al. 2009). Thus, the need for alternative protein sources, such as cultured meat (Fayaz Bhat and Fayaz 2011), seaweed (Fleurence 1999), and mini-livestock (Paoletti 2005), would build up rapidly.

15.1.2.2 Benefits of Mini-livestock

15.1.2.2.1 Greenhouse Gas and Ammonia Emissions

Livestock production and transportation are believed to contribute a substantial share (18%) of human activity resulting greenhouse gas (GHG) emissions (Steinfeld

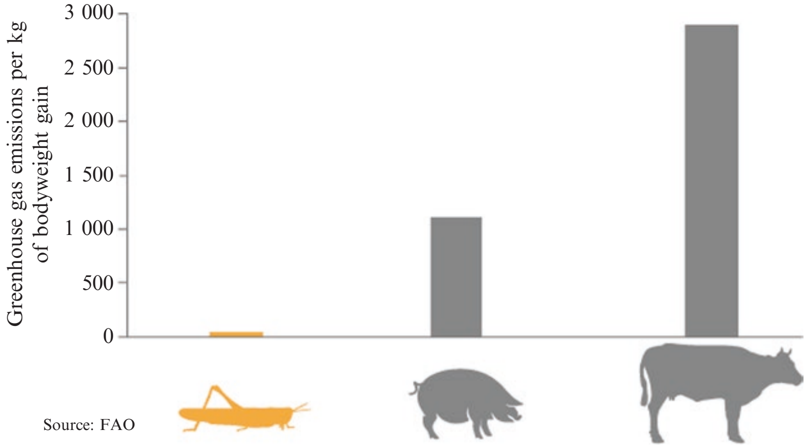

Fig. 15.3 Greenhouse gas emissions by macro- and mini-livestock (www, http://entomo.farm/insect-farming-systems/industrial-systems-insect-farming/)

et al. 2006). Enteric fermentation and manure leads to a substantial 31 and 6% contribution, respectively, to global methane emissions. Similarly, 65% of the N_2O released into the atmosphere owing to human activity is due to prolific used of fertilizers and manure. A kilogram each of beef, pork and chicken contributes 14.8, 3.8 and 1.1 kg of CO_2, respectively (Fiala 2008).

Insects such as cockroaches (Blaberidae and Blattinae), termites (Isoptera) and scarab beetles (Scarabaeidae) also produce GHGs (Hackstein and Stumm 1994). However, commonly reared edible insect species such as the yellow mealworm (*Tenebrio molitor*), the house cricket (*Acheta domesticus*) and the migratory locust (*Locusta migratoria*) emit much less GHG compared to the current major sources of animal protein (Oonincx et al. 2010; Fig. 15.3).

15.1.2.2.2 Feed Conversion Ratio

The amount of feed that is converted into meat or feed conversion ratios (FCRs) is an important factor to consider as increased demand for meat is inextricably linked to a similar increase in that of grains, water, etc.

FCRs for chicken (2.5), pork (5) and beef (10) were calculated in the United States following long-term studies (Smil 2002a, b). On the other hand, FCR values are relatively economical for insects such as *Acheta domesticus* (0.9–1.1; Nakagaki and deFoliart 1991; 1.7 for fresh weight; Collavo et al. 2005). Also, the proportion of edible portions (edible weight) of the livestock differs vastly amongst macro-livestock and insects. However, in chicken, pork and beef, 55, 55 and 40%, respectively, of live weight can be consumed (Flachowsky 2002; Smil 2002a, b). Insects can usually be eaten whole, with the exception of its indigestible chitin exoskeleton leading to 80% edible weight (Nakagaki and deFoliart 1991). Thus crickets are 2, 4 and 12 times more efficient than chickens, pigs and cattle, respectively (Fig. 15.4). The protein content per kg body weight for poultry, pork, beef, cricket nymph and

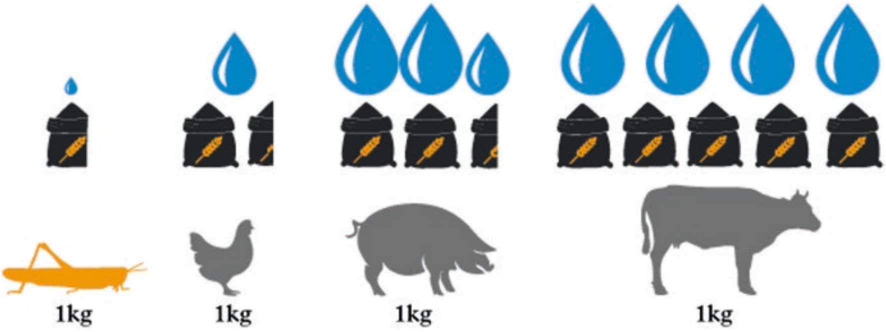

Fig. 15.4 Food conversion ratios by macro- and mini-livestock (www, http://entomo.farm/insect-farming-systems/industrial-systems-insect-farming/)

adults is 200, 150, 190, 154 and 205 g, protein per kilogram edible weight, respectively (Flachowsky 2002; Finke 2002).

15.1.2.2.3 Zoonoses

When animals are reared under high-density conditions, it increases multifold the risks of diseases gaining epidemic proportion as well as the emergence of antibiotic-resistant pathogens. Avian influenza (H5N1), foot-and-mouth disease, bovine spongiform encephalopathy (BSE) and classical swine fever are amongst some such infectious diseases that have led to severe global economic losses (King et al. 2006). These diseases in some cases, as the mad cow disease, have been known to be transmitted to humans (King et al. 2006) and also being a cause of cardiovascular disease and cancer (Pan et al. 2012). The taxonomical distance of humans from insects makes rearing and consuming of insects a very low-risk area as far as disease transference is concerned.

15.1.2.2.4 Water Use

Water is an increasingly rare commodity internationally and of its total virtual flow, nearly half of the volume is involved in raising feed crops (Chapagain and Hoekstra 2003). Beef in particular requires 22,000–43,000 l/kg of meat produced (Chapagain and Hoekstra 2003; Pimentel et al. 2004). The increased animal protein diet has already resulted in water scarcity issues in China from 1961 to 2003 (Liu et al. 2008a, b). On the other hand, virtual water flows for insect that are to be reared as food sources are going to be much lower. One reason for this is that many of these insects are drought resistant, such as yellow and lesser mealworm (Ramos-Elorduy et al. 2002), and have efficient FCRs.

15.1.2.3 Insects as Feed Ingredients

Insects are also potential replacements of fish meal and oil or at least major components of animal diets. Meal and oil from fish and soybean are major components of feed for aqua-organisms as well as livestock. In 2008, 19% of the global fish production, usually from small pelagic forage fish (Tacon and Metian 2008), was used in the production of fish meal and oil (FAO 2010). Aquaculture, which accounted a minor portion (4%) of the fish supplies across the globe, accounted for 38% in 2008 (FAO 2010), with future growth rates being estimated at 8% annually. Marine over-exploitation (FAO 2010) also adds to the cost of producing fish oil and meal (Deutsch et al. 2007; Tacon and Metian 2008). An increment in global demand for soy products has also led to a subsequent rise in cost of soybean (Trostle 2008). As these traditional protein sources become exorbitantly priced and their attainment prohibitive, the search for alternative sources has gained momentum (FAO 2012). Insects form a not so alien, cheap and massively available protein source. Insects which show much promise for mass production are black soldier fly, the common house fly, the yellow mealworm, the lesser mealworm, silkworm (*Bombyx mori*) and several grasshopper species (Anand et al. 2008).

Black soldier fly larvae develop by converting manure into body mass. They are rich in protein (42%) and fat (35%), making them suitable as livestock (Newton et al. 2005) and fish feed (Bondarik and Sheppard 1984). House fly maggots that can be reared on poultry manure can also be used as poultry feed in (Zuidhof et al. 2003; Awoniyi et al. 2004; Hwangbo et al. 2009; Teguia and Beynen 2005). Their pupae have high levels of proteins (61%; El Boushy 1991). The rearing techniques need to be fine-tuned and preferably automated to cater to the large demand from aquatic, poultry and livestock feed requirements.

15.1.2.4 Farming Insects

Other than being harvested from the wild, which is one of the most common means of procuring edible insects, they can also be farmed. They can, like silkworms and honeybees, be reared for purposes other than edible and also consumed as a byproduct (Bodenheimer 1951). Cochineal dye is also obtained from a farmed insect (*Dactylopius coccus*). They are usually found on prickly pear plants and, other than being collected from the wild, can be grown on prickly pear fences around houses. In Mexico, they are grown in plastic environment-controlled microtunnels, on prickly pear (Aldama-Aguilera et al. 2005).

Other than being farmed, insects can also be semi-cultivated by performing environmental manipulations. Examples of this are (a) harvesting eggs of aquatic hemipterans from artificial oviposition sites in lakes, (b) cutting palm trees to trigger egg laying by palm weevils followed by harvesting of larvae and (c) manipulating host tree distribution, preservation and abundance, along with artificial inoculation (Van Itterbeeck and van Huis 2012).

House crickets, palm weevil, giant water bug (*Lethocerus indicus*) and water beetles (Jäch 2003) are farmed for consumption in many parts of the world. While these commercial methods may suffice for human consumption in the current date, they will not be enough for meeting the current let alone the future demands from the feed industry. The primary challenge is developing an automated large-scale rearing method, which would provide quantity as well as quality hygienically and under sterile conditions (Bolckmans 2010). Sterility is of prime importance as pathogens have been known to seriously interfere with attempts to do commercial rearing (Szelei et al. 2011).

While it is not so difficult to use large-scale industrial methods for mass production of edible insects (Kok et al. 1988), its economic feasibility depends on the labour costs incurred. Automation is definitely going to enhance the quality and quantity of the product leading to more production in less space as well as reduced chances of microbial contamination by humans (Parker 2005). Silkworm, termite and drugstore beetle can be used for the dual purpose of recycling waste material as well as production of food (Katayama et al. 2008).

15.1.2.5 Conservation

Insects are largely a non-domesticated resource, with only few species being reared and most being gathered. Gathering from the wild carries the advantage of them being relatively free from pesticides. However, human greed has led to the overexploitation and subsequent local disappearance of many species (Nel and Illgner 2001; Madibela et al. 2009), an example being the mopane caterpillars (*Imbrasia belina;* Fig. 15.1). One method that has been found to deal with this problem is the placing of local embargos for certain periods (Mbata et al. 2002), but it is found to afflict sustainable harvesting (Akpalu et al. 2009).

A major edible insect of the Central African Republic, *Imbrasia oyemensis*, has been threatened due to commercial exploitation of its host plants (Vantomme et al. 2004). The solution to this has been the protection of at least one seed tree for 10 hectares of logged forests, but it is not the satisfactory solution to the scarcity of the insects.

Deforestation, water pollution and bush burning are a major cause of reduction in availability of edible insects in Nigeria (Agbidye et al. 2009). Fourteen edible insects have been documented as threatened owing to overexploitation or ecosystem degradation (Ramos-Elorduy 2006). Higher demand as well as incompetent, insincere and illegal harvesters are also responsible for overexploitation of edible insects (Cesard 2004). Multiple causes of ecosystem degradation such as pollution and pesticide use are recognized as reasons for insect insufficiency (Ramos-Elorduy 2006). In France, development of river banks has led to the drastic decline in mayfly (*Ephoron virgo*) populations, which were abundant till the mid-1980s (Cesard 2010). To effectively conserve relevant insect populations, detailed investigations into their effect on livelihoods, ecosystem, legislation, etc. are required.

Other than this, aiding and sustaining insect reproduction and survival by creating suitable habitats, sustainable harvesting and rearing can help conserve and sustain insect populations and even post their utilization as food. Semi-captive or sheltered rearing of insects is one such tool, which reduces attack by pathogens, parasitoids and predators (Silow 1976; Latham 1999; Ngoka et al. 2008).

15.1.2.6 Controlling Insects by Using Them as Feed and Food

Not only non-pest insects but also pests can be exploited as both food and feed (Cerritos and Cano-Santana 2008; DeFoliart 1997; Latham 1999). Locusts are one such example, the consumption of which was encouraged by the government in Thailand during their infestation (Yhoung-Aree et al. 1997). Sometimes, unintentional control can also take place, as is in the case of edible grasshoppers, which sell

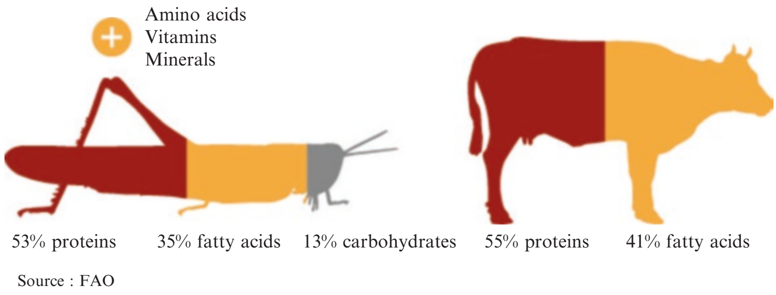

Fig. 15.5 Nutritional composition of macro- and mini-livestock (www, http://entomo.farm/insect-farming-systems/industrial-systems-insect-farming/)

for more than the crop value at times in Niger (van Huis 2003). In Laos, electric-light water traps are placed facing ricefields, with the primary aim of capturing edible insects and not controlling pests (van Huis 2013). In certain instances, control by pesticides results in lesser profits than physical control via harvesting; grasshopper *Sphenarium purpurascens* is a pest of corn, bean, alfalfa, squash and broad bean in Mexico, Guatemala and some Caribbean islands (Cerritos and Cano-Santana 2008). Also, in the Philippines, harvesting of several edible insect species, e.g. a migratory locust (*Locusta migratoria manilensis*), a mole beetle (*Gryllotalpa* sp.), a June beetle (*Leucopholis irrorata*) and the Korean bug (*Palembus dermestoides*), is reported to serve as a control strategy (Adalla and Cervancia 2010).

During the winter of 1988/1989, locusts invading Kuwait were sprayed with insecticides, even though the local population consumed them (DeFoliart 1997). Samples had high levels of phosphorus- and chlorine-containing pesticide residues (Saeed et al. 1993).

An example of biological control in conjunction with entomophagy is that of weaver ants, *Oecophylla*, which are effective predators of many pest species in orchards (Van Mele 2008). Their queen brood is highly popular in many Eastern countries, and making available as cat food and sucrose for the ants in mango orchards increases both biological control of many pests as well as doubles the brood size and number (Offenberg and Wiwatwitaya 2009).

15.1.2.7 Nutrition

The nutritional value of many of the edible insects has been of interest to many researchers, with that of almost 1900 such insects having been recorded (Bukkens 1997; DeFoliart 1992; Fig. 15.5). However, these values are not constant and are known to vary with life stage and diet (Oonincx and Dierenfeld 2011).

Most edible insects are complete diets, with many of the amino acids missing in cereal and legume diets, such as lysine, being provided by them (Bukkens 1997). *Imbrasia belina*, *Rhynchophorus phoenicis*, *Oryctes rhinoceros* and *Macrotermes bellicosus* contain all essential amino acids (Ekpo 2011). The use of such nutritious insects can be a major step in reducing malnutrition (Allotey and Mpuchane 2003; Ohiokpehai 2003). The amount of fat and the ratio of saturated/unsaturated fatty acids are better than even fish (DeFoliart 1991; Bukkens 1997).

Not only substantial amount of protein but also micronutrients and trace metal are provided by insects (Michaelsen et al. 2009). In countries facing deficiencies of metals, especially iron and zinc (Müller and Krawinkel 2005), encouraging consumption of insects, such as termites and crickets (Christensen et al. 2006), can be extremely helpful, as they are loaded with these.

Chitin, chitosan and chitooligosaccharides are purported to enhance immunity (Lee et al. 2008; Muzzarelli 2010; Reese et al. 2007; Xia et al. 2011), promote the growth of friendly microflora and prevent pathogenic activity (Khempaka et al. 2011; Liu et al. 2010; Muzzarelli 2010). The reduction in allergies in developing countries has been attributed to the exposure to more chitin-containing intestinal parasites due to lower hygiene levels (Brinchmann et al. 2011). This begs the point, whether increased consumption of chitin through promotion of insects as food in early childhood may protect against allergy later.

15.1.2.8 Food Safety

While insects form an extremely nutritious, low-polluting, cost-effective mode of meeting the global food scarcity situation, which is sure to follow in the coming years, it is essential to keep in mind the potential consumer and animal health issues. The Hazard Analysis and Critical Control Point System is a preventive system adopted by the Codex Alimentarius Commission (FAO/WHO 2008). This is essential, as consumption of insects has not been without incidence. A case in point is the ataxic syndrome that occurs after the consumption of the African silkworm *Anaphe venata* (Adamolekun 1993). It is only after thorough detoxification via heat treatment can this insect be safely consumed (Nishimune et al. 2000). In most insects that are toxic in their raw form, heating, boiling or sundrying makes them less toxic (Akinnawo et al. 2002).

Quick, even drying of mopane caterpillar being post degutted, boiled, dried, and stored can save it from fungal attack (Mpuchane et al. 2000; Simpanya et al. 2000). A heating step is sufficient for inactivation of Enterobacteriaceae; however, spore-forming bacteria, most probably introduced through soil, survive this treatment. Attempts to find noninstrumental approach for insect preservation seem more practical and promising (Klunder et al. 2012).

15.1.3 Preservation and Processing

Preservation of edible insects, especially those that are not mass reared and only seasonally available, increases storage and access for the rest of the year. Wasp larvae, weaver ant brood, silkworm pupae, giant water bugs, crickets and grasshoppers are quite commonly canned.

Preservation is also important as many of the freshly caught insects have a limited shelf life, post which they get spoilt. Early preservation increases their reach and also provides a large number of tastes. Weaver ant larvae and pupae and stink bugs are placed on ice in markets.

In tropical countries, fresh caterpillars undergo prior processing before they hit the market. In Zambia, caterpillar processing for long-term storage in the household or for sale involves the following steps: (*a*) eviscerating (degutting) live caterpillars soon after they are collected from the foliage of host plants; (*b*) roasting the eviscerated caterpillars over hot coals, from bonfires set up in the woodlands, until the setae and spine body adornments are burned off and the caterpillars become hardened; (*c*) sundrying the roasted caterpillars until they are crispy; and (*d*) packaging the sundried caterpillars in sacks or other materials (Mbata et al. 2002).

Producing conventional consumer foods such as crackers, muffins, sausages and meat loaf from termites and lake flies enhances their consumption (Ayieko et al. 2010). Caterpillars on being mixed with sorghum and Bambara nuts provided a protein-rich diet for children of more than 10 years of age (Allotey and Mpuchane 2003). The nutritional content of the insects differs with the processing method; degutting improves crude protein and digestibility, whereas cooking lowers it and roasting on hot coal enhances mineral content (Madibela et al. 2007). Smoke drying is known to reduce cholesterol levels in many caterpillars (Edijala et al. 2009).

Not only does the nutritional content change for the better with processing but is also likely to influence the sensibilities of the consumer, increasing its acceptance (Damodaran 1997).

15.1.4 Commercialization

In many tropical countries, edible insects are preferred over conventional meat despite their higher costs, owing to the status of the former as a delicacy. For example, the presence of the mopane caterpillar and grasshoppers in the market reduces the sale of beef, which is much lower in price (Quin 1959; Agea et al. 2008). Lowering of the costs by doing away with middlemen and high market dues may further promote the sale of insects. Another factor that affects their sale is the low shelf life (Cesard 2004); though processing can make the shelf life longer, it reduces the price.

The positive aspect of insect retail is that most of the collection is done by nonskilled personnel providing them a means of major earning during insect season. This along with the collection timings (dawn or dusk) allows them to pair this source of income with other sources (Mbetid-Bessane 2005; Meyer-Rochow et al. 2008).

15.1.5 Consumer Acceptance

Prior to commercialization of insect production, it is essential to know and understand the prejudices, the preferences and the barriers in society for their use as food and feed. While in some instances such as aquaculture, provision of insects as feed would probably not change societal perception (since it is the natural food), doing the same in poultry and cattle industry may be objected too.

While culturally insects are acceptable in large parts of the world, and the current global trends are also promoting gourmet insect food, there still are many taboos, which need to be addressed (Lawal and Banjo 2007). Food acceptance is a result of the satiation of the five senses as well as cultural and societal conditioning. Furthermore the innate reluctance to open up to new experiences, especially food such as insects which seem alien, leads to complication in the promulgation of entomophagy. While the nutrient value and environmental friendliness can act as convincing reasons (Fischer and Frewer 2009; Frewer et al. 2011) to try insects as food, the battle takes place against the innate conditioning.

Proper promotion, along with better processing and presentation of insects can increase the acceptance of this food of the future (Martins and Pliner 2005). A case in point of overcoming feelings of aversion is the promotion of Sushi in the Western world. Providing conditions leading to informed choice would also enable conversion (Houghton et al. 2006).

For persons concerned about animal welfare, usual aspects such as animal density per unit surface area are not of concern when it comes to insects. However, aspects such as pain perception (Kang et al. 2010) and cognition abilities (Elwood 2011) are recognized in insects and so good care of them is also required.

15.2 Conclusions

In a world where the ways of the Western world are copied and accepted all over, entomophagy has been shifted to the back burner despite it being an innate part of many cultures. But as meat-centric diets become increasingly less sustainable both economically and environmentally, there is need to opt for other strategies to fulfil our nutrient requirements and also stimulate our taste buds, at the same time being ecofriendly and sustainable. Insects form the ideal food solution for the future.

Opting for entomophagy would not only lead to reduction in land use and greenhouse gas problems but also do away with nutrition-related challenges, simply owing to both the quantity and quality of insects produced much more easily than other livestock. High nutrient value, high edible weight, easy rearing, low GHGs, possible degradation of garbage, etc. all make insects the food and feed of the future. “Chirpy food” is the only way forward.

References

Adalla CB, Cervancia CR (2010) Philippine edible insects: a new opportunity to bridge the protein gap of resource-poor families and to manage pests. In: Durst PB, Johnson DV, Leslie RN, Shono K (eds) Edible forest insects: humans bite back. Food Agriculture Organisation Regional Office. Asia and the Pacific, Bangkok, pp 151–160

Adamolekun B (1993) Anaphe venata entomophagy and seasonal ataxic syndrome in southwest Nigeria. Lancet 341:629

Agbidye FS, Ofuya TI, Akindele SO (2009) Some edible insect species consumed by the people of Benue State Nigeria. Pak J Nutr 8:946–950

Agea JG, Biryomumaisho D, Buyinza M, Nabanoga GN (2008) Commercialization of Ruspolia nitidula (Nsenene grasshoppers) in Central Uganda. Afr J Food Agric Dev 8:319–332
Akinnawo OO, Abatan MO, Ketiku AO (2002) Toxicological study on the edible larva of Cirina forda (Westwood). Afr J Biomed Res 5(1, 2):43–46
Akpalu W, Muchapondwa E, Zikhali P (2009) Can the restrictive harvest period policy conserve mopane worms in Southern Africa? A bio-economic modelling approach. Environ Dev Econ 14:587–600
Aldama-Aguilera C, Lianderal-Cazares C, Soto-Hernandez M, Castillo-Marquez LE (2005) Cochineal (Dactylopius coccus Costa) production in prickly pear plants in the open and in microtunnel greenhouses. Agrociencia 39:161–171
Allotey J, Mpuchane S (2003) Utilization of useful insects as food source. Afr J Food Agric Nutr Dev 3:1–6
Alston JM, Beddow JM, Pardey PG (2009) Agricultural research, productivity, and food prices in the long run. Science 325:1209–1210
Anand H, Ganguly A, Haldar P (2008) Potential value of acridids as high protein supplement for poultry feed. Int J Poult Sci 7:722–725
Ashiru MO (1988) The frequency distribution of eggs and larvae of Anaphe venata Butler (Lepidoptera: Notodontidae) on Triplochiton scleroxylon K Schum. Int J Trop Insect Sci 9(05):587–592
Awoniyi TAM, Adetuyi FC, Akinyosoye FA (2004) Microbiological investigation of maggot meal, stored for use as livestock feed component. J Food Agric Environ 2:104–106
Ayieko MA, Oriamo V, Nyambuga IA (2010) Processed products of termites and lake flies: improving entomophagy for food security within the Lake Victoria region. Afr J Food Agric Nutr Dev 10:2085–2098
Bequaert J (1921) Insects as food. How they have augmented the food supply of mankind in early and recent times. J Am Mus Nat Hist 21:191–200
Bodenheimer FS (1951) Insects as human food: a chapter of the ecology of man. Junk, The Hague, 352 pp
Bolckmans KJF (2010) New, novel, innovative and emerging applications of insect rearing. Symposium No. 5. 12th workshop of the arthropod mass rearing and quality control working group of the IOBC, Vienna, Austria, 19–22 October
Brinchmann BC, Bayat M, Brøgger T, Muttuvelu DV, Tjønneland A, Sigsgaard T (2011) A possible role of chitin in the pathogenesis of asthma and allergy. Ann Agric Environ Med 18:7–12
Bukkens SGF (1997) The nutritional value of edible insects. Ecol Food Nutr 36:287–319
Cerritos R, Cano-Santana Z (2008) Harvesting grasshoppers Sphenarium purpurascens in Mexico for human consumption: a comparison with insecticidal control for managing pest outbreaks. Crop Prot 27:473–480
Cesard N (2004) Harvesting and commercialisation of kroto (*Oecophylla smaragdina*) in the Malingping area, West Java, Indonesia. In: Kusters K, Belcher B (eds) Forest products, livelihoods and conservation: case studies of non-timber forest product systems, vol 1. Central International Forest Research, Jakarta
Cesard N (2010) Vie et mort de la manne blanche des riverains de la Saône. Etudes Rurales 185:83–98
Chapagain AK, Hoekstra AY (2003) Virtual water flows between nations in relation to trade in livestock and livestock products. Value Water Research Report Series No. 13, U.N. Education, Science, Cultural Organ, Institute. Water Education, Delft, the Netherland. 60 pp
Chavunduka DM (1975) Insects as a source of protein to the African. Rhodesia Sci News 9:217–220
Cherry R (1991) Use of insects by Australian aborigines. Am Entomol 32:8–13
Chowdhury SN (1982) Eri silk industry (ed) Gov. of Assam
Christensen DL, Orech FO, Mungai MN, Larsen T, Friis H, Aagaard-Hansen J (2006) Entomophagy among the Luos of Kenya: a potential mineral source? Int J Food Sci Nutr 57:198–203
Collavo A, Glew RH, Huang Y-S, Chuang L-T, Bosse R, Paoletti MG (2005) House cricket small-scale farming. See Ref 115:519–544

Damodaran S (1997) Food proteins: an overview. In: Damodaran S, Paraf A (eds) Food proteins and their applications. Marcel Dekker, New York, pp 1–21
DeFoliart GR (1991) Insect fatty acids: similar to those of poultry and fish in their degree of unsaturation, but higher in the polyunsaturates. Food Insects Newsl 4:1–4
DeFoliart G (1992) Insect as human food Gene DeFoliart discusses some nutritional and economic aspects. Crop Prot 11:395–399
DeFoliart GR (1993) Hypothesizing about palm weevil and palm rhinoceros beetle larvae as traditional cuisine, tropical waste recycling, and pest and disease control on coconut and other palms-can they be integrated? Principes 37(1):42–47
DeFoliart G (1997) An overview of the role of edible insects in preserving biodiversity. Ecol Food Nutr 36:109–132
DeFoliart GR (1999) Insects as food: why the Western attitude is important. Annu Rev Entomol 44:21–50
DeFoliart G (2012) The human use of insects as a food resource: a bibliographic account in progress. http://www.food-insects.com
DeFoliart G, Dunkel FV, Gracer D (2009) The food insects newsletter: chronicle of a changing culture. Aardvark, Salt Lake City, 414 pp
Deutsch L, Gräslund S, Folke C, Troell M, Huitric M, et al (2007) Feeding aquaculture growth through globalization: exploitation of marine ecosystems for fishmeal. Glob Environ Chang 17:238–249
Diamond J (1991) The rise and fall of the third chimpanzee. Random House, London
Dufour DL (1987) Insects as food: a case study from the northwest Amazon. Am Anthropol 89(2):383–397
Edijala JK, Egbogbo O, Anigboro AA (2009) Proximate composition and cholesterol concentrations of Rhynchophorus phoenicis and Oryctes monoceros larvae subjected to different heat treatments. Afr J Biotechnol 8:2346–2348
Ekpo KE (2011) Effect of processing on the protein quality of four popular insects consumed in Southern Nigeria. Arch Appl Sci Res 3:307–326
El Boushy AR (1991) House-fly pupae as poultry manure converters for animal feed: a review. Bioresour Technol 38:45–49
Elwood RW (2011) Pain and suffering in invertebrates? Inst Lab Anim Res J 52:175–184
Expat World (1992) The newsletter of international living (vol 4, No. 1, January 1992, P.O. Box 1341, Raffles City, Singapore 9117
Fasoranti JO, Ajiboye DO (1993) Some edible insects of Kwara state, Nigeria. Am Entomol 39(2):113–116
Food and Agriculture Organization (FAO) (2010) The state of world fisheries and aquaculture 2010. FAO, Fish Aquaculture Department, Rome http://www.fao.org/docrep/013/i1820e/i1820e00.htm
Food and Agriculture Organization (FAO) (2012) Assessing the potential of insects as food and feed in ssuring food security. Presented at Technical Consultation Meet, FAO, Rome, Italy, January 23–25
Food and Agriculture Organization/World Health Organization (FAO/WHO) (2008) Guideline for the validation of food safety control measures. FAO/WHO, Rome
Fayaz Bhat Z, Fayaz H (2011) Prospectus of cultured meat—advancing meat alternatives. J Food Sci Technol 48:125–140
Fiala N (2008) Meeting the demand: an estimation of potential future greenhouse gas emissions from meat production. Ecol Econ 67:412–419
Finke MD (2002) Complete nutrient composition of commercially raised invertebrates used as food for insectivores. Zoo Biol 21:269–285
Fischer ARH, Frewer LJ (2009) Consumer familiarity with foods and the perception of risks and benefits. Food Qual Prefer 20:576–585
Flachowsky G (2002) Efficiency of energy and nutrient use in the production of edible protein of animal origin. J Appl Anim Res 22:1–24

Fleurence J (1999) Seaweed proteins: biochemical, nutritional aspects and potential uses. Trends Food Sci Technol 10:25–28

Frewer LJ, Bergmann K, Brennan M, Lion R, Meertens R et al (2011) Consumer response to novel agri-food technologies: implications for predicting consumer acceptance of emerging food technologies. Trends Food Sci Technol 22:442–456

Gomez P, Halut R, Collin A (1961) Production of animal proteins in the Congo. Bull Agric Congo Belge 52:689–815

Gope B, Prasad B (1983) Preliminary observation on the nutritional value of some edible insects of Manipur. J Adv Zool 4(1):55–61

Hackstein JH, Stumm CK (1994) Methane production in terrestrial arthropods. Proc Natl Acad Sci USA 91:5441–5445

Hodgson EF (1955) An ecological study of the leaf-cutting ant, Atta cephalotes. Ecology 36:298–304

Holden S (1991) Edible caterpillars – a potential agroforestry resource? Food Insects Newsl 4(2):3–4

Holt VM (1885) Why not eat insects?. Field & Tuer

Houghton JR, van Kleef E, Rowe G, Frewer LJ (2006) Consumer perceptions of the effectiveness of food risk management practices: a cross-cultural study. Health Risk Soc 8:165–183

Hwangbo J, Hong EC, Jang A, Kang HK, Oh JS et al (2009) Utilization of house fly–maggots, a feed supplement in the production of broiler chickens. J Environ Biol 30:609–614

Ingold T (1994) Compendium encyclopedia of anthropology. Routledge, London

Jäch MA (2003) Fried water beetles: Cantonese style. Am Entomol 49:34–37

Jones S, Martin RD, Pilbeam DR, Bunney S (eds) (1992) The Cambridge encyclopedia of human evolution. Cambridge University Press, Cambridge

Kang K, Pulver SR, Panzano VC, Chang EC, Griffith LC et al (2010) Analysis of Drosophila TRPA1 reveals an ancient origin for human chemical nociception. Nature 464:597–600

Katayama N, Ishikawa Y, Takaoki M, Yamashita M, Nakayama S et al (2008) Entomophagy: a key to space agriculture. Adv Space Res 41:701–705

Kevan PG, Bye RA (1991) Natural history, sociobiology, and ethnobiology of Eucheira socialis Westwood (Lepidoptera: Pieridae), a unique and little-known butterfly from Mexico. Entomologist

Khempaka S, Chitsatchapong C, Molee W (2011) Effect of chitin and protein constituents in shrimp head meal on growth performance, nutrient digestibility, intestinal microbial populations, volatile fatty acids, and ammonia production in broilers. J Appl Poult Res 20:1–11

King DA, Peckham C, Waage JK, Brownlie J, Woolhouse MEJ (2006) Epidemiology infectious diseases: preparing for the future. Science 313:1392–1393

Klunder HC, Wolkers-Rooijackers J, Korpela JM, Nout MJR (2012) Microbiological aspects of processing and storage of edible insects. Food Control 26:628–631

Kok R, Lomaliza K, Shivhare US (1988) The design and performance of an insect farm/chemical reactor for human food production. Can Agric Eng 30:307–317

Latham P (1999) Edible caterpillars of the BasCongo Region of the Democratic Region of the Democratic Republic of Congo. Antenna 23:135–139

Lawal OA, Banjo AD (2007) Survey for the usage of arthropods in traditional medicine in Southwestern Nigeria. J Entomol 4:104–112

Lee CG, Silva CAD, Lee J-Y, Hartl D, Elias JA (2008) Chitin regulation of immune responses: an old molecule with new roles. Curr Opin Immunol 20:684–689

Liu Q, Tomberlin JK, Brady JA, Sanford MR, Yu Z (2008a) Black soldier fly (Diptera: Stratiomyidae) larvae reduce *Escherichia coli* in dairy manure. Environ Entomol 37:1525–1530

Liu J, Yang H, Savenije HHG (2008b) China's move to higher-meat diet hits water security. Nature 454:397

Liu P, Piao XS, Thacker PA, Zeng ZK, Li PF et al (2010) Chito-oligosaccharide reduces diarrhea incidence and attenuates the immune response of weaned pigs challenged with *Escherichia coli* K881. J Anim Sci 88:3871–3879

Luo ZY (1997) Insects as food in China. Ecol Food Nutr 36(2–4):201–207

Madibela OR, Seitiso TK, Thema TF, Letso M (2007) Effect of traditional processing methods on chemical composition and in vitro true dry matter digestibility of the mophane worm (Imbrasia belina). J Arid Environ 68:492–500

Madibela OR, Mokwena KK, Nsoso SJ, Thema TF (2009) Chemical composition of mopane worm sampled at three different sites in Botswana and subjected to different processing. Trop Anim Health Prod 41:935–942

Malaisse F, Parent G (1980) Les chenilles comestibles du Shaba méridional (Zaïre). Naturalistes Belges 61(1):2–24

Martins Y, Pliner P (2005) Human food choices: an examination of the factors underlying acceptance/rejection of novel and familiar animal and nonanimal foods. Appetite 45:214–224

Mbata KJ (1995) Traditional use of arthropods in Zambia. Food Insects Newsl 8(1):5–7

Mbata KJ, Chidumayo EN, Lwatula CM (2002) Traditional regulation of edible caterpillar exploitation in the Kopa area of Mpika District in northern Zambia. J Insect Conserv 6:115–130

Mbetid-Bessane E (2005) Commercialization of edible caterpillars in Central African Republic. Tropicultura 23:3–5

McGregor J (1991) Woodland resources: ecology, policy and ideology. An historical case study of woodland use in Shurugwi Communal Area, Zimbabwe. PhD Dissertation, Loughborough University of Technology. (Introduction and several orders and families)

Mercer CWL (1993) Insects as food in Papua New Guinea. In: Hardouin J, Stievenart C (eds) Invertebrates (Minilivestock) Farming., pp 157–162

Mercer CWL (1994) Sago grub production in Labu swamp near Lae – Papua New Guinea. Klin (J Forestry Papua New Guinea) 5(2):30–34

Meyer-Rochow VB, Nonaka K, Boulidam S (2008) More feared than revered: insects and their impact on human societies (with some specific data on the importance of entomophagy in a Laotian setting). Entomol Heute 20:3–25

Michaelsen KF, Hoppe C, Roos N, Kaestel P, Stougaard M et al (2009) Choice of foods and ingredients for moderately malnourished children 6 months to 5 years of age. Food Nutr Bull 30:343–404

Mitsuhashi J (1997) Insects as traditional foods in Japan. Ecol Food Nutr 36(2–4):187–199

Mpuchane S, Gashe BA, Allotey J, Siame B, Teferra G, Dithlogo M (2000) Quality deterioration of phane, the edible caterpillar of an emperor moth Imbrasia belina. Food Control 11:453

Msangi S, Rosegrant MW (2011) Feeding the future's changing diets: implications for agriculture markets, nutrition, and policy. In: 2020 conference: leveraging agriculture for improving nutrition and health. International Food Policy Research Institute, Washington, DC

Müller O, Krawinkel M (2005) Malnutrition and health in developing countries. CMAJ 173:279–286

Munthali SM, Mughogho DE (1992) Economic incentives for conservation: beekeeping and Saturniidae caterpillar utilization by rural communities. Biodiv Conserv 1(3):143–154

Muzzarelli RAA (2010) Chitins and chitosans as immunoadjuvants and non-allergenic drug carriers. Mar Drug 8:292–312

Nakagaki BJ, deFoliart GR (1991) Comparison of diets for mass-rearing *Acheta domesticus* (Orthoptera: Gryllidae) as a novelty food, and comparison of food conversion efficiency with values reported for livestock. J Econ Entomol 84:891–896

Nel E, Illgner P (2001) Tapping Lesotho 's' white gold': inter-basin water transfer in Southern Africa. Geography 86(2):163–167

Nelson GC, Rosegrant M, Koo J, Robertson R, Sulser T et al (2009) Climate change: impact on agriculture and costs of adaptation. Food policy report. International Food Policy Research Institute, Washington, DC

Newton L, Sheppard C, Watson DW, Burtle G, Dove R (2005) Using the black soldier fly, *Hermetia illucens*, as a value-added tool for the management of swine manure. Report for Mike Williams, Dir. Animal Poultion Waste Management Center, North Carolina State University, Raleigh

Ngoka BM, Kioko EN, Raina SK, Mueke JM, Kimbu DM (2008) Semi-captive rearing of the African wild silkmoth Gonometa postica (Lepidoptera: Lasiocampidae) on an indigenous and a non-indigenous host plant in Kenya. Int J Trop Insect Sci 27:183–190

Nishimune T, Watanabe Y, Okazaki H, Akai H (2000) Thiamin is decomposed due to Anaphe spp. entomophagy in seasonal ataxia patients in Nigeria. J Nutr 130:1625–1628

Offenberg J, Wiwatwitaya D (2009) Sustainable weaver ant (*Oecophylla smaragdina*) farming: harvest yields and effects on worker ant density. Asia Myrmecol 3:55–62

Ohiokpehai O (2003) Nutritional aspects of street foods in Botswana. Pak J Nutr 2:76–81

Oliveira JS, de Carvalho JP, De Sousa RB, Simao MM (1976) The nutritional value of four species of insects consumed in Angola. Ecol Food Nutr 5(2):91–97

Oonincx DGAB, Dierenfeld ES (2011) An investigation into the chemical composition of alternative invertebrate prey. Zoo Biol. 29:1–15

Oonincx DGAB, van Itterbeeck J, Heetkamp MJW, van den Brand H, van Loon JJA, van Huis A (2010) An exploration on greenhouse gas and ammonia production by insect species suitable for animal or human consumption. PLoS One 5:e14445

Pan A, Sun Q, Bernstein AM, Schulze MB, Manson JE et al (2012) Redmeat consumption andmortality: results from two prospective cohort studies. Arch Intern Med 172:1134845

Paoletti MG (2005) Ecological implications of minilivestock: potential of insects, rodents, frogs and snails. Science, Enfield, 648 pp

Parker AG (2005) Mass-rearing for sterile insect release. In: VA D, Heindrichs J, AS R (eds) Sterile insect technique. principles and practice in area-wide integrated pest management. Springer, Dordrecht, pp 209–232

Pimentel D, Pimentel M (2003) Sustainability of meat-based and plant-based diets and the environment. Am J Clin Nutr 78(Suppl. 3):660S–663S

Pimentel D, Berger B, Filiberto D, Newton M, Wolfe B et al (2004) Water resources: agricultural and environmental issues. Bioscience 54:909–918

Ramos-Elorduy J (2006) Threatened edible insects in Hidalgo, Mexico and some measures to preserve them. J Ethnobiol Ethnomed 2:1–10

Ramos-Elorduy J, Pino JM (1990) Contenido calórico de algunos insectos comestibles de México. Soc Quim Mex 34(2):56–68

Ramos-Elorduy de Conconi J, Bourges Rodríguez H, Pino Moreno JM (1982) Valor nutritivo y calidad de la proteína de algunos insectos comestibles de México. Folia Entomológica Mexicana, Mexico

Ramos-Elorduy J, Moreno P, Ramos-Elorduy JMJ, Moreno JMP (1989) Los insectos comestibles en el México antiguo: Estudio etnoentomológico (No. 641.696 R3I55 F1219. 3. F7)

Ramos-Elorduy J, González EA, Hernández AR, Pino JM (2002) Use of Tenebrio molitor (Coleoptera: Tenebrionidae) to recycle organic wastes and as feed for broiler chickens. J Econ Entomol 95(1):214–220

Reese TA, Liang H-E, Tager AM, Luster AD, Rooijen NV et al (2007) Chitin induces accumulation in tissue of innate immune cells associated with allergy. Nature 447:92–96

Ruddle K (1973) The human use of insects: examples from the Yukpa. Biotropica 5:94–101

Saeed T, Dagga FA, Saraf M (1993) Analysis of residual pesticides present in edible locusts captured in Kuwait. Arab Gulf J Sci Res 11:1–5

Silow CA (1976) Edible and other insects of Mid-Western Zambia, Studies in Ethno-Entomology II. Almqvist/Wiksell, Stockholm, 223 pp

Simpanya MF, Allotey J, Mpuchane SF (2000) Amycological investigation of phanen and edible grasshopper of an emperor moth. Imbrasia belina J Food Prot 63:137–140

Smil V (2002a) Eating meat: evolution, patterns, and consequences. Popul Dev Rev 28:599–639

Smil V (2002b) Worldwide transformation of diets, burdens of meat production and opportunities for novel food proteins. Enzym Microb Technol 30:305–311

Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M (eds) (2006) Livestock's long shadow: environmental issues and options. Food Agric. Organ, Rome, 319 pp

Sungpuag P, Puwastien P (1983) Nutritive values of protein food sources of rural people: insects. J Nutr Assoc Thailand 17:5–12

Szelei J, Woodring J, Goettel MS, Duke G, Jousset FX et al (2011) Susceptibility of North-American and European crickets to *Acheta domesticus* densovirus (AdDNV) and associated epizootics. J Invertebr Pathol 106:394–399

Tacon AGJ, Metian M (2008) Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: trends and future prospects. Aquaculture 285:146–158

Teguia A, Beynen AC (2005) Alternative feedstuffs for broilers in Cameroon. Livest Res Rural Dev 17:34 http://www.lrrd.org/lrrd17/3/tegu17034.htm

Tindale NB (1966) Insects as food for the Australian aborigines

Trostle R (2008) Global agricultural supply and demand: factors contributing to the recent increase in food commodity prices. Economic research service report WRS-0801, US Department of Agriculture, Washington, DC, pp. 1–30, July 2008 rev

van Huis A (2003) Insects as food in sub-Saharan Africa. Insect Sci Appl 23:163–185

Van Huis A (2013) Potential of insects as food and feed in assuring food security. Annu Rev Entomol 58:563–583

Van Itterbeeck J, van Huis A (2012) Environmental manipulation for edible insect procurement: a historical perspective. J Ethnobiol Ethnomed 8:1–19

Van Mele P (2008) A historical review of research on the weaver ant Oecophylla in biological control. Agric For Entomol 10:13–22

Vantomme P, Göhler D, N'Deckere-Ziangba F (2004) Contribution of forest insects to food security and forest conservation: the example of caterpillars in Central Africa. Odi Wildl Policy Brief 3:1–4

Vara-asavapati V, Visuttipart J, Maneetorn C (1975) Edible insects in north-east Thailand. Res

White CMN (1961) Elements in Luvale beliefs and rituals (No. 32). Rhodes-Livingstone Institute by the Manchester University Press and in the USA by Humanities Press, New York

Wilson KB (1989) The ecology of wild resource use for food by rural southern Africans: why it remains so important. Paper presented to the conference at the destruction of the environment and the future of life in the Middle East and Africa, 14–17 July 1989. (Introduction)

Xia W, Liu P, Zhang J, Chen J (2011) Biological activities of chitosan and chitooligosaccharides. Food Hydrocoll 25:170–179

Yen AL (2009) Entomophagy and insect conservation: some thoughts for digestion. J Insect Conserv 13:667–670

Yhoung-Aree J, Puwastien P, Attig GA (1997) Edible insects in Thailand: an unconventional protein source? Ecol. Food Nutr. 36:133–149

Yhoung-Aree J, Viwatpanich K (2005) Edible insects in the Laos PDR, Myanmar, Thailand, and Vietnam. See Ref 115:415–440

Zhang CX, Tang XD, Cheng JA (2008) The utilization and industrialization of insect resources in China. Entomol Res 38(s1):S38–S47

Zuidhof MJ, Molnar CL, Morley FM, Wray TL, Robinson FE et al (2003) Nutritive value of house fly (*Musca domestica*) larvae as a feed supplement for turkey poults. Anim Feed Sci Technol 105:225–230