Insects in the human food chain: global status and opportunities

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Insects are part of the traditional diets of approximately 2 billion people worldwide. Insects can contribute to food security and be a part of the solution to protein shortages, given their high nutritional value, low emissions of greenhouse gases, low requirements for land and water, and the high efficiency at which they can convert feed into food. This article outlines the potential of insects as a food for humans as well as a feedstock for animals and fish. The majority of insects consumed in developing countries today are harvested in nature from wild populations. In Western countries, the disgust factor in considering insects as food, combined currently with their limited availability on the market, and a lack of regulations governing insects as food and feed, are major barriers for their further expansion. However, the biggest opportunity may well lie in the production of insect biomass as feedstock for animals and fish, to partly replace the increasingly expensive protein ingredients of compound feeds in the livestock industries. Considering the immense quantities of insect biomass needed to replace current protein-rich ingredients such as meal from fish and soybeans, automated mass rearing facilities need to be developed. For this to occur, significant technological innovations, changes in consumer food preferences, insect-encompassing food and feed legislation, and progress towards more sustainable food production systems are needed. The close collaboration of government, food and feed industry, media, chefs, and academia will be essential for success.

Keywords: entomophagy, gastronomy, insects, sustainable diets, nutrition, health food, feed production

Setting the context for entomophagy: why are we revisiting it now?

In western countries, the call for promoting entomophagy is neither new nor recent. Since 1885, when British entomologist V.M. Holt published his booklet, *Why not eat Insects?*, many papers and books have been published to document and further promote the topic of insects as food. However, what is now underlying the recent initiatives for advocating the use of insects is their value as an alternative and *healthy* food with a smaller environmental footprint then meat and the fact

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http://dx.doi.org/10.3362/2046-1887.2014.011 ISSN: 2046-1879 (print) 2046-1887 (online)

that insect rearing emits less greenhouse gases and ammonia compared to cattle and pig farming (Oonincx et al., 2010) and requires less land (Oonincx and de Boer, 2012). Rearing insects can also be done on organic waste streams, and as such, huge quantities of grains and soybeans presently used as animal feed could be made available for direct human consumption.

Insect rearing can be done not only in large-scale producing units, but also on a small scale in the backyard. Setting up small cricket-rearing units is possible for even a single person, as well as in urban areas and with little investment. Rearing insects can help the poor to grow additional food and earn money by selling off excess production to local markets. The very fact that insect rearing can address environmental, socio-economic, and health concerns simultaneously makes insect farming for food *and* feed production an attractive and very timely option in our search for a more sustainable global food supply. As the global population increases coupled with the demand for more protein (FAO, 2013c, d), the pressure on producing these proteins with shrinking resources is growing (Heinrich Böll Foundation, 2014). The search for alternative and sustainable animal protein sources is more acute now than ever, and insects are a major component in that search.

While insects as food may seem like some new high in protein 'superfood' for a growing but still quite limited number of 'adventurous' consumers in the West, insects are and have always been part of the traditional diets of approximately 2 billion people worldwide (FAO, 2013a; van Huis, 2013). Some 2000 species of insects are referred to in literature (Figure 1) as used for food (Jongema, 2012). In addition, insects are already consumed indirectly, as trace amounts of unwanted matter,

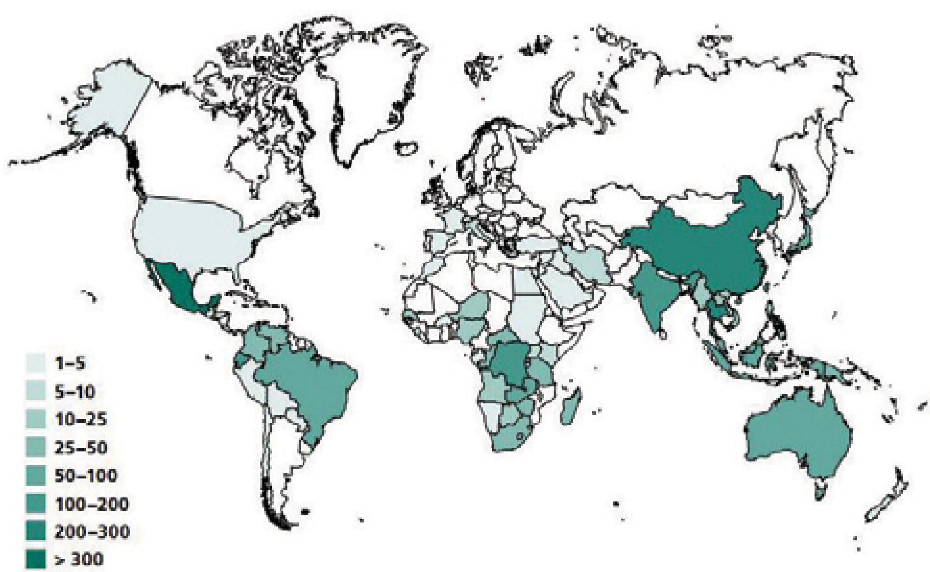

Figure 1 Recorded number of edible insect species, by country
Source: Centre for Geo Information, Wageningen University, based on data compiled by Jongema, 2012.

which end up in the food we eat (FDA, 2011). Insects are also part of the 'natural' diets of some animals we farm, such as free roaming chickens, pigs, and fish.

Insects make up one of the largest percentages of terrestrial animal biomass (Losey and Vaughan, 2006), with ants alone contributing an estimated 15 per cent (Hölldobler and Wilson, 1990). Moreover, they are the most diverse group of animals on the planet amounting to approximately 1 million identified species (Chapman, 2006). Although there has been a lot of attention placed on insects as food and feed in the past few years, this should not detract from the importance of environmental services that insects as 'ecosystem engineers' provide, such as pollination, decomposition, pest control, and provision of food for wildlife species. In the United States alone it is estimated that the value from the four most important services of wild insects, dung burial, pest control, pollination, and wildlife nutrition, is approximately US$57 bn (Losey and Vaughan, 2006).

Nutritionally, 'insects' are comparable to conventional animal protein sources such as beef and fish. That being said, the nutritional composition of insects varies substantially among species: along the metamorphic stages (eggs, larvae, pupae or adults), the habitat, and the insect's diet (FAO, 2013a).

Due to the wide global range in which edible insect species occur and their vast numbers, the nutritional values of those approximately 2000 species of insects as yet identified as edible in the literature are incomplete (FAO, 2013a). In 2013, Rumpold and Schlüter compiled 236 nutrition compositions for approximately 140 different edible insect species. On the whole insects are comparable to conventional meat sources (see Table 1). Many edible insects provide satisfactory amounts of energy and protein, meet amino acid requirements for humans, are high in monounsaturated and/or polyunsaturated fatty acids, and are rich in micronutrients such as

Table 1 Nutritional composition [%] and energy content [kcal/100 g] of some common edible insects (based on dry matter)

Edible insects (based on dry matter)	*Protein %*	*Fat %*	*Fibre %*	*Energy content Kcal/100 g*	*Origin*
African palm weevil (larvae) *Rhynchophorus phoenicis*	35.63	19.50	Data not available	479.14	Nigeria
Western honey bee (larvae)					
Apis mellifera	42.00	19.00	1.00	475.00	Mexico
Asian weaver ant					
Oecophylla smaragdina	53.46	13.46	15.38	Data not available	Thailand
Domesticated silkworm (larvae)					
Bombyx mori	58.00	35.00	2.00	555.00	Mexico
Mopane caterpillar (larvae)					
Imbrasia belina	54.26	23.38	Data not available	Data not available	Nigeria

Source: adapted from Rumpold and Schlüter (2013) copper, iron, magnesium, manganese, phosphorus, selenium, and zinc, as well as riboflavin, pantothenic acid, biotin and, in some cases, folic acid. Insects are also rich in fibre (Rumpold and Schlüter, 2013).

Approximately 85 per cent of the population of the Central African Republic consumes caterpillars. For example, in Bangui, 29 per cent of annual animal protein consumption per person per year (14.6 kg) is provided through caterpillars (N'Gasse et al., 2004). Seventy per cent of Kinshasa's 8 million inhabitants are estimated to eat caterpillars, for both their nutritional value and their taste (Vantomme et al., 2004). In the Amazon Basin at least 32 Amerindian groups consume terrestrial invertebrates as food. For example, the Guajibo of Venezuela and Colombia get 60 per cent of their animal source protein in the form of insects during the rainy season (Paoletti et al., 2000; Melo et al., 2011).

Crickets are a popular street food in Thailand, as well as a component of other traditional dishes. Crickets contain approximately 60 per cent protein, 20 per cent fat, 20 per cent fibre and 450 kcal/100g (Rumpold and Schlüter, 2013). Because of their high protein content some companies in the West (France, UK, USA) are selling energy bars enriched with cricket powder.

Edible insects are generally a low risk food. However, they may pose a risk to some people who already have allergies to house dust mites and shellfish (Verhoeckx et al., 2014). This is because insects are arthropods like shrimp, lobster, crayfish, and dust mites. Cultures with a history of entomophagy may not experience significant risk of allergies.

The majority of insects consumed in developing countries today are harvested in nature from wild populations (FAO, 2013a). Farming can be an option to help conserve wild populations from overharvesting (Yen, 2009). In the developed countries up to some 10 species of insects are farmed, mainly for pet food. Recently, a part of the production of some of these species is sold as food for humans in countries such as Thailand, China, South Africa, the Netherlands, Belgium, USA, and France. The perceived economic and environmental benefits of rearing insects for food and feed are founded on the high feed conversion efficiency of insects. Crickets, for example, require only 2 kilograms of feed for every 1 kilogram of bodyweight gain, whereas cattle require four times more (Nakagaki and de Foliart, 1991).

Getting insects on the plate

One of the largest factors barring the widespread acceptance of insects as food is 'culture'. *Taste is culture* and in many countries and societies there is a strong emotion of disgust when considering insects as food (Looy et al., 2014; Rozin et al., 2008). Humans are food generalists who make choices of what to eat based on education, experience, economics, and fashion trends in food selection, among others (Rozin, 2002). Given that most human–food relationships are acquired, they can also be altered both positively and negatively. However, food choices change over time and are pushed by socio-economics, culinary innovation, and advances in agro-food business and technology, through chefs, trendy cuisine magazines and TV shows, slow food concepts, health and/or environmental/social concerns. For example, renowned chefs such as Kylie Kwong (Australia), Alex Atala (D.O.M., Brazil), and Rene Redzepi (Noma, Denmark) have been preparing courses containing insects for the past few years. In several countries where edible insects constitute regular elements in traditional diets, food regimes change and the shift towards Western foods constitutes a real threat to entomophagy in that traditional practices of eating insects may disappear.

Another main barrier in Western countries to a widespread adoption of insects as food is that they are not really available on the market as (semi-) processed food products that can be easily included in food preparation at any level from home cooking to industrial size catering. Because insects were never considered as food before, hardly any regulatory framework governing production, trade, and consumption of insects and their derived food products yet exists (Grabowski et al., 2013). Supply chains are relatively undeveloped.

In Europe, legislation for insects as food is a relatively grey area as insects have not been explicitly mentioned in general food regulations (Belluco et al., 2013). Under Regulation (EC) 258/1997 novel food and ingredients that were not consumed 'to a significant degree' before 1997 may have to undergo an authorization before entering the market. As proposed in the new draft Novel Food Regulation, in order to be recognized as a novel food, evidence of significant consumption in Europe before 1997 needs to be recorded, or proof that the insect has been and continues to be part of the normal diet for at least one generation in a large part of the population of a given country outside Europe (COM (2007) 872 final). Progress is under way in the EU to elaborate appropriate regulations. Progress at the national level has been demonstrated, for example, by the approval of 10 farmed insect species as novel foods by the Federal Food Agency of Belgium in December 2013 (FAVV, 2013).

Developing insect cuisine has been demonstrated for example by the Nordic Food Lab (NFL Copenhagen, Denmark) through their gastronomic innovation with ants, crickets and bees, based on the point that taste is the most important component of food. New research indicates that attitudes are changing towards entomophagy and insects do have the potential to become an accepted food ingredient (Caparros et al., 2013). Furthermore, the past few years have experienced a boom in startups specializing in insect-based foods. This trend has been seen at its strongest in France, the Netherlands, and the USA.

The socioeconomic contribution of edible insects

The overall contribution of edible insects to livelihoods is difficult to estimate because of a lack of reliable statistics; data on production, trade, and consumption is almost non-existent as insects are not an established entry point (yet) into national statistical databases, nor are they yet a component of national agriculture and nutrition programmes (FAO, 2013a). Most of the available data deals with a few species and is often obtained from local household interviews (FAO, 2011). A comprehensive understanding of the dynamics of value chains and markets at the national level in any country has only been studied in more depth for the market in Thailand and Southern Africa (FAO, 2013a, b; Yhoung-Aree and Viwatpanich, 2005). One of the best studied species is the mopane caterpillar (Ghazul, 2006; Kozanayi and Frost, 2002; Hobane, 1994; Makhado and Makhado, 2009; Styles, 1994).

Edible insect value chains often represent informal markets and are region-specific (FAO, 2013a). While some insects are collected to supplement diets of the collectors, others are sold on local markets by adding limited value through washing and cooking. This is the case, for example, in north-eastern Limpopo Province in South Africa where edible locusts are harvested by children and women and then fried and eaten fresh or dried in the sun for use the next day (Makhado et al., 2009). On the other hand, value chains become more complex when they are targeting export markets, for example for diaspora communities, and include more actors involved in informal cross-border trade. Tabuna stated in N'Gasse et al. (2004) that there is an estimated informal trade of 5 tonnes of dried caterpillars from Central Africa to Paris and 3 tonnes to Brussels annually.

Since most insect species are only seasonally available in nature, insect farming has been promoted as a means of producing a consistent supply to the market. A commonly farmed insect species is the house cricket (*Acheta domesticus*). In Thailand alone there are approximately 20,000 cricket farms producing 7,500 tonnes per year (FAO, 2013b). What makes cricket rearing an interesting business is the fact that cricket farms produce three main products: eggs, crickets, and waste (FAO, 2013b). These products can be sold to farmers, wholesale buyers/retailers, and as fertilizers for farmers, respectively. Wholesale buyers sell either to market vendors or cooked cricket outlets, which in turn sell these products to consumers. Retailers sell the crickets directly to consumers or to reptile or fish breeders as pet feed (FAO, 2013b).

A good example of an insect species reared for food and fibre is the silkworm. They are grown for silk production and can also be consumed in the larval or pupal state (DeFoliart, 1995, 1997). Silkworms (*Bombyx mori*) are one of the oldest domesticated insect species (over 5,000 years) and have been cultivated even in several European countries. Silkworms are also a promising species for industrial feed production, as the processed pupae can be turned into chicken feed (FAO, 2013a). Honey and bee brood (pupae and larvae), from a number of bee families including Meliponidae, and Apidae (Banjo et al., 2006; Ramos Elorduy, 2006), provide both food and wax (DeFoliart, 1999). Bee brood provides protein, fat, and carbohydrates, as well as phosphorus, magnesium, potassium, and the trace minerals iron, zinc, copper, and selenium (Finke, 2007; FAO, 2009).

Mopane caterpillars in southern Africa, and bamboo caterpillars and weaver ants in south-eastern Asia have been fairly well researched and will serve as cases to illustrate the substantial socio-economic benefits of edible insects in some developing countries.

Case 1: Southern Africa – mopane caterpillar (Imbrasia belina)

The mopane caterpillar, the larvae of the mopane emperor moth *Imbrasia belina*, is endemic to the mopane woodlands of Angola, Botswana, Mozambique, Namibia, South Africa, Zambia, and Zimbabwe. These woodlands extend over 384,000 km^2 of forest in southern Africa (FAO, 2003). An estimated 9.5 billion mopane caterpillars are harvested annually in southern Africa. The economic contribution of this production is approximately \$85 m (Ghazul, 2006). Trade of mopane caterpillars harvested in the mopane woodlands of southern Africa extends as far north as the Democratic Republic of the Congo (Ghazul, 2006; DFID, 2006). A study by Shackelton and Shackelton (2004) in South Africa concluded that more than half of the rural households surveyed in their study made use of edible insects.

In 1999 the value of mopane caterpillars in South Africa was estimated to be £2,850 (\$4,671) per hectare of mopane woodland (Rebe, 1999). Forty per cent of the harvesting is carried out by poor rural women (Styles, 1994). At the height of the season the average caterpillar collector can gather up to 20 litres per day in Zambia; seven days of collection equates to one month's salary for the average Zambian (DeFoliart, 1999). In Botswana, the average annual harvest amounts to 350–400 tonnes (\$3.3 m) and employs approximately 10,000 people. The majority of these wild-gathered mopane caterpillars are exported to South Africa (Styles, 1996) and the value of the export business is approximately \$1.3 m (CSO, 2004).

Case 2: South-east Asia: bamboo caterpillars (Omphisa fuscidentalis) and weaver ant (Oecophylla smaragdina)

Two seasonal insects, bamboo caterpillars (*Omphisa fuscidentalis*) and weaver ants (*Oecophylla smaragdina*), are commonly harvested and consumed in South-eastern Asia. These insect species contribute significantly to rural livelihoods and can fetch high market prices (Table 2).

Bamboo caterpillars, also known as bamboo borers, are found in the bamboo groves and forests of northern Thailand, and neighbouring countries China, Myanmar, and Laos (FAO, 2013b). The bamboo caterpillars feed on 11 species of bamboo (Kayikananta, 2000). Traditionally, the caterpillars were harvested by cutting down bamboo clumps. However, a new approach to sustainable harvesting has been developed which allows for the caterpillars to be harvested without killing the bamboo plant by cutting a hole in the bamboo and removing the larvae (FAO, 2013b). On average, a person can collect approximately 13 kilograms per day of bamboo caterpillars (\$50) when they are in season (Table 2) (Leksawasdi, 2010).

Weaver ants, another popular food in Thailand, are harvested from host trees in the wild. When in season daily collection usually amounts to 1–2 kg. Although weaver ant harvesting is not a full-time occupation, the additional income generated from the harvest contributes substantially to livelihood diversification in rural areas. However, this seasonal activity often generates more income for households than normal farm activities (FAO, 2013a). In Thailand, collectors receive a daily income of \$12 over the 4–5 month weaver ant season. In the Thai province of Nakhon Rachasima the total yearly income generated by weaver ant collectors was estimated at \$620,000 (Sribandit et al., 2008).

Weaver ants are also consumed in parts of Africa, Australia, India, Laos PDR, Myanmar, Vietnam, Borneo, Papua New Guinea, and the Philippines (Offenberg

Table 2 Two commonly marketed and consumed wild harvested edible insects in Thailand

Common name	*Scientific name*	*Seasonal occurrence*	*Wholesale price/kg (US$) fresh*
Asian weaver ant	*Oecophylla smaragdina Fabricius*	March–May	9.50
Bamboo caterpillar	*Omphisa fuscidentalis Hampson*	August–November	9.50

Source: adapted from FAO, 2013a

and Wiwatwitaya, 2010; Rastogi, 2011). In Indonesia, weaver ants are also used as bird feed or fish bait. Collectors receive approximately $1.4 per kg, while the market price is usually two to three times higher (CIFOR, 2004).

Up to some 10 insect species in developed countries are reared by a few producers (often family farms) as feed for birds, reptiles or for use as fishing bait. Insects are often also raised by zoos to supply their animals that feed on insects. Production quantities are quite limited and do not appear in agricultural census data on feed production. Over the last few years there has been a growing demand (although still small) for some of these insect species for direct human consumption, featuring three main species: mealworms, grasshoppers, and crickets. Prices of these freeze-dried insects are relatively high: for example, mealworms are 3.3 times more expensive than pork and 4.8 times more expensive than chicken (Cazaux et al., 2010). So far, insects are supplying a very small but fast growing niche in the food market (FAO, 2013a).

However, the most promising potential for a wider impact on the food system, may well be through the indirect use of insects as feed for livestock and fish production. This stems from the need to find alternative protein sources to fishmeal, fish oil, soybeans, and grains. The International Feed Industry Federation estimated that feed production will have to increase by 70 per cent to be able to feed the world in 2050, with meat outputs (poultry, pork, and beef) expected to double. Approximately 10 per cent of global fish production in 2011 was used as fishmeal (FAO, 2012). The increasing global demand for and decreasing availability of fishmeal has led to sharp increases in the price: from $600/metric tonne in 2005 to $2,000/metric tonne in June 2010 (Barroso et al., 2014; Sánchez-Muros et al., 2014). Soybean meal is the best available vegetable protein source, but the amino-acid profile makes it less interesting than insect meal (Barroso et al., 2014). Average prices for soybean meal have increased from $220 per tonne in 2005 to $400 in 2010 (OECD-FAO, 2010). Just as greater emphasis has been placed on finding more sustainable sources of animal protein for human consumption, the same need exists for developing alternative protein sources to feed our livestock and fish farms (Gatlin et al., 2007).

Interest in using insects as feed has recently been witnessed worldwide, especially in China, South Africa, the Netherlands, USA, Canada, and Spain. The black soldier fly (*Hermetia illucens*) and common housefly (*Musca domestica*) larvae, the domesticated silkworm (*Bombyx mori*), and several mealworm species (mainly yellow mealworm, *Tenebrio molitor*) have shown the most promising results so far

(FAO, 2013a). Usually the larvae are raised on a substrate of organic waste, such as distillers waste, pig and chicken manure or other agricultural/urban food wastes. The challenge lies in having the quality and quantities of the substrate needed to feed the insects under control, while producing at competitive market prices. These start-ups are still experimenting with their technological systems, increasing scale of production processes, improving feed quality control measures, and trying to solve legal issues with local food and feed authorities for obtaining permits to operate and market their products. The real challenge is to have the insect-based feed produced at competitive costs compared to the traditional vegetal (soy, beans, and grains) and animal (fishmeal) based protein sources. However, in this context it is important to closely follow the tendency to relax the EU ban on using processed animal protein (PAP) for feeding animals that enter the human food chain. Since mid-2013 waste from fish processing and uncommercial fish landings are allowed for processing into such feed (Regulation (EC) Nr 56/2013 of the European Parliament and of the Council 2013). At the same time policy changes allowing the use of slaughterhouse waste as raw materials for PAP into feed is gaining the support of interest groups (Regulation (EC) Nr 1774/2002 of the European Parliament and of the Council 2013). This may have a profound influence on the financial profitability of insect-based feed manufacturing in the EU.

The way forward

Recent research and development show edible insects to be a promising alternative to the conventional production of meat, either for direct human consumption or for indirect use in feedstock. Nevertheless, a tremendous amount of work still needs to be done by a wide range of stakeholders to fully realize the potential that insects offer for food and feed security both in developing and in developed countries.

The overwhelming majority of insects are informally harvested from wild populations. There is little legislation governing the sustainable harvest of edible insects. For example, in southern Africa widespread poverty in rural areas coupled with increasing poverty in urban centres has prompted overharvesting of mopane caterpillars (FAO, 2013a). Moreover, a number of anthropogenic factors, such as pollution, wildfire, and habitat degradation, have contributed to a decline in many edible insect populations. This has turned the promise of a new source of income and cheaper protein into a conservation dilemma. The sustainable harvesting of edible insects in the wild requires nature conservation strategies (Yen, 2009; Ramos-Elorduy, 2006).

There is a need for more empirically based research including the identification of edible insect species, estimating population dynamics, and understanding the ecology and biology of species and their interactions with their habitats. Habitat manipulation measures can increase the abundance and accessibility of insect populations (Van Itterbeeck and van Huis, 2012). Already some wild insect species have been successfully semi-domesticated or domesticated, such as palm weevils, crickets, grasshoppers, and bamboo caterpillars. To guarantee that insects can remain part of the diets of 2 billion people, action is urgently needed to ensure more sustainability in gathering wild insect populations, to promote simple semi-domestication techniques, and to farm the insects at a household or an industrial level. Tools for sustainable management of forest and other natural resources have already been developed by organizations such as CIFOR, FAO, and ICRAF; it is now time to also integrate insects as a parameter contributing to biodiversity in nature and human diets.

Considering that insects already form part of the human diet in many countries, their potential needs to be re-evaluated. Agriculture and horticulture development and extension programmes may investigate the possibility of simultaneously controlling pest insects by harvesting them as food/feed, as is done already in Mexico for grasshoppers in corn, bean, and alfalfa (Cerritos and Cano-Santana, 2008; Cerritos, 2009). Simple on-farm rearing procedures for more promising insect species need to be developed. Preservation and processing techniques are needed to increase shelf life, conserve quality, and increase the acceptability of insect food products. Processing methods need to be further developed in order to transform insects into protein meal for animal/fish feedstock and for the extraction of insect proteins to be used as ingredients in the food industry.

Integrating edible insects as *healthy* food onto the political agenda of food security, health and nutritional agencies and campaigns requires a better and more comprehensive understanding of the nutritional values of (more) insect species. In particular, the bio-availability of micronutrients (mainly of iron and zinc) in edible insects needs further investigation, given the massive occurrence of these deficiencies in the tropics, leading to stunted growth of children (Bauserman et al., 2013). FAO estimates that 26 per cent of all children under five are stunted and 31 per cent suffer from vitamin A deficiency (FAO, 2013e).

National and international poverty alleviation agencies and aid programmes need to be made aware that gathering and farming insects is a viable option to help the urban and rural poor to improve their livelihoods. Global, national, and local study cases documenting the roles of edible insects in subsistence and improved diets are needed, as well as assessments of the dynamics of their value chains and markets. Their monetary contribution to the local economy and for international trade is largely unknown. Therefore data collection, methodologies, and procedures need to be adjusted to incorporate production and trade in edible insects and their products. There is an urgent need to clarify and augment the socio-economic benefits that insect gathering and farming can offer, with a focus on improving the food security of the poorest of society. Additionally, insect rearing should be promoted and encouraged as a socially inclusive activity. Rearing insects requires minimal technical knowledge and capital investment and, since it does not require access to or ownership of land, lies within the reach of even the poorest and most vulnerable members of society.

Legislators need to include insects as feed and food to improve existing national policy and legal frameworks covering the food and feed sectors. In most countries insects are not legally recognized as a food or feed source. This creates difficulties for investors and producers alike. However, mounting research coupled with a growing amount of lobbying from insect producers and consumers have managed to put insects on the radar of many decision-makers worldwide. The gradual recognition of insects as food and feed is happening at different levels: international (e.g. Codex Alimentarius), regional (e.g. European Union), and national (e.g. Switzerland, Belgium). Developing a clear and comprehensive legal framework at the (inter-)national level can pave the way for more investment, leading towards the full development (from the household scale to the industrial scale) of production, consumption, and trade in insect products for food and feed internationally.

The case needs also to be made to consumers that eating insects is not only good for their health, it is good for the planet. More scientific evidence to investigate the sustainability and quantify the environmental impacts of harvesting and farming insects compared with traditional farming and livestock-raising practices would help to inform the public and consumers about the real footprint and costs of our food choices and their socio-economic and environmental consequences.

Conclusion

Insects can contribute to food security and be a part of the solution to protein shortages, given their high nutritional value, low emissions of greenhouse gases, low requirements for land and water, and the high efficiency at which they can convert feed into edible mass (edible body parts). In the Western world, consumer acceptability will be determined, in large part, by pricing, perceived environmental benefits, and development by the catering industry of tasty insect-derived products.

The production of insect biomass as feedstock for animals and fish can be combined with the biodegradation of manure and the composting and sanitizing of waste. Insects can partly replace the increasingly expensive protein ingredients of compound feeds in the livestock, poultry, and aquaculture industries. Grains now used as livestock feed, which often comprise half the cost of meat production, could then be used for human consumption. As the cost of conventional animal proteins increase, insects may well become a cheaper source of protein than conventionally produced meat and ocean-caught fish. For this to occur, there will need to be significant technological innovation for farming, changes in consumer preferences, insect-encompassing food and feed legislation, and more innovative ways of using insects as a valuable food ingredient.

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