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Review

Insects as food and feed: A review

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This research reviews the contribution of insects to man in his zeal to improve and widen his sources of food, feed and nutrition. It critically looks at major edible insects and how flies and other insects can contribute to the growing demand for cheap protein in the food and feed industry. Priority is also given to nutrition and some rearing models that have been developed and how these can be improved to domesticate these insects into mini-livestock.

Keywords: Insects, nutrition, protein, mini-livestock.

INTRODUCTION

The Earth's population is expected to exceed over 9 billion by 2050, and so humanity's need for food, fuel, fibre and shelter will need to be met with minimal ecological footprint (Ramaswany, 2014). Feeding the 9 billion people has implications for how we grow and view food now and in the future. Insects have served as a food source for humanity since the first bipedal human ancestor came down from the trees and started walking across the Savannahs (Ramaswary, 2014). Interestingly, however, today insect eating is rare in the western world, but remains a significant source of food for people in other cultures. Insects provide food at low environmental cost, contribute positively to livelihoods, and play a fundamental role in nature. Some of these benefits are largely unknown to the general public. Contrary to popular belief, insects are not merely "famine foods" eaten in times of food scarcity or when purchasing and harvesting "conventional foods" becomes difficult; many people throughout the world eat insects out of choice, largely because of their palatability and established place in local food cultures in many regional and national diets (FAO/WUR, 2012).

Insects have long been used as human food and animal feed in West Africa (Kenis and Hein, 2014; Riggi et al., 2014). However, compared to Central and Southern Africa, only few species are reported as being traditionally consumed by humans, the most common being grasshoppers and termites. This is partly due to a lack of specific studies in West Africa in the past. Recent investigations focusing on specific regions however showed that more species are consumed than previously reported (Kenis and Hein, 2014). Nevertheless, it cannot be denied that, in general, entomophagy, the consumption of insects, is less widely practiced in West Africa than in other regions of Sub-Saharan Africa (Kenis and Hein, 2014).

It is estimated that 1,900 species of insects are consumed by over two billion people in about 80 countries across Asia, Africa, and the Americas (van Huis et al., 2013). Edible species are eaten as immature (eggs, larvae, pupae, and nymphs) and in some cases also as adults. Edible insects are obtained by three main strategies: wild harvesting, semi-domestication of insects in the wild, and farming. The degree to which each of these contributes varies regionally. While entomophagy has decreased in westernized societies, the demand for edible insects has apparently increased in parts of Asia in association with increased standards of living (Yen, 2014). Recently, entomophagy is being promoted for several reasons (van Huis et al., 2013; Ramaswany, 2014). Firstly, insects are healthy and nutritious alternatives to mainstream staples such as chicken,

Table 1: Number of edible insect species reported in the world.

Order	Common English name	Number of species
Thysanura	Silverfish	1
Anoplura	Lice	3
Ephemeroptera	Mayflies	19
Odonata	Dragonflies	29
Orthoptera	Grasshoppers, cockroaches, Crickets	267
Isoptera	Termites	61
Hemiptera	True bugs	102
Homoptera	Cicadas, leafhoppers, mealybugs	78
Neuroptera	Dobson flies	5
Lepidoptera	Butterflies, moths (silkworms)	253
Trichoptera	Caddis flies	10
Diptera	Flies, mosquitoes	34
Coleoptera	Beetles	468
Hymenoptera	Ants, bees, Wasps	351
Total		1,681

Source: Ramos-Elorduy (2005).

pork, beef and even fish because many insects contain more protein and are lower in fat than traditional meats, and high in calcium, iron and zinc (van Huis et al., 2013). Secondly, because they are cold-blooded, insects are very efficient at converting feed into protein. For example, crickets need 12 times less feed than cattle, four times less feed than sheep, and half as much feed as pigs and broiler chickens to produce the same amount of protein. Insects save a substantial amount of energy and natural resources by their high metabolic rates. Thirdly, since insects require less space and food, the ecological footprint of insects as food is smaller than that of traditional livestock. Fourthly, insects used as food emit considerably fewer greenhouse gases (GHGs) than most livestock (methane, for instance, is produced by only a few insect groups such as termites and cockroaches). The ammonia emissions associated with insect rearing are also far lower than those linked to conventional livestock, such as pigs (van Huis et al., 2013). Insect rearing is also not necessarily a land-based activity and does not require land clearing to expand production. Furthermore, their reproduction rate is significantly higher, making them much easier to produce in large numbers than other livestock. Finally, economically and socially, entomophagy enhances the livelihoods of many people. Insect harvesting and rearing is a low-tech, low-capital investment option that offers entry even to the poorest sections of society, such as women and the landless. Mini-livestock production offers livelihood opportunities for both urban and rural people.

To promote the use of insects as human food, we need to understand a number of issues, such as biology of edible species, biotic and abiotic constraints to insect livestock production, health and environmental risks, food safety and regulatory frameworks, human behaviour and attitudes to consumption of insects, production challenges, and critical infrastructure needs (Ramaswany, 2014).

Major Groups of Edible Insect Species Consumed Worldwide

Globally, the most common insects consumed are beetles (31%) (van Huis et al., 2013). This is not surprising given that the group contains about 40% of all known insect species. The consumption of caterpillars, which is especially popular in sub-Saharan Africa, is estimated at 18%. Bees, wasps and ants come in the third place at 14% and are especially common in Latin America. Following these are grasshoppers, locusts and crickets (13%); cicadas, leafhoppers, plant-hoppers, scale insects and true bugs (10%); termites (3%); dragonflies (3%); flies (2%); and others (5%) (van Huis et al., 2013). Lepidoptera are consumed almost entirely as caterpillars and Hymenoptera are consumed mostly in their larval or pupal stages. Both adults and larvae of the Coleoptera order are eaten, while the Orthoptera, Homoptera, Isoptera and Hemiptera orders are mostly eaten in the mature stage (Cerritos, 2009). The number of edible insect species reported worldwide is indicated in Table 1.

Coleoptera (beetles)

There are many kinds of edible beetles, including aquatic beetles, wood-boring larvae, and dung beetles. Ramos Elorduy and co-workers listed 78 edible aquatic beetle species, mainly belonging to the Dytiscidae, Gyrinidae and Hydrophilidae families (Ramos et al., 2009). Typically, only the larvae of these species are eaten. The most popular edible beetle in the tropics, by far, is the palm weevil, *Rynchophoru spp*, a significant palm pest distributed throughout Africa, southern Asia and South America (van Huis et al., 2013). The oil palm weevil *R. phoenicis* is found in tropical and equatorial Africa, *R. ferrugineus* in Asia and *R. palmarum* in the tropical Americas. In the Netherlands, the larvae of mealworm species from the Tenebrionidae family, such as the yellow mealworm (*Tenebrio molitor* Linnaeus), the lesser mealworm (*Alphitobius diaperinus* Panzer) and the superworm (*Zophobas morio*), are reared as feed for reptiles, fish and avian pets. They are also considered particularly fit for human consumption and are offered as human food in specialized shops.

The Palm Weevil

The larvae of the palm weevil (*Rynchophorous* spp.) are consumed in Asia (*R. ferrugineus*), Africa (*R. phoenicis*) and Latin America (*R. palmarum*). Their delicious flavour is credited by some to their elevated fat content (Fasoranti and Ajiboye, 1993; Cerda et al., 2001). In the tropics, the insects occur all year-round where hosts are found. Often these hosts are trees under stress; that is, trees previously damaged by other insects, notably rhinoceros beetles (*Oryctes* spp.) or by the local traditional tapping for palm wine (Fasoranti and Ajiboye, 1993). Fallen palms can serve as breeding sites and support hundreds of larvae; for this reason, palms are often felled intentionally. This is a common practice among the Akans and Ewes of Ghana (Anankware et al., 2013). Van Itterbeeck and van Huis (2012) noted that many indigenous people have excellent ecological knowledge of the palm weevil and can increase its availability and predictability through semi-cultivation practices. Research at Kade and the Jema districts of Ghana are currently exploring ways of rearing and producing oil palm weevils (*R. phoenicis*) in a more sustainable manner without felling the oil palm trees (Anankware, personal communication, 2014).

Lepidoptera (Butterflies and Moths)

Butterflies and moths are typically consumed during their larval stages (caterpillars), but adult butterflies and moths are also eaten. Indigenous Australians have been reported to eat moths of the cutworm *Agrotis infusa* (Flood, 1980) and in the Lao People's Democratic Republic, people have been observed eating hawkmoths (*Daphnis* spp. and *Theretra* spp.) after removing the wings and legs (Van Itterbeeck and van Huis, 2012).

The mopane caterpillar (*Imbrasia belina*) is arguably the most popular and economically important caterpillar consumed. Endemic to the mopane woodlands in Angola, Botswana, Mozambique, Namibia, South Africa, Zambia and Zimbabwe, the caterpillar's habitat extends over about 384 000 km^2 of forest (FAO, 2003). An estimated 9.5 billion mopane caterpillars are harvested annually in southern Africa, a practice worth US$85 million (Ghazoul, 2006). Other caterpillars are also consumed, but to a lesser extent. Malaisse (1997) identified 38 different species of caterpillar across the Democratic Republic of the Congo, Zambia and Zimbabwe. Latham (2003) documented 23 edible species in the Bas-Congo, a western province of the Democratic Republic of the Congo.

Hymenoptera (Wasps, Bees and Ants)

Ants are highly sought-after delicacies in many parts of the world (Del Toro et al., 2012). They also render important ecological services, including nutrient cycling, and serve as predators of pests in orchards, although negative effects are also reported (Del Toro et al., 2012). The weaver ant (*Oecophylla* spp.) is used as a biological control agent on various crops, such as mangoes and citrus (Van Mele, 2008), and the larvae and pupae of the reproductive form (queen brood), also called ant eggs, constitute a popular food in Asia. In Thailand they are sold in cans. Shen and co-workers reported that the black weaver ant (*Polymachis dives*) is widely distributed in subtropical south-east China, Bangladesh, India, Malaysia and Sri Lanka (Shen et al., (2006). It is used as a nutritional ingredient and processed into various tonics or health foods available on the Chinese market. The State Food and Drug Administration and State Health Ministry of China have approved more than 30 ant-containing health products since 1996.

In Japan, the larvae of yellow jacket wasps (*Vespula* and *Dolichovespula* spp.), are commonly consumed. During the annual Hebo Festival, food products made from the larvae of the wasps are popular delicacies (Nonaka et al., 2008), so much so that the local supply is insufficient and imports from Australia and Viet Nam are necessary to keep up with demand (Shono, 2012).

Orthoptera (Locusts, Grasshoppers and Crickets)

About 80 grasshopper species are consumed worldwide, and the majority of grasshopper species are edible. Locusts may occur in swarms, which makes them particularly easy to harvest. In Africa, the desert locust, the migratory locust, the red locust and the brown locust are eaten. However, due to their status as agricultural pests they may be sprayed with insecticides in large-scale international control programmes or by individual farmers (van Huis et al., 2013). For example, relatively high concentrations of residues of organophosphorus pesticides were detected in locusts collected for food in Kuwait (Saeed et al., 1993).

In Niger, it is not uncommon to find grasshoppers on sale in local markets or sold as snacks on roadsides. Remarkably, researchers found that grasshoppers collected in millet fields fetched a higher price in local markets than those obtained from millet grains (van Huis, 2003b).

The chapuline is probably the best-known edible grasshopper in Latin America. This small grasshopper has been part of local diets for centuries and is still eaten in several parts of Mexico (Cohen et al., 2009, Durst, 2010).

Hemiptera: Homoptera (Cicadas, Leafhoppers, Planthoppers and Scale Insects)

In Malawi, several cicada species (*Ioba*, *Platypleura* and *Pycna*) are highly esteemed as food. Cicadas can be found on the trunks of trees and collected using long reeds (*Phragmites mauritianus*) or grasses (*Pennisetum purpureum*) with a glue-like residue on them, such as latex from the *Ficus natalensis* tree. The latex adheres to the cicadas' wings, which are removed before consumption. Some Homoptera produce products commonly eaten by humans, such as carmine dye (a bright red pigment also called E120) derived from the cactus cochineal bug (*Dactylopius coccus*) often used in food products (Yen, 2005).

Humans also consume lerp, a crystallized, sugary secretion produced by the larvae of psyllid insects as a protective cover (Yen, 2005).

Hemiptera: Heteroptera (True Bugs)

Pentatomid bugs are eaten widely throughout sub-Saharan Africa, particularly in southern Africa. In the Republic of Sudan, the pentatomid *Agonoscelis versicolor*, a pest of rain-fed sorghum that causes considerable damage, is eaten roasted. Oil is also derived from these insects and is used in preparing food and for treating scab disease in camels (van Huis et al., 2013). Most pentatomids consumed as food, however, live in water. The famous Mexican caviar, ahuahutle, is composed of the eggs of at least seven species of aquatic Hemiptera (the *Corixidae* and *Notonectidae* families). These insects have been the backbone of aquatic farming, or aquaculture, in Mexico for centuries. The semi-cultivation of these species is simple and inexpensive because it can be undertaken using traditional local practices (Parsons, 2010). The insects fetch high prices, particularly during the *Semana Santa* (the week preceding Easter). However, the semi-cultivation of Hemiptera is under threat, as a result of heavy pollution and dried-up water bodies (Ramos Elorduy, 2006).

Isoptera (Termites)

The most commonly eaten termite species are the large *Macrotermes* species. The winged termites emerge after the first rains fall at the end of the dry season, from holes near termite nests. van Huis (2003b) observed that, in Africa, locals beat the ground around termite hills (simulating heavy rain) to provoke the termites to emerge. *Syntermes* species are the largest termites eaten in the Amazon. They are gathered by introducing a palm leaf rib into the galleries of the nest; the soldiers biting it are then fished out (Paoletti and Dufour, 2005). Termites are commonly sold at markets in Northern Ghana, especially in Navrongo and its environs (Anankware et al., 2013).

Insects as animal feed

According to van Huis et al., (2013), in 2011, combined world feed production was estimated at 870 million tonnes, with revenue from global commercial feed manufacturing generating approximately US$ 350 billion.

Apart from human consumption, insects have been used as feed for poultry and pigs. Throughout West Africa, termites are collected in the wild to feed poultry (Kenis and Hein, 2014). Chippings of termite mounds are collected and given to poultry on-farm, particularly to chicks (Kenis and Hein, 2014).

In a traditional Ghanaian home in northern Ghana, each farmer has several termitaria that are harvested daily to augment the protein requirements of their poultry birds. This is harvested very early in the morning (before sunrise) with cow dung, dried grass and/or corn cobs/stalk and given to the fowls. This is fed to the fowls first in the morning before allowing them out of their pen to forage on their own. This is repeated in the afternoon and evenings depending on their availability. (Anankware, 2014). Such a practice not only provides cheap and good nourishment for the birds but also helps the farmers to keep their birds in check since the fowls will always return on time for 'mid-day lunch and dinner'. This serves as a security check and also prevents the fowls from roaming very far from home.

Worldwide, several insect species are used as feed for animals. These include the black soldier fly, *Hermetia illuscens*, the house fly, *Musca domestica*. In the Netherlands, the larvae of the mealworm *T. molitor*, the lesser mealworm (*A. diaperinus*) and the superworm (*Z. morio*), are reared as feed for reptiles, fish and avian pets.

Black soldier flies

Black soldier flies, (*Hermetia illucens* Linnaeus) (Diptera: Stratiomyidae) are found in abundance and naturally occur around the manure piles of large poultry, pigs and cattle. For this reason, they are known as latrine larvae (van Huis et al., 2013). The larvae also occur in very dense populations on organic wastes such as coffee bean pulp, vegetables, distillers' waste and fish offal (fish processing by-products). They can be used commercially to solve a number of environmental problems associated with manure and other organic waste, such as reducing manure mass, moisture content and offensive odours. At the same time they provide high-value feedstuff for cattle, pig, poultry and fish (Newton et al., 2005). The adult black soldier fly, moreover, is not attracted to human habitats or foods and for that reason is not considered a nuisance. The high crude fat content of black soldier flies can be converted to biodiesel: 1 000 larvae growing on 1 kg of cattle manure, pig manure and chicken manure produce 36 g, 58 g and 91 g, respectively, of biodiesel (Li et al., 2011).

Common housefly larvae

Maggots, the larvae of the common housefly, *M domestica* develop predominantly in tropical environments. Maggots are important sources of animal proteins for poultry: they have a dry matter of 30% of their total wet larval mass, 54% of which is crude protein (van Huis et al., 2013). Maggots can be offered fresh, but for intensive farming they are more convenient as a dry product in terms of storage and for transport. Studies have shown that maggot meal could replace fish meal in the production of broiler chickens (Hwangbo et al., 2009). At the same time, maggot production can contribute to manure decomposition.

Termites

Termites caught in the wild can be used to catch fish and birds. Silow (1983) reported from Zambia the use of snouted termites (*Trinervitermes* spp.) as fish bait in conical reed traps and as bait to attract insectivorous birds (such as guinea fowl, francolins, quails and thrushes). The birds were caught by setting a snare across the broken top of a termite mound, where soldiers mass for hours (van Huis et al., 2013). However, rearing termites is very difficult and should not be recommended, also bearing in mind their high emissions of methane (Hackstein and Stumm, 1994).

Mealworms

Mealworms (such as *T. molitor*) are already raised on an industrial scale. They can be grown on low-nutritive waste products and fed to broiler chickens. Ramos Elorduy *et al.* (2002) reared *T. molitor* larvae on several dried waste materials of different origin. They used three levels of larvae (0, 5 and 10% dry weight) in a 19% protein content sorghum–soybean meal basal diet to evaluate feed intake, weight gain and feed efficiency. After 15 days there were no significant differences between treatments. Mealworms are promising alternatives to conventional protein sources, particularly soybean meal (van Huis et al., 2013).

Semi-Cultivation and Farming of Edible Insects

Global enthusiasm for insect farming is growing as its diverse range of potential commercial and environmental benefits become well recognized (Devic et al., 2014). One key issue in realizing the potential of edible insects in improving food security, sustainable food production, and biodiversity conservation, is assuring an adequate supply of the edible insect resource in a sustainable way. This can be achieved by semi-cultivation and farming edible insects (Van Itterbeeck, 2014).

Research has been carried out to semi-cultivate and farm other edible insects and to optimize existing techniques, e.g. bamboo worm (*Omphisa fuscidentalis*), Mopane worm (*I. belina*), termites, palm weevil larvae (e.g. *R. palmarum* and *R. ferrugineus*), cricket (*Acheta domesticus*), and the Asian weaver ant (*Oecophylla smaragdina Fab.*).

Maggots of flies can be cultured on various organic wastes or by-products such as manures, food leftovers, etc. hence reducing volumes, odours and alternative disposal costs. Products include a high quality protein source (maggots) that can be fed to livestock and fish in nutrient deficit areas, as well as nutrient rich biofertilisers (residues) (Devic et al., 2014). Devic and co-workers have described the iterative learning-process involved in the development of a pilot-scale production system in Ghana, the first of its kind in West Africa. They have demonstrated the feasibility of producing a local, low-cost and high quality source of nutrients that could be used in aquaculture. This is because fish farming is growing fast in Ghana though constrained by availability of quality feed ingredients. Starting from a green-field site, production was progressively scaled-up to a medium-scale demonstration pilot for two fly species (*Hermetia illucens* and *M. domestica*) producing several kilograms of maggots per week (Devic et al., 2014).

Figure1. Feed conversion from flies (Courtesy: Kenis, 2014)

The shea caterpillar, *Cirina forda* (Westwood), is considered a delicacy in the south-west Burkina Faso, but neglected in other regions. Caterpillars can now be conserved in sterile packages and methods are presently being developed to transform the caterpillars into enriched protein powder or sauce that can be used as food supplement, in particular for pregnant women, babies and young children, and thereby combat malnutrition (Kenis and Hein, 2014).

Current and Future Research Needs

Currently, over 90% of the protein required for livestock rearing in Ghana is imported, thus making it unsustainable. Meat consumption has dramatically increased in recent years (Kenis, 2014). Animal feed needs a substantial amount of proteins such as soybean and fish meal. Insects provide a more sustainable source of protein for animal feed (Figure 1.) and human food. Although many insects also need agricultural products to feed on (grasshoppers, mealworms, etc.), certain insects such as flies and their maggots can be produced on organic waste products.

Taxonomic identities and details of the life cycles of many edible insects as well as protein rich insects are unavailable. Hence there is an urgent concerted need to conduct research on the identification, distribution, conservation and economic potential of neglected and underutilized insect species in Africa to enable us identify and modernize this readily available and accessible alternative food and feed to help solve the problem of food insecurity and malnutrition on the continent. Issues that need to be resolved include efficient production methods, transformation and inclusion in animal feed, quality and safety and acceptability to consumers.

Very little has been done in the area of entomophagy in Ghana. Fortunately, Anankware and co-workers are currently conducting a nationwide survey in an attempt to identify the major edible insects in Ghana. Rearing modules for the black soldier fly, *H. illuscens* and the house fly, *M. domestica* have been successfully carried out in Ghana in conjunction with other European partners (CABI, ProtINSECT, Devic Emilie and Maciel-Vergara Gabriela). Successful rearing of the oil palm weevil is also on-going in three regions (Eastern, Ashanti and Brong-Ahafo) of Ghana by an international organization (Aspire Food Group) with Anankware P. J. as its Country Director. Further research is underway evaluating how the resulting maggots can substitute for conventional sources of proteins (fishmeal, soybean meal, etc.) in poultry or aqua feeds or be used to supplement nutrient-deficient diets (Devic et al., 2014).

Protein

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).

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.
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).

Fat content

Edible insects are a considerable source of fat. According to van Huis et al., (2013), Womeni and co-workers investigated the content and composition of oils extracted from several insects. 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).

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).

Minerals

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).

Vitamins

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).

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, 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).

CONCLUSION

Insects are sustainable source of protein for use in animal feed and for human consumption. Entomophagy is an age-old phenomenon dating back to pre-historic era and has served man for several millennia. However, a lot still needs to be done and many issues ought to be resolved in elaborating normative frameworks and adjusting for insect-inclusive food laws. Scientists, industry and regulators need to collaborate proactively and contribute to self-regulation in the sector. An analysis of existing policies and regulations on food and feed ingredients is necessary and can be achieved by communicating with the relevant regulatory bodies and their key contact persons; identifying impediments and finding out where the existing framework needs to be improved. The development of new policies is inevitable. It will be necessary to listen to regulators to determine what is expected, to be sensitive to consumers who might demand specific regulations, and to collaborate with retailers. Promotion of private and public standardization at the national and international levels for insects as food and feed, accompanied by a premarket safety evaluation (under Codex Alimentarius, among other standard-setting organizations) is crucial. We need to promote the establishment of appropriate international and national standards and legal frameworks to facilitate the use of insects as food and feed and the development and formalization of the sector. Finally, the potential effects of insect production and rearing on the environment, and the environmental and trade implications of the international movement of insects, when drafting and implementing regulatory frameworks for insect production and use must be considered. This would oblige regulators to pay attention to a broad range of regulatory areas, including phytosanitary legislation, biodiversity, disease control and environmental protection.

REFERENCES

Anankware PJ, Obeng-Ofori D, Osekre E (2013). Neglected and Underutilized Insect Species for Nutrition and Health. In*: International Conference on Neglected and Underutilized Species for a Food-Secure Africa*. Accra, Ghana, 27-29 September, 2013.

Bukkens SGF (1997). The nutritional value of edible insects. *Ecology of Food and Nutrition*, 36: 287–319.

Bukkens SGF (2005). Insects in the human diet: nutritional aspects. *In* M.G. Paoletti, ed. *Ecological implications of minilivestock; role of rodents, frogs, snails, and insects for sustainable development*, pp. 545–577. New Hampshire, Science Publishers.

Cerda H, Martinez R, Briceno N, Pizzoferrato L, Manzi P, Tommaseo Ponzetta M, Marin O, Paoletti MG (2001). Palm worm (*Rhynchophorus palmarum*): traditional food in Amazonas, Venezuela. Nutritional composition, small scale production and tourist palatability. *Ecology of Food and Nutrition* 40 (1):13–32.

Cerritos R (2009). Insects as food: an ecological, social and economical approach. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources* 4 (27): 1–10.

Cohen, J.H., Sánchez, N.D.M. and Montiel-ishinoet, F.D. 2009. Chapulines and food choices in rural Oaxaca. Gastronomica. J. Food and Cult. 9(1):61–65.

Del Toro I, Ribbons RR, Pelini SL (2012). The little things that run the world revisited: a review of ant-mediated ecosystem services and disservices (Hymenoptera: Formicidae). *Myrmecological News* 17: 133–146.

Devic E, Anankware JP, Murray F, Little DC (2014). Breeding flies in Ghana: Implications of scaling up from pilot trials to commercial production scale. Book of Abstracts of Conference on Insects to Feed the World, the Netherlands 14-17 May 2014.

Durst PB, Shono K (2010). Edible forest insects: exploring new horizons and traditional. *In practices in Forest insects as food: humans bite back, pp 1-3* Proceedings of a workshop on Asia-Pacific resources and their potential for Development 19-21 February 2008, Chiang Mai, Thailand.

FAO (2003). *State of forest and tree genetic resources in dry zone Southern Africa Development Community countries*. Rome.

FAO (2011c). *State of food and agriculture 2010-2011. Women in agriculture: closing the gender gap for development*. Rome.

FAO/WHO (2001b). *Human vitamin and mineral requirements*. Rome.

FAO/WUR (2012). *Expert consultation meeting: assessing the potential of insects as food and feed in assuring food security*. P. Vantomme, E. Mertens, A. van Huis and H. Klunder, eds. Summary report, 23–25 January 2012, Rome. Rome, FAO.

Fasoranti JO, Ajiboye DO (1993). Some edible insects of Kwara State, Nigeria. *American Entomologist* 39 (2):113–116.

Finke MD (2002). Complete nutrient composition of commercially raised invertebrates

used as food for insectivores. *Zoo Biology*, 21(3): 269–285.

Finke MD (2005). Nutrient composition of bee brood and its potential as human food. *Ecology of Food and Nutrition*, 44(4), 257–270.

Finke MD (2007). Estimate of chitin in raw whole insects. *Zoo Biology*, 26, 105–115.

Flood J (1980). *The moth hunters: Aboriginal prehistory of the Australian Alps*. Canberra, Humanities Press, Inc.

Ghazoul J (2006). *Mopani woodlands and the mopane worm: enhancing rural livelihoods and resource sustainability. Final technical report*. London, DFID.

Hwangbo J, Hong EC, Jang A, Kang HK, Oh JS, Kim BW, Park BS (2009). Utilization of house fly-maggots, a feed supplement in the production of broiler chickens. J. Environ Biol., 30(4):609–614.

Kenis, M. and Hien, K. 2014. Prospects and constraints for the use of insects as human food and animal feed in West Africa. Book of Abstracts of Conference on Insects to Feed The World, The Netherlands 14-17 May 2014

Latham P (2003). *Edible caterpillars and their food plants in Bas-Congo*. Canterbury, Mystole Publications.

Li Q, Zheng L, Cai H, Garza E, Yu Z, Zhou S (2011). From organic waste to biodiesel: black soldier fly, *Hermetia illucens*, makes it feasible. *Fuel*, 90: 1545–1548.

Malaisse (1997). *Se nourir en foret claire africaine: approche écologique et nutritionnelle*.

Gembloux, Les Presses Agronomiques de Gembloux.

Michaelsen KF, Hoppe C, Roos N, Kaestel P, Stougaard M, Lauritzen L, Mølgaard C (2009). Choice of foods and ingredients for moderately malnourished children 6 months to 5 years of age. *Food and Nutrition Bulletin*, 30(3): 343–404.

Newton L, Sheppard C, Watson DW, Burtle G (2005). *Using* *the black soldier fly, Hermetia illucens, as a value-added tool for the management of swine manure*. North Carolina, North Carolina State University. (available at www.cals.ncsu.edu/ waste_mgt/smithfield_projects/phase2report05/cd,web%20files/A2.pdf)

Nonaka K, Sivilay S, Boulidam S (2008). *The biodiversity of insects in Vientiane*. Nara, Japan, National Agriculture and Forestry Institute and Research Institute for Hamanity and Nature.pages?

Oonincx DGAB, van Itterbeeck J, Heetkamp MJW, van den Brand H, van Loon

J, van Huis A (2010). An exploration on greenhouse gas and ammonia production by insect species suitable for animal or human consumption. *Plos One*, 5(12): e14445.

Paoletti MG, Dufour DL (2005). Edible invertebrates among Amazonian Indians: a critical review of disappearing knowledge. *In* M.G. Paoletti, ed. *Ecological implications of minilivestock; role of rodents, frogs, snails, and insects for sustainable development*, pp. 293–342. New Hampshire, Science Publishers.

Ramos Elorduy J, Pino JM (2002). Edible insects of Chiapas, Mexico. *Ecology of Food and Nutrition* 41 (4): 271–299.

Ramos Elorduy J, Pino JM, Martínez VHC (2009). Edible aquatic Coleoptera of the world with an emphasis on Mexico. J. Ethnobiol. Ethnomed. 5(11): 1-10.

Riggi LG, Verspoor RL, Veronesi M, MacFarlane C, Tchibozo S (2014). Exploring entomophagy in Northen Benin: Practices, perceptions and possibilities. Book of Abstracts of Conference on Insects to Feed the World, The Netherlands 14-17 May 2014.

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):1–5.

Shen L, Li D, Feng F, Ren Y (2006). Nutritional composition of *Polyrhachis vicina* Roger (edible Chinese black ant). Songklanakarin J. Sci. Technol. 28 (1):107–114.

Silow CA (1983). Notes on Ngangela and Nkoya ethnozoology. Ants and termites. *Etnologiska Studier*, 36: 177.

van Huis A (2003b). Insects as food in sub-Saharan Africa. *Insect Science and its Application* 23 (3): 163–185.

van Itterbeeck J, van Huis A (2012). Environmental manipulation for edible insect procurement: a historical perspective. J. Ethnobiol. Ethnomed. 8 (3):1–19.

Van Itterbeeck J (2014). Semi-cultivating edible insects: A historical perspective and future prospects. Book of Abstracts of Conference on Insects to Feed the World, The Netherlands 14-17 May 2014.

van Mele P (2008). A historical review of research on the weaver ant Oecophylla in biological control. *Agricultural and Forest Entomology* 10: 13–22.

van Huis A, Van Itterbeeck J, Klunder H, Mertens E, Halloran A, Muir G, Vantomme P (2013). Edible insects Future prospects for food and feed security. FAO Forestry, Paper 171.

Yen AL (2005). Insects and other invertebrate foods of the Australian aborigines. *In* M.G. Paoletti, ed. *Ecological implications of minilivestock: potential of insects, rodents, frogs and snails*, New Hampshire, USA, Science Publishers, pp. 367–388.