Entomological Research

Entomological Research **39** (2009) 289–298

INVITED REVIEW

Edible insects: Traditional knowledge or western phobia?

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Received 30 June 2009;
accepted 16 July 2009.

doi: 10.1111/j.1748-5967.2009.00239.x

Abstract

With an increasing human population and environmental degradation, the world faces a major problem in providing adequate animal based proteins. Many traditional societies have used or still use insects as a protein source, while westernized societies are reluctant to use insects, despite being the major consumers of animal proteins. We now need to consider insects as a source of food for humans in a manner that acknowledges both the role of entomophagy in indigenous societies and the need for westernized societies to reduce the size of their environmental footprint with regard to food production. The situation on continents such as Africa, Asia, and Central and South America has some parallels to Australia in that there are two forces in operation: the sustainable traditional use of edible insects and the "westernization" of these societies leading to a movement away from entomophagy. However, the potential to reach a compromise is greater in these continents because entomophagy is already accepted. The major challenges will be establishing sustainable production systems that include food safety and security as well as environmental protection. Whether this will happen or not will depend upon: (i) a major change in attitude in westernized societies towards entomophagy; (ii) pressure to conserve remaining habitats in a sustainable manner; (iii) economic impetus to develop food production systems that include insects; and (iv) an acknowledgement that achieving adequate nutrition on a global basis will involve different diets in much of the developed world.

Key words: edible insects, entomophagy, traditional knowledge.

Introduction

Over the last two decades, there have been several conferences and many publications on the human consumption of edible insects and other invertebrates (such as Paoletti 2005). Most of the published works involve descriptive overviews of edible insects in different countries and observations on the ways various ethnic groups identify, collect and cook insects. The vast majority of this literature is associated with different ethnic groups in Africa, Asia, Central and South America and Australia. There is frequent reference to the fact that deliberate human entomophagy is very rare in westernized societies.

World food crisis

Discussion about the world food crisis is often directed towards overpopulation and famine in developing nations and the fact that people in developed nations have a greater effect on the environment because of the need to use more resources to produce animal protein for their consumption. There is no argument on two facts: (i) the rapid growth of the human population increases demand for food; and (ii) there are limited energy (fossil fuels) and land resources to produce this food (Pimentel *et al.* 1975). People in developed western nations generally have higher protein consumption than those in underdeveloped nations and a greater proportion of this is derived from meat. For example, in 1975, protein consumption in Asia was 56 g protein/person/day (48 g from grain and 8 g from animals) compared to 96 g/person/day (66 g from animals) in the USA (Pimentel *et al.* 1975). Livestock production, including feedcrop production, occupies 70% of the world's agricultural land (or 30% of the earth's land), and consumes 77 million tonnes of protein to produce 58 million tonnes of protein for human consumption annually (Steinfeld *et al.* 2006). While these figures refer to animal protein for human consumption, there is an increasing demand for animal protein as pet food in westernized societies. The situation may be worse than these figures suggest. First, with increasing urbanization, more arable land is lost for food production. Second, there is the matter of how climate change will affect food production across the world.

Potential of insects

Insects are a readily available source of protein, lipids, carbohydrates and certain vitamins (MacEvilly 2000). Apart from Europe and North America, approximately 1500–2000 species of insects and other invertebrates are consumed by 3000 ethnic groups across 113 countries in Asia, Australia, and Central and South America (MacEvilly 2000).

Animal proteins have higher nutritional value than plant proteins because the former have larger amounts of eight essential amino acids for human development. Humans do not obtain all necessary amino acids, vitamins and trace minerals by consuming large quantities of cereal and other vegetable food sources (Pimentel *et al.* 1975; Ladron de Guevara *et al.* 1995). Neumann *et al.* (2002) advocated the need to develop different animals as sources of protein to alleviate the mild to moderate protein–energy malnutrition prevalent throughout the developing world, but they only suggested vertebrate animals and did not include insects. The mass production of insects has great potential to provide animal proteins for human consumption, either directly, or indirectly as livestock feed. The latter could reduce energy requirements in livestock production. The use of insects as an additional source of protein could result in increased conversion efficiencies and a smaller environmental footprint in our livestock production, especially if closed systems can be developed at the village or farm level (Steinfeld *et al.* 2006).

In the debate on how to feed the increasing world population, few would disagree with the view that entomophagy has the potential to supply a significant proportion of the nutritional requirements of humans, either as a direct food source or indirectly as food for livestock. We need to consider why we should use insects as a food source, and this raises the questions of how we would do it, and people would accept insects as food.

Problems: Western phobia and globalization

While human entomophagy is accepted as a normal part of the diet in many continents, the main problems are: (i) a phobia of eating insects in western societies (DeFoliart 1999); and (ii) globalization that has seen adoption of a universal cultural system based largely on western values, customs and habits including changes in food customs. Globalization is resulting in the use of more fast foods and pre-prepared foods and the loss of traditional ways of life (Illgner & Nel 2000).

If insects are to be widely adopted as a protein source, there are few issues involved in getting support from traditional societies. The major challenge is getting entomophagy into westernized societies. The main attitude towards insects as food in westernized societies is either one of fear and abhorrence, or one of curiosity. The approach of highlighting apparently strange insect foods may well be an incorrect one if we are serious about integrating insects as a protein source for humans. Instead, entomophagy needs to be assessed in terms of food security and food safety. Traditional knowledge is an essential foundation for advancing entomophagy, but it also has to address food security and food safety issues. This paper will examine human entomophagy in traditional and westernized societies to suggest ways in which it can be furthered in both societies. First, it will briefly consider the situation in Australia because it is an example of a nation where the traditional Aboriginal use of insects and westernized dietary customs intersect.

Edible insects in Australia

Yen (2005) summarized the invertebrate foods of Australian Aboriginal people. The better known insect foods include edible grubs (mainly Coleoptera and Lepidoptera), honey ants, scale insects, lerps (Hemiptera: Psylloidea) and Bogong moths *Agrotis infusa* Boisduval (Lepidoptera: Noctuidae). A large proportion of the Australian insect fauna coevolved with *Eucalyptus* and *Acacia* and there are no recorded large foliage chewing species consumed (probably because of plant chemicals consumed by the insects). Most of the larger grubs consumed in Australia are wood or root feeding species. Traditional animal foods eaten by Australian Aboriginal people are low in fat and contain a high proportion of polyunsaturated fatty acids; the European diet and lifestyle has resulted in a high incidence of diabetes and heart diseases in Australian Aboriginal people (Naughton *et al.* 1986). Interestingly, the preferred edible grubs such as cossid moth larvae have a high fat content, while the Australian plague locust *Chortoicetes terminifera* Walker (Orthoptera: Acrididae), with 25% protein content (Brand *et al.* 1982), was ignored as a dietary item.

There has been considerable discussion on the need for forest conservation in Asia, Africa and South America for edible insects (e.g. Pimentel *et al.* 1997; FAO Département des Forêts 2004; Vantomme *et al.* 2004). While forests have a greater number of edible species and definitely a greater number of people depend upon them, edible insects are still important in non-forest environments. For example, Cane (1987) documented the diet of a Western Desert tribe in the Great Sandy Desert of northwestern Australia. The availability of different foods is seasonal: some tubers, reptiles and birds are available most of the year, but seeds, fruits, nectar and mammals are not. Insects are available throughout most of the year except in mid-summer. Six plant species were hosts for edible grubs, and an adult human can collect 30–40 grubs/hour (400 g).

There is still a lot to be learned about the use of edible invertebrates by Australian Aboriginal people. There are reports of invertebrates used as food that need to be confirmed; for example, the use of the land snail *Xanthomelon durvillii* (Hombron & Jacquinot) (Gastropda: Camaenidae) in Arnhem Land (Naughton *et al.* 1986). Then there is the question of why some species that are eaten in other nations are not eaten in Australia; these include grasshoppers and locusts, and possibly shield shrimps *Triops australiensis* Thomas (Branchiopoda: Triopsidae) (Henrikson *et al.* 1998). One interesting observation is the use of insects to collect food; for example, Aboriginal people at Macdonald Downs made flour from the grass seeds that ants had collected and arranged around the opening of their nests (Cleland 1936).

In Australia, the use of edible insects by traditional Aboriginal owners has dramatically declined since European settlement. This is partly due to the displacement of some traditional owners from their lands, loss of traditional knowledge and languages and adoption of European diets (often to the detriment of the health of the Aboriginal people).

There has been limited renewed interest in the insect foods of Australian Aboriginal people. This has been driven by three main factors: (i) a desire by some of the Aboriginal elders to revive traditions that can be passed on to younger generations; (ii) an interest in the Aboriginal food experience (known as "bushtucker") that has been stimulated primarily by tourism; and (iii) attempts to get traditional Aboriginal foods into gourmet restaurants (Yen 2009a).

The harvesting of edible insects in Australia, especially associated with ecotourism, has the potential to result in their overharvesting. This, along with other environmental factors (such as land use changes, habitat destruction, inappropriate use of agricultural chemicals and climate change) may become a conservation issue for some of these edible insect species (Yen 2009a). The future of human entomophagy in Australia involves understanding how Aboriginal people used insects as food and developing sustainable harvesting protocols to fulfill indigenous requirements, bushtucker ecotourism and gourmet restaurant markets.

Attempts at commercialization of edible invertebrates in Australia have primarily been aimed at the restaurant trade or as bait for recreational fishing (Yen 2009a). It is unlikely that insects will become a mainstream dietary item in Australia, but there is potential to use them as a nutritional food supplement. More importantly, they could be incorporated into the food production chain of food animals such as poultry and pigs, and in aquaculture.

Traditional societies

Food security

Insect diversity may be the key to food security in traditional societies. It is likely that in some traditional societies, humans do not use all of the potentially edible insects. There are numerous lists of edible species in different societies, but information still needs to be gathered and confirmed if this valuable resource is to be used effectively.

It is essential that the names of edible species are confirmed scientifically for accurate exchange of information. Lists need to be regularly upgraded. Some older lists need to be reassessed because either: (i) those groups of people no longer use those insects; or (ii) there have been recent dietary changes; for example, in the Kaleum district of Sekong Province in Laos, the Katu considered belastomatid water bugs inedible, but have started to eat them in response to a decrease in other sources of protein (Krahn 2003).

There are still considerable knowledge gaps for known edible insects. While there may be a lot of information available for a few edible species, details are lacking for most species, including preparation methods and recipes. It is important to record and maintain traditional knowledge about edible insects while respecting traditional ways of life; for example, gender is often important in food harvesting, and in northeastern Thailand, women are the main collectors of insect food (Somnasang *et al.* 1998). The nutritional value of different edible species needs to be assessed (Ademolu *et al.* 2004; Fagbuaro *et al.* 2006). Research should also be undertaken on the value and the sustainability of products with a long traditional use history. For example, *Cordyceps*, a caterpillar whose body is taken over by a fungus (Clavicipitaceae), has a long history of human use in China and India (Holliday & Cleaver 2008). It is an important part of the Tibetan rural economy (Winkler 2008), but management plans are required for its sustainability because of the decline from overcollecting and other environmental factors such as grazing and firewood harvesting (Sharma 2004; Devkota 2006).

The consumption of plant pests is sometimes advocated to reduce damage and to reduce pesticide usage. Many plant pests have high nutritional value; for example, *Cirina forda* Westwood (Lepidoptera: Saturniidae) is added to vegetable soups in Nigeria, where the larvae provide high levels of protein, minerals and polyunsaturated fatty acids to people whose diets are deficient in animal protein (Akinnawo & Ketiku 2000). An important question is whether collecting plant pests is an effective means of pest control. In the case of the variegated grasshopper *Zonocerus variegates* (Linné) (Orthoptera: Pyrgomorphidae) in the Cameroon, traditional hand collecting for human consumption does not have the same impact in reducing numbers as the late season rains (Kekeunou *et al.* 2006).

Supply can be unpredictable because of factors beyond the control of people at the local level. These include rainfall and extreme climatic conditions such as droughts and floods. The uncertainty of supply can be exacerbated by human factors: overexploitation of edible insects, bad land management practices (overgrazing, overharvesting of trees), conflict with other animals, conflict in land use and the availability of other food sources.

Traditional owners have, in most cases, developed harvesting protocols and habitat management practices that ensure sustainability. These include the timing of fire, if appropriate, in habitat management (DeFoliart 1997). Problems can arise when there are market demands that encourage non-specialist harvesters to collect, such as the case of mopane worms *Gonimbrasia belina* Westwood (Lepidoptera: Saturniidae) in Zimbabwe (Maviya & Gumbo 2005).

With changes in land tenure, such as the establishment of nature conservation reserves to protect remnant habitats and wildlife, conflict can arise from preventing the harvesting of food by traditional owners (DeFoliart 1997), or competition can develop between protected wildlife and local villagers such as the conflicting uses of woodlands by elephants and humans for food and other products (Hrabar *et al.* 2009). There can be direct competition between humans and wildlife for edible insects, such as aardwolves and humans competing for alates of the termites *Hodotermes mossambicus* (Hagen) and *Macrotermes falciger* (Gerstacker) (Isoptera) during the rainy season (Kruuk & Sands 2008). One termite mound can result in 50 kg of termites and they can be preserved for up to one year by salting and sun-drying (Gardiner & Gardiner 2003).

While promoting the use of insects as food in traditional societies, it is important that only local species be used and if people decide to bring in species from elsewhere, that any potential adverse effects be determined beforehand. For example, the giant African snail *Achatina fulica* Férussac (Gastropoda: Achatinidae) is an edible species that can become a pest itself if taken out of its natural range (Mead 1961).

Traditional societies can achieve better food security through: (i) more knowledge about the range of edible insects that they could use; (ii) sustainable harvesting protocols; (iii) environmental management protocols; (iv) development of limited controlled production if appropriate; and (v) sustainable closed food production systems, if possible. However, it is important that edible insects are considered as part of the wider food spectrum of plants and other animals.

The risk of variability in insect numbers could be reduced by the development and adoption of closed production systems at the local level. These are either: (i) field manipulations of wild populations for sustainable harvesting; and/or (ii) small captive breeding programs such as those developed for snail farming in Africa (FAO 1986a,b). If possible, the development of controlled production systems that are more energy efficient (e.g. recycling organic waste) to produce edible insects for both livestock and human consumption would be ideal. These systems would not alleviate the problems caused by large livestock animals, but could be integrated with small aquaculture or with poultry production. Fishmeal is often used as a food item in aquaculture, and there are studies that indicate termites, and garden snail and other insect meals are effective food sources in aquaculture (Ogunleye & Omotoso 2005; Sogbesan & Ugwumba 2008).

Appropriate systems would need to be developed for different environments. In Laos, edible insects can be integrated into the FAO model for home gardens. The model's aim is to increase food production, diversify food production, increase food supply and availability and meet nutritional needs of households (Dyg & Phithayaphone 2004). This system could be linked to aquatic resources (including aquaculture) (Friend *et al.* 2004), management of adjacent ecotones for sustainable production (Nonaka 2008) and the use of forests for non-wood forest products (Foppes & Ketphanh 2004).

Food safety

Not all insects are edible. Some contain toxins, either produced by the insect themselves or plants (DeFoliart 1992), and some people have allergies to insects (Auerswald & Lopata 2005). Some societies have managed to determine how to make apparently inedible species edible. In Africa, the edible stink bug *Encosternum delegorguei* Spinola (Hemiptera: Tessaratomidae) is available as adults in winter when the mopane worm is in the underground pupal stage. Stink bugs are made palatable by washing with warm water to make them release their pheromones (repeated three times), then boiled in water, killed and sun-dried. The armored ground cricket *Acanthoplus spiseri* Brancsik (Orthoptera: Tettigoniidae) is made edible by removing its gut after carefully pulling off its head, boiling for a minimum of 5 hours, frying in oil and serving with a relish of tomato and onion. Boiling is important as it removes the toxic substances that can cause severe bladder irritation. (Gardiner & Gardiner 2003; Toms & Thagwana 2003; Teffo *et al.* 2007). The methods developed to make inedible species edible are an important intellectual property of the traditional societies that discovered them.

The African silkworm *Anaphe venta* Butler (Lepidoptera: Notodontidae) is eaten in southwestern Nigeria. During the rainy season, many less-wealthy people have a high carbohydrate and low protein diet of cassava (which contains cyanogenic glycosides), and those who consume the silkworm larvae exhibit an acute ataxic syndrome. While these larvae provide high levels of protein, they lack the sulfur-containing amino acids (cysteine, methionine) required to detoxify the cyanogenic glycosides consumed in cassava. The seasonal ataxic syndrome is an acute thiamine deficiency due to the monotonous diet of carbohydrate meals containing cyanogenic glycosides. Their thiamine deficiency is exacerbated by consumption of anti-thiamine factors in *Anaphe venata* (Adamolekun 1993; Adamolekun *et al.* 1997).

Any living organism can be infected by microorganisms or parasites (Hardouin 1995). For example, the larvae of *Bunaea alcinoe* Stoll (Lepidoptera: Saturniidae) in the Niger Delta has high levels of enterotoxin-producing bacteria on the exterior surface of the body. The cooking process eliminates these bacteria (Amadi *et al.* 2005). The quality of stored mopane worms also deteriorates due to bacteria, fungi and insects (Mpuchane *et al.* 2000). These issues can be simply overcome through the development of protocols for production, preparation, storage and transport, and appropriate education (Ghazoul 2006; Ohiokpehai 2006). This is important as increased urbanization has seen an increase in the purchase of food as street food (Ohiokpehai 2003).

A danger of eating harvested insects is pesticide residues. While health risks should be the main issue, often it is economic issues that decide whether insecticides are applied. In some cases, farmers may be reluctant to use insecticides because they affect edible insects and the value of edible insects may be greater than income from grain (Abate *et al.* 2000). Another example is rice-field grasshoppers in Korea; numbers declined with insecticide use, but a decline in pesticide use and a desire for pesticide-free rice resulted in a resurgence in sales of these insects, with financial benefit to farmers (Pemberton 1994). Other examples of reduced pesticide use to increase edible insects are found in the Philippines and Thailand (DeFoliart 1997).

Other benefits

While use of individual insect species as food is important, the development of multiple-product food–insect systems can be of greater benefit (DeFoliart 1997). Mopane worms can be used as either human or livestock food; they need to be gutted for human consumption but not if fed to livestock because the livestock benefit from fiber in the guts (Madibela *et al.* 2007). Another approach is to consider a particular plant as a source of multiple food products: the mopane tree *Colophospermum mopane* is host to mopane worms, the sweet wax–producing psyllid *Arytaina mopane* Pettey (Hemiptera: Psylloidea) and edible honey (Mojeremane & Lumbile 2005). Edible insects can provide an additional source of income for local communities; in Venezuela, the palm worm *Rhynchophora palmarum* (L) (Coleoptera: Curculionidae) is collected by Indian people as food but there is potential for them to develop small-scale production systems to sell the worm to tourists (Cerda *et al.* 2000).

There may be non-food values of insects, such as the use of insects for medicines or as cultural icons (Pemberton 1999). Examples include the edible Chinese black ant *Polyrachis vicina* (Shen *et al.* 2006) and hornets in Yunnan sold as medicine (soaked in spirits) or as luxury food (Matsuura *et al.* 1999). The caterpillar fungus *Cordyceps sinensis* is important for Tibet's rural economy because it is the single most important source of cash for rural households (40% of rural cash income). In 2004, 50 000 kg of this fungus was harvested and it was worth US$225 million to the Tibetan GDP. However, increased harvest pressures may not be sustainable (Winkler 2008).

Insects such as silkworms, bees and ants can be considered as multiple-product food–insect systems, meaning there are multiple uses for the species.

1. Silkworms have been cultivated for several thousand years to obtain silk fibers. However, the pupae are a high-quality source of protein and are comparable to the dietary profile recommended by FAO/WHO (DeFoliart 1995; Mishra *et al.* 2003; Zhou & Han 2006). Silk production is widespread in Asia and Brazil (Speight 2001), so there is potential to encourage the use of silkworms for both a valued product (silk) and a food source. Research is also underway on the use of the silkworm *Bombyx mori* Linnaeus (Lepidoptera: Bombycidae) as part of bioregenerative life support system for space travel (Yu *et al.* 2008).
2. Honey is a desired food item in many different societies (DeFoliart 1995). Honey and edible insects are highly sought by the Mbuti of Eastern Zaire. The seasonality of these foods limits their importance to a few months each year. Honey production is also dependent upon mass flowering of nectar-providing bee-pollinated trees (Hart & Hart 1986). The Hazda foragers of Tanzania collected honey, which has low crude protein levels, but has higher protein levels than American honeys because the Hazda do not remove the bee larvae from the combs as they are eaten (Murray *et al.* 2001). Bees may be threatened by environmental changes and inappropriate management (overhar-

vesting) by Mayans of the Yucatán peninsula (Villanueva *et al.* 2005), highlighting the need to reinforce traditional methods of honey production by using native bees as a flagship for bee and forest conservation.

3. The Asian weaver ant *Oecophylla smaragdina* Fabricius (Hymenoptera: Formicidae) is used in various ways globally, from human food to bird food and medical uses. They are very important as a food source and for additional income to the local community in Northeast Thailand (Sribandit *et al.* 2008). Increasing numbers of ant collectors travel long distances to ants and increased harvesting pressure may threaten natural ant populations. Ant farming is suggested as a potential solution but it needs to be assessed in terms of viability, practicality and biological impacts on other insects (Sribandit *et al.* 2008). Weaver ant husbandry is practiced in the Mekong Delta of Vietnam as a natural biological control of insect pests (Barzman *et al.* 1996; Lim *et al.* 2008) and there has been research on the use of weaver ant colonies for biocontrol of crop pests in Australia (Peng *et al.* 1999).

Westernized societies

There is a major attitudinal barrier to the use of insects as human food in western societies (DeFoliart 1999). The limited interest is mainly from a novelty approach (Gordon 1998; Menzel & D'Aluisio 1998), although hygiene issues are high in people's minds (Zaragozano 2007). Interestingly, most people in western societies inadvertently consume insects because of the levels permitted in food products. For example, in the USA, the allowable amounts of insects per 100 g of processed food products are 80 insect fragments (chocolate), 60 aphids, thrips or mites (frozen broccoli), 100 insect fragments (macaroni and other noodle products), 60 insect fragments (peanut butter) and 150 insect fragments (wheat flour) (Gorham 1979).

Education on cultural, nutritional and ecological issues associated with entomophagy can partly overcome the aversion towards insects (Mignon 2002). Looy and Wood (2006) surveyed the effect of "bug banquets" on attitudes towards invertebrates. Results were found to be related to age, and responses to eating insects were polarized: people found it either disgusting or interesting. However, many were open to the idea if it was necessary for survival, or in the context of it being a normal part of the diet.

As acceptance of insects or insect-based protein in western diets is a major barrier, there can be questions about the value of the novel food approach. Instead, a more appropriate approach would be promoting insects as a source of protein in human food supplements or as food for livestock for human consumption. The main message would be the environmental benefits derived from food production that requires less energy and less land.

Food security

Westernized nations have the technological capabilities to ensure greater food security. It is more likely that they will have controlled production systems that will ensure a more reliable supply. The controlled production systems may vary from small concerns to large factories. Examples of small production systems include snail farms for gourmet restaurants (Yen 2009a), earthworms for chicken or pig food (Hardouin 1995), or mosquito larvae for fish culture (Shaw & Mark 1980). Kok (1983) advocated the development of "insect farms" to mass produce insects for human food. In the case of larger production units, there are already controlled production systems used to produce insects for biological control; it would not be too difficult to set up systems to produce food insects in bulk.

The main issues to be addressed are: (i) which species to produce based on ease of production and on nutritive value; and (ii) the number of species to be produced. There are advantages and disadvantages to mass producing a small number of species; the advantages include economic efficiencies, the main disadvantage is the potential loss of diversity through the globalization of edible insects and the production of only a few common species.

There has been considerable research on the nutritive value of insects as livestock food. For example, Hernández-Martínez *et al.* (2008) found that flour made from the cockroach *Periplaneta americana* Linnaeus (Blattodea: Blattidae) was a suitable alternative food for rearing Japanese carp compared to fishmeal. In China, insects (housefly larvae and pupae, silkworm pupae, mealworm larvae) are used to feed fish, poultry and pigs, and are cost-effective alternatives to conventional fishmeal diets. In some cases, the insect food may need supplementation to be a suitable alternative to more ecologically expensive sources (Irwin & Kampmeier 2003).

Food safety

One major advantage that wealthier western societies would have is the ability to better regulate controlled rearing facilities for better food safety. This includes control of insect-rearing facilities, insect preparation procedures (for human consumption or for livestock food), control of storage methods and more efficient distribution systems.

Other benefits

Potential side benefits from research on the nutritive value and other uses of edible insects could include bioprospecting for new compounds (e.g. antibacterial compounds); biotechnology (such as culturing insect cells as a source of protein) (Verkerk *et al.* 2007); nutritional, pharmaceutical, industrial and cosmetic potential of oils from edible insects (Dué *et al.* 2009; Lawal & Banjo 2007; Ekpo *et al.* 2009); and the use of edible insect extracts for human health such as reducing cholesterol levels (Koide 1998; Hwang *et al.* 2004; Ogunleye 2006).

The major potential benefit for using insects as a source of protein in westernized societies is environmental. Livestock production for human consumption could be undertaken using less land, less energy, and using a cheaper protein source as livestock food (insects instead of marine resources). There are opportunities to produce insects locally (on-farm) to feed livestock; poultry and aquaculture are two areas that could be involved immediately. It may be possible to develop energy-saving food production systems that involve recycling of organic wastes by insects and using these insects as livestock food.

There are also a number of economic benefits of a large insect industry. For example, there has been a large increase in market size in Korea due to an anticipated increase in the use of insects as food, dietary supplements and medicines, and in disposal of food and animal wastes (Kim *et al.* 2008).

Conclusions

This paper has outlined two different attitudes and uses of edible insects: their use in traditional societies across several continents, and the reluctance to use them in westernized societies. If we wish to reduce the gap between the quality of life (in terms of food availability and quality and environmental quality) between wealthy and less-wealthy nations, another source of protein is required to sustain current and future demands.

Traditional societies are likely to maintain the direct use of insects as food. Food security can be enhanced by the development and implementation of environmental management protocols for sustainable production, and small scale controlled insect production systems for human or livestock food should be encouraged. Research, in collaboration with the traditional owners, is still required to identify edible species, document their biology and ecology, and determine their potential uses. The intellectual property rights of traditional owners need to be recognized. The world is not uniform; it is important to value and use local diversity. Our knowledge on edible insects is based on a relatively small number of species, and if we want to document edible insects, the best place to start is with the traditional societies that actively use them.

Encouraging the direct use of insects as food in westernized societies should not be the major objective at this stage. Changing attitudes to eating insects is paramount to success; the main challenge is to change western attitudes to eating insects. Rather than encouraging western societies to eat insects directly, the strategy should be promoting: (i) insects as food supplements; and (ii) insects as part of livestock production systems to reduce adverse environmental effects of animal protein production. Westernized societies have the resources to develop small (on-farm) to large (factory) controlled insect production systems for human use (food supplements) or livestock food.

DeFoliart (1989, 1997) covered some of the issues discussed in this paper on the value of using insects as food. These include assisting forest conservation and management, reducing poaching in reserves by allowing sustainable use, reducing pesticides by more efficient means of harvesting pests, increasing environmental and economic efficiency by developing dual product systems and reducing waste by recycling. Yet these ideas seem to have only advanced in a very small way in western societies, and it is there where adoption of human entomophagy is essential for environmental reasons. DeFoliart (1975) suggested that the repugnance of insects as food in industrialized countries meant that promoting them as livestock food by using them to recycle wastes into protein-rich foods was the way to go. It is important to consider edible insects in the wider context of global food security and safety. Traditional societies have a lot of knowledge about edible insects; westernized societies have financial and technological resources to produce large amounts of insect protein. Both need to be used to provide food and to assist conservation. The exploitation of a resource may at times seem contradictory if we wish to conserve it; however, Yen (2009b) outlines the potential of promoting edible insects as a flagship for both insect and habitat conservation.

Most people in western societies see eating insects as a risk: a health risk and a risk to their apparent sense of social and economic wellbeing. But contrast this with the risk we currently take: the inability to provide a required level of animal protein to the world and major environmental degradation associated with livestock production. The risks of entomophagy, in terms of food security and food safety, are small compared to overexploitation of the earth's resources and the inability to feed an increasing human population. There is already a wealth of traditional knowledge that can and should be used.

Acknowledgements

The author thanks the Entomological Society of Korea for sponsoring him to attend their international symposium on edible insects in Hampyeong in 2009. Thanks to Professor Y. S. Han (Chongnam National University) and especially to Professor O. Kwon (Kyungpook National University) for his assistance and friendship. The author acknowledges J. Yen for his helpful comments on the manuscript.

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