Edible insects and other invertebrates in Australia: future prospects

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At the time of European settlement, the relative importance of insects in the diets of Australian Aborigines varied across the continent, reflecting both the availability of edible insects and of other plants and animals as food. The hunter-gatherer lifestyle adopted by the Australian Aborigines, as well as their understanding of the dangers of overexploitation, meant that entomophagy was a sustainable source of food. Over the last 200 years, entomophagy among Australian Aborigines has decreased because of the increasing adoption of European diets, changed social structures and changes in demography.

Entomophagy has not been readily adopted by non-indigenous Australians, although there is an increased interest because of tourism and the development of a boutique cuisine based on indigenous foods (bush tucker). Tourism has adopted the hunter-gatherer model of exploitation in a manner that is probably unsustainable and may result in long-term environmental damage. The need for large numbers of edible insects (not only for the restaurant trade but also as fish bait) has prompted feasibility studies on the commercialization of edible Australian insects. Emphasis has been on the four major groups of edible insects: witjuti *grubs (larvae of the moth family Cossidae),* bardi *grubs (beetle larvae), Bogong moths and honey ants. Many of the edible moth and beetle larvae grow slowly and their larval stages last for two or more years. Attempts at commercialization have been hampered by taxonomic uncertainty of some of the species and the lack of information on their biologies. This has made it difficult to establish rearing facilities that can raise large numbers of edible insects in a short time. Even if effective mass rearing techniques for edible insects can be developed, the next hurdle is overcoming the cultural barriers against consuming insects in Australia. Notwithstanding these problems, there is considerable potential for greater use of insects as human food (either as insects* per se *or as food supplements) or as stock food (especially for poultry and fish). This will result in more energy-efficient food production and facilitate environmental conservation.*

Keywords: Aborigines, animal food, conservation, entomophagy, indigenous food, protein

Entomophagy

At a time when scientists acknowledge the importance and need for ecosystem services provided by insects, western society does not seriously consider them for human consumption. Their small body sizes, difficulty in collection and processing and unpredictability in obtaining large numbers in the wild are major practical impediments. There

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are two main barriers to the acceptance of eating insects: (1) the bad reputation they have as unhygienic and disease-spreading species; and (2) their association with the concept that they are only eaten in times of starvation or as a food source of primitive hunter-gatherer societies (MacEvilly 2000; DeFoliart 1999). There is legislation in some countries regarding insects in food products, ranging from zero tolerance in the United Kingdom to allowing maximum permissible levels in the United States (MacEvilly 2000; Gorham 1979); the basis of this legislation is food contamination and perceived health issues associated with insects (Gorham 1979).

Over 1 500 species of insects are known to be consumed by humans from over 300 ethnic groups in 113 countries (MacEvilly 2000). Most of this entomophagy occurs in central and southern Africa, Asia, Australia and Latin America, and can provide 5 to 10 percent of the annual animal protein consumed by various indigenous groups as well as fat and calories, and various vitamins (A, B_1, B_2 and D) and minerals (iron, calcium) (Gullan and Cranston 2005; MacEvilly 2000).

Entomophagy and the Australian Aborigines

Until European settlement, Aborigines lived as nomadic hunter-gatherers. Survival required a comprehensive knowledge of the flora and fauna and their responses to varying geographic and climatic conditions (O'Dea 1991). They consumed a varied diet in which plants provided fibre but animal foods predominated. This diet was not high in fat as the meat was lean most of the year. Most food was either eaten raw, roasted on ashes, or baked whole in an earth oven. Most Aborigines lived in bands based on extended family groups (20 to 30 individuals) and there were larger gatherings for traditional ceremonies when there was sufficient food available to support larger numbers. Examples included men gathering in the Alps of southeastern Australia during summer to feast on Bogong moths (Flood 1980) and groups meeting at Waikerie on the River Murray in South Australia to collect adult giant swift moths (*Tricenta argentata*) that emerge in autumn after rain (South Australian Museum, n.d.). Men and women contributed differently; women provided subsistence diet (plants, honey, eggs, small vertebrates, invertebrates) and men were primarily hunters of larger vertebrates. Hunting and gathering was time-consuming, and there was generally only one main meal late in the afternoon after a day of hunting or gathering (O'Dea 1991).

Traditionally, Aborigines in Central Australia of different language groups considered the honey ant an important object of ritual and ceremony, and they were linked by the song cycles and ceremonies associated with it (Devitt 1986). The search and excavation for honey ants involve much time for relatively little return (Devitt 1986), and it was an important group activity for women and children who learned about and *looked after their country*.

Information on entomophagy among the various groups of Australian Aborigines has been summarized by Yen (2005), Meyer-Rochow (2005, 1975), Defoliart (2002), Tindale (1966), Reim (1962), Bodenheimer (1951), McKeown (1936) and Campbell (1926). The information is very patchy and has been confused by linguistic issues, incorrect recording of information, traditional beliefs of the Aborigines, incorrect use of common and scientific names of insects and lack of information on the biology and distribution of most species (Yen 2005). This has resulted in more detailed information about entomophagy among Australian Aborigines involving a small number of charismatic species (or species groups): *witjuti* grubs, *bardi* grubs, honey ants, *Bogong* moths and sugar bags (native bees).

The common names of some of these insects are based on Aboriginal names. As there are 270 different Aboriginal languages with 600 to 700 dialects in Australia (Australian Info International 1989), this has led to much confusion and different spellings. For example, the name *witjuti* grubs (also spelled *witchetty* or *witchety*) is derived from the Pitjantjatjara name for *Acacia kempeana*, but it has now been loosely applied to many edible grubs across Australia. Among the Arerrnte, the same species is known as *tyape atnyematye*, with *tyape* indicating edible grub, *atneyeme* is the *witchetty* bush and *atnyematye* is the grub from the root of the *witchetty* bush (Central Land Council 2007b). The name *bardi* grubs is based on a buprestid beetle from *Xanthorrhoea* in southwestern Western Australia, but has also been loosely applied to edible grubs across Australia. Some Aboriginal groups had a better naming system for edible grubs: they used a term for *edible grub*, such as *maku* in Pitjantjatjara, followed by the name of the plant (Yen *et al.* 1997). Hence the edible grub from *Acacia kempeana* is known as *maku witjuti* among Pitjantjatjara speakers or *tyape atnyematye* by the Arrernte (Plate 1).

Plate 1. Witjuti grub from Central Australia *(Courtesy A.L. Yen)*

An important question is whether the information we have available today is an accurate reflection of the full range of insects (and other invertebrates) eaten by Australian Aborigines. Other edible insects may not have been recorded in the literature. In addition, there is the question of why groups of insects eaten by other indigenous groups outside of Australia were apparently not favoured in Australia. For example, termites (Isoptera), leaf-feeding caterpillars (Lepidoptera) and grasshoppers (Orthoptera) are major components of insect diets in most other continents (Banjo *et al.* 2006b; DeFoliart 2005; Malaisse 2005; FAO Départment des Forêts 2004; Paoletti *et al.* 2003; Bodenheimer 1951), but only figure as minor items in a few Australian records (Meyer-Rochow and Changkija 1997; Meyer-Rochow 1975; Reim 1962).

To better understand entomophagy in Australia, it is important to consider the Australian environment and how it was exploited by the Aborigines before European settlement. Australia is an arid continent with soils poor in nutrients, unpredictable availability of water (droughts and floods) and wildfire hazards. The unpredictable climatic patterns result in a huge variation in plant species composition and reproduction, and population fluctuations of animals, leading to opportunistic and flexible activities that resulted in the seasonal movements of Aborigines (Allen 1974). There was no cultivation of grain and little agriculture as we know it (O'Dea 1991). The main habitat manipulation to increase plant production was controlled mosaic burning or *fire-stick farming* (Jones 1980).

The Australian environment is dominated by two plant genera, *Eucalyptus* and *Acacia*. This has resulted in enormous diversification of several families of insects (Yen 2002), and may be one reason for the absence of leaf-feeding caterpillars in the diet of Australian Aborigines. Many of the larger species feed on eucalypts and the oils and other chemicals in the eucalypt leaves make the caterpillars unpalatable. The major factor is climate unpredictability resulting in enormous variation in occurrence and abundance of insects. Many insects have long periods of relative inactivity or have well-protected immature life history stages; some have long life cycles, followed by mass emergence at times of adequate resources.

The nutritional value of insects to the pre-European settlement Aboriginal diet has received relatively little attention compared to the contribution of larger vertebrates. For many years, even the value of plants in the diet has been underestimated and only in recent years has this matter been addressed. With insects, more information is required about the role of entomophagy in traditional diets. It is difficult to generalize about the diet of Aborigines because it would have varied considerably across the continent, which is generally semi-arid or arid but with subtropical environments in the north and temperate conditions in the east, southeast and southwest. The insect diets would have reflected availability and need. Did entomophagy represent a need for proteins, fats and other substances of animal origin? How much of entomophagy is due to food deficiency (protein) or to tradition? It has to be remembered that Australian Aborigines ate their food raw, roasted on ashes, or baked in ashes. They did not use cooking utensils (except wrapping food in leaves or bark in northern Australia), and there was a lack of herbs and spices. The current indication is that insects provided sugar (honey ants, sugar bags, lerps) and fat (grubs, *Bogong* moths), although *witjuti* grubs have 38 percent protein and nearly 40 percent fat (a composition similar to olive oil [Naughton *et al.* 1986 in O'Dea 1991]). Native bees and honey ants were important seasonal sources of carbohydrates (Plate 2). Interestingly, Orthoptera are rich in proteins but were not eaten widely in Australia. Bukkens (2005) summarized nutrient aspects of insects for human diet around the world, but detailed information from Australia is lacking. Rich (2006 citing Miller *et al.* 1993) provided information on the nutritional value of raw and cooked *witjuti* grubs (species not cited) and the abdomen of *Bogong* moths.

The importance of insects in the diets of Australian Aborigines varied across the continent before European settlement, reflecting both the availability of edible insects and of other plants and animals as food. The hunter-gatherer life style adopted by the Australian

Aborigines involved patterns of movement determined by resource availability, and this, combined with low population numbers, reduced the danger of overexploitation of food resources.

Plate 2. Honey ants *(Courtesy R. Start)*

Current status of entomophagy in Australia

Over the last 200 years, entomophagy among Australian Aborigines has decreased because of the increasing adoption of European diets, changed social structures and changes in demography.

Entomophagy has not been readily adopted by non-indigenous Australians, although there is an increased interest because of tourism and the development of a boutique cuisine based on indigenous foods (bush tucker). Tourism has generally adopted the hunter-gatherer model of exploitation in a manner that is probably unsustainable and may result in long-term environmental damage. The exceptions are (1) promotion of iconic Aboriginal insect foods (*witjuti* and *bardi* grubs, honey ants) either as a boutique cuisine or part of a bush tucker tourism experience; (2) use of freshwater and burrowing crayfish as food items in their own right; (3) farming of exotic garden snails (*Helix aspera*) for restaurants; (4) insects, crayfish and earthworms (both native and introduced species) as recreational fish bait; and (5) insects bred as pet food (primarily for reptiles). Except for the first category, indigenous Australians are rarely associated with these activities.

There is a small industry in Australia that breeds the exotic snail *Helix aspera* for the restaurant trade and for personal consumption. There have been government-funded feasibility studies on this snail (Murphy 2001; Begg 2006, 2003). Snails are reared and purged on a high fibre diet before processing. They are sometimes cooked, de-shelled and sold bottled. Regulatory authorities in Australia face a dilemma in that on the one hand, they want to encourage the development of alternative farm products such as snails, yet on the other hand, they need to protect existing industries (such as crops) from pest snails. Teo (2004) gives an example of the adverse environmental effects of a snail introduced to provide protein but escaping and becoming a crop pest. The same issue applies to the breeding of exotic earthworm species that are sold to gardeners and farmers.

Recreational fishing is a major industry in Australia, and there is a wealth of information on the use of live insects and other invertebrates (freshwater crayfish and earthworms) as bait, in fishing magazines and on fishing organization Web pages. While the information is interesting, some of it is full of errors and biases. Recreational anglers generally use fresh insect bait, and there is a preference in temperate Australia for what are incorrectly call *bardi* grubs found in the ground under River Red Gums. These are in fact hepialid moth larvae, more akin to *witjuti* grubs. They are dug up, stored separately (or else they can damage each other) either in the refrigerator or they are blanched in milk and frozen. They are sold for A$1.50-2.50 each.

These activities have environmental and social consequences. The wild harvests of *witjuti* and *bardi* grubs and honey ants were sustainable activities when small numbers of traditional owners traveled by foot and collected them at appropriate times of the year. Today, tourism companies take bus loads of visitors to dig up edible insects. Some of these tourism ventures are led by traditional owners. However, the sustainability of a tourism-driven market using motor vehicles to access food has to be determined. Large numbers of recreational anglers digging up *bardi* grubs, in conjunction with other threats to forests (inappropriate forestry, fuelwood collection, eucalypt dieback due to changed hydrological regimes, cattle grazing, to name a few) could threaten the long-term viability of these grubs. There are now artificial grubs available, including a mould to make a *bardi* grub out of soft cheese!

Commercialization issues

The need for large numbers of edible insects (not only for the restaurant trade but also as fish bait) has prompted feasibility studies on the commercialization of edible Australian insects. Emphasis has been on the four major groups of native edible insects: *witjuti* grubs (larvae of the moth family Cossidae), *bardi* grubs (beetle larvae), *Bogong* moths and honey ants (Rich 2006), and the exotic snail *Helix aspera* (Berg 2006, 2003). Many of the edible moth and beetle larvae grow slowly and their larval stages last for two or more years. Attempts at commercialization, either by wild harvest or by mass rearing, have been hampered by taxonomic uncertainty of some of the species and the lack of information on their biologies. The small sizes of insects make collection or rearing and processing difficult; in the wild their locations and population numbers are unpredictable. This has made it difficult to establish rearing facilities that can raise large numbers in a short time.

Large-scale harvest or production of insects for human consumption has several issues that have to be considered, including the practicality of collecting from the wild and the possibility of overharvesting, economic mass rearing techniques, preservation and storage of the products and marketing.

Despite these issues, it has to be remembered that many invertebrates are unsafe to eat; some are inedible while others may initiate allergic reactions among humans (Gullan and Cranston 2005; MacEvilly 2000; Phillips and Burkholder 1995; Blum 1994; Berenbaum 1993), although this equally applies to all other plant and animal foods. Although many insects contain toxic chemicals, there are few records of harm to humans (Gorham 1979). Insects may also contain pathogenic microbes as a result of improper processing or handling, just like all food products, and preventive measures need to be in place (Banjo *et al.* 2006a).

Collecting (harvesting)

Most edible insects are harvested from the wild (DeFoliart 1995). The availability of edible insects in Australia is unpredictable, both in time and location. There are suggestions that wild harvesting of crop pests is a possibility (Banjo *et al.* 2006) and that this can also reduce pesticide use (DeFoliart 2005; Gullan and Cranston 2005). There is another aspect, as some insects may contain higher than acceptable levels of chemicals (as will be discussed with *Bogong* moths later). In Australia, the major mobile plant pest is the Australian plague locust, *Chortoicetes terminifera* (Hunter 2004), although Schulz (1891) reported that the Aborigines around the Finke River region would not eat them.

Better management of sustainable harvesting of wild populations and more dependable supplies based on economically feasible mass rearing will only be possible in Australia with more information about the biology of edible species. This will require involving indigenous groups to participate and benefit from the exercise.

Mass rearing

Rich (2006) examined the feasibility of establishing a closed production system facility to rear *witjuti* grubs commercially under controlled conditions. The proposed method involved: (1) sourcing a generic pool from the wild; (2) rearing larvae through to adults; (3) getting adults to mate; (4) female oviposition and eggs transferred to bark crevices in containers (each female may carry up to 20 000 eggs); (5) egg hatching; (6) caterpillars maintained and farmed when they have grown to up to 15 centimetres in length. Rich (2006) defined *witjuti* grubs as moths in the Cossidae family (wood moths with stem-boring or root-feeding larvae) of which there are over 100 species in Australia (Common 1990), hepialid moth larvae and some beetle larvae.

The life cycle of wood moths takes over two years (Monteith 2006). The question has been raised as to whether the life cycle can be hastened by diet using synthetic diets or semi-synthetic diets such as those used for the hepialid *Wiseana copularis* in New Zealand (Allan *et al*. 2002). Even the life history of well-known species such as the giant wood moth (*Endoxyla cinerea*) is not completely understood; although later stage caterpillars live in trunks, the biology of younger stages is not known and they may be root feeders (Monteith 2006). Dann (2003) inadvertently reared two *bardi* grubs through to pupation by keeping them in sawdust, indicating that a fully functional trunk may not be required for their survival.

To fully utilize mass insect rearing facilities, Rich (2006) suggested supplementary production activity of other insects such as *Bardistus cibarius* (*bardi* grub), honey ants, and the *Bogong* moth (*Agrotis infusa*). *Bardi* grub rearing would be suitable for the protocol outlined by Rich (2006); however, the other two species have their own unique biological characteristics that could make mass rearing a challenge.

The honey ant (*Melophorus bagoti*) is a social species that relies on two other biological components for successful production of honey by the repletes: its host *mulga* trees (*Acacia aneura*) and the scale insect *Austrotachardia acaciae* (Latz 1995). The honey ant workers collect honeydew from the scale insect to feed the repletes. Keeping social species like ants in captivity for food production can be difficult and the output is low compared to the commercial honey bee (*Apis mellifera*); individual honey ant nests rarely supply more than 100 grams of honey, comparable to commercial honey (Gullan and Cranston 2005). In Australia, other ant species have been maintained in culture for either venom research or as a source of chemicals such as antibiotics (Beattie 1994); these efforts may provide useful information on mass rearing for edible ants.

The *Bogong* moth is characterized by adult flight involving distances of more than 1 000 kilometres that may be necessary for breeding. Their life cycle is about six to seven months (eggs to adult). The main breeding grounds are pastures west of the Dividing Range and adults fly to the Southern Alps for the summer (Common 1954). The Aborigines (generally men) collected adults in the Alps, cooked and ate the bodies (over 60 percent of which is fat) or ground them into cakes for storage (Flood 1980). The *Bogong* moth can be an agricultural pest, but it faces several threats itself: loss of summer alpine habitat (cattle-grazing, wildfire, climate change) and accumulation of arsenic from agricultural sprays such as the herbicide monosodium methylarsenate. While individual moths have low arsenic content, accumulation from large numbers of moths has resulted in high arsenic levels in alpine soils at summer sites. Furthermore, the *Bogong* moths are a main food item of the endangered mountain pygmy possum (*Burramys parvus*) (Green *et al.* 2001).

There are over 100 species of freshwater crayfish in Australia, including the world's largest species, *Astacopsis gouldi* from Tasmania which reaches weights up to 4.5 kilograms (Short 2000). Some species, for example the burrowing crayfish (*Engaeus* species), are actually terrestrial but live in subterranean cavities full of water, while others live in freshwater bodies (*Cherax, Euastacus, Astacopsis*). Australian Aborigines ate the yabby (*Cherax destructor*) (Gillon and Knight 1986), and it has been suggested that they translocated this species into central Australia (Horwitz and Knott 1995). Australia currently has three species that are commercially exploited for the food industry: the yabby (*Cherax destructor*), redclaw (*C. quadricarinatus*) and marron (*C. tenuimanus*). The yabby naturally occurs in southeastern Australia, but the main production output is from populations translocated to southwestern Australia. Redclaw is produced in Queensland and northern New South Wales. The marron occurs in southwestern Western Australia but has been translocated to South Australia for production. Both redclaw and marron are bred in aquaculture facilities, while yabbies are mainly harvested from farm dams. From 1996 to 1999, production of these three species in Australia amounted to 421 tonnes (valued at approximately A$5 million), and the projected output in 2004/2005 was 1 589 tonnes (Piper 2000). Many of the burrowing and freshwater crayfish are restricted in their distribution, and several threatened species are listed (O'Brien 2007).

Preservation and storage

The mass rearing of insects for consumption or sustainable harvesting from the wild is an important hurdle that needs to be overcome. Australian Aborigines generally ate the food they collected or caught on the same day or not long after. There are only a few recorded examples of Aborigines preserving insect food to eat later. These include making *Bogong* moths into a cake (Flood 1980), a caterpillar (could be *muluru* of the Wangkangurru and Yarluyandi people or *anumara* of the Arrente people) that fed on grass that had its head pulled off, its body contents squeezed out and the body dried in hot ashes and was either eaten or stored (Hercus 1989; Kimber 1984) and collection of psyllid lerps from eucalypt leaves (Plate 3) that were rolled into a ball that could be stored for months (Central Land Council 2007b; Bin Salleh 1997). The *ayeparenye* caterpillar feeds on tar vine (*Boerhavis* spp.) and was collected in large numbers and gutted (*werlaneme*) and cooked in hot ash; it can also be stored (Central Land Council 2007b). *Witjuti* grubs that are dug out from inside a piece of *Acacia kempeana* root will seal up the exposed ends of the root and they can be kept alive for several days and transported within the root (author, personal observation).

Plate 3. Lerps or sweet secretions of psyllid bug nymphs *(Courtesy A.L. Yen)*

The storage and transport of fresh insects is a problem if large distances are involved, while dried, canned or bottled specimens are common (Ramos-Elorduy 2005). With modern food preservation methods such as freeze drying and cryovacking, long-term storage for transport should not be a major problem. If international export of insects is to be considered, one important issue that requires consideration is the contamination level of the insects, which may breach quarantine regulations in different countries.

Marketing

Possibly the most difficult task in expanding the value of entomophagy is getting people to accept the practice. The shunning of entomophagy is primarily cultural (Gullan and Cranston 2005). The first step is to counter western bias against insects as food; this strong public bias in the west also influences perceptions of entomophagy in traditional societies (Morris 2004). The issues that need to be considered are whether people in western societies will eat insects and whether they will aid developing nations that may need to mass produce insects as food.

In Australia, a market evaluation survey indicated that the idea of consuming *witjuti* grubs was a challenge for nearly half the 1 273 people interviewed; 33 percent were neutral, and only 20 percent considered them acceptable (Rich 2006).

People need to be given reasons why insects should be eaten other than the fact that they play a crucial role in diets of many peoples (Morris 2004). The messages should be that: (1) most insects have high food conversion efficiency compared with conventional livestock (Gullan and Cranston 2005); (2) cultivating insects for protein is less environmentally damaging than cattle ranching; (3) minilivestock (insect farming) can be a low-input, sustainable form of agriculture (Gullan and Cranston 2005);[2] and (4) semi-domestication of invertebrates could reduce pressures on natural populations (Paoletti and Dreon 2005; Paoletti and Dufour 2002).

The ways in which insects are eaten also need to be addressed. They can be eaten by people directly (either insects *per se* or insect additives to food), or indirectly by having them in the food production chain.

Eating insects whole or their body parts can be difficult for those brought up in western societies. This is overcome by presentation (mixing insects into more complex dishes) or by comparing them to currently accepted food types (especially crustaceans). If we are seeking to include insects for nutritional reasons, then perhaps we should consider the addition of ground-up insects in prepared foods (such as flour or pastes). This raises the question of whether we simply farm known species such as silkworms (*Bombyx mori*), house flies (*Musca domestica*) and mealworms (*Tenebrio monitor*). The answer is that we probably need to find out what other insects can provide that these species do not.

Insects and other invertebrates such as earthworms can be an important food for domesticated animals, and there are many examples of where they are used as feed for fish, poultry and pigs (Oyegoke *et al.* 2006; Gullan and Cranston 2005). The earthworm *Eisenia fetida* fed to

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[2] Insects could provide alternative forms of income to current production farms and involve much less land. In a study on the feasibility of commercializing bush food plants in Queensland, Phelps (1997) found that there was less interest while income from more traditional forms of farming was greater.

aquarium fish (*Poecilia reticulata*) resulted in significantly increased brood numbers (double) compared to standard food (Kostecka and Paczka 2006).

The future: entomophagy and conservation in Australia

What are the main requirements if entomophagy is to be advocated as a serious option for Australia? They involve advocacy (DeFoliart 1989); more attention to the biological potential of edible forest insects, including conservation, forest management, agriculture, nutrition and processing and storage (includes inventory of species); and stakeholder involvement (Vantomme *et al.* 2004).

Advocates

Advocacy for entomophagy needs a concerted effort (DeFoliart 1989). This can be at several levels involving: (1) scientists and conservationists on the potential benefits of entomophagy from an energy and conservation perspective; (2) nutritionalists on dietary advantages; and (3) farmers to establish minilivestock activities. A clear message needs to be delivered that entomophagy is not simply a developing world phenomenon, and developed nations can benefit if it is more widely adopted.

It could be a three-pronged advocacy strategy: (1) promoting iconic species as food for direct human consumption (*witjuti* and *bardi* grubs, yabbies, honey ants, etc); (2) allowing insects as food additives for provision of protein and other nutrients; and (3) encouraging the use of insects as animal (poultry, pig and fish) food.

Museums and zoos could play an important role as advocates. Live invertebrate displays are paramount in improving the profile of “creepy-crawlies” (Yen 1993) and many of these displays have associated captive breeding. This is an opportunity to study the biology of edible species and promote the use of edible invertebrates.

More information on edible insects

An up-to-date inventory of entomophagous insects in Australia is required. This will involve both working with traditional landowners to obtain more information on which species they consider edible as well as information on their biology, collecting, preservation and cooking techniques. Research is also needed on the potential of species that are not eaten by traditional landowners.

Agreement is needed on definitions of scientific and common names for edible insects. As Yen *et al.* (1997) indicated, some Aboriginal groups have more accurate naming systems for edible grubs than those used by scientists. This situation is due to insufficient study on the taxonomy and distribution of these species. However, entomologists need to provide the lead on using correct names (such as *witjuti* and *bardi* grubs); the guide for the official common names of Australian insects (Naumann 1993) lists three taxa of insects as *bardi* grubs: the hepialid moths *Trictena atripalpis* and *Abantiades marcidus* and cerambycid beetles; the term should only be applied to beetle larvae and strictly to the buprestid *Bardistus cibarius* (Yen 2005).

Involvement of stakeholders

There are four groups of stakeholders that need to have active involvement: (1) traditional owners; (2) landowners (whether government or private); (3) industry (food production, processing and marketing; and (4) consumers (Charnley *et al*. 2007).

With regard to the traditional Australian Aboriginal owners, there is an urgent need to document information and traditional stories because the loss of local knowledge is a major issue (Paoletti and Dreon 2005). This information is being lost with the passing of the current generation of elders and often the information is not being handed on to the next generations.

It is not simply a matter of recording the information because traditional knowledge is a complex mixture of language and custodianship (initiated and uninitiated; men and women; and the custodians of knowledge for a particular area). There have been attempts to document insect names among Australian Aborigines (Yen *et al.* 1997; Meyer-Rochow 1975), and the Aborigines themselves have provided much information on the species that they eat (Central Land Council 2007b; Dann 2003; Goddard and Kalotas 2002; Bryce 1998; Bin Salleh 1997; Latz 1995; Turner 1994; Hercus 1989; Devitt 1986; Gillon and Knight 1986).

There are often deeper meanings to names and ceremonies that involve restricted knowledge associated with looking after the land or with growing up. For example, some Central Australian songs and dances about *witjuti* grubs may refer to more complex social issues related to growing up and marriage (Roheim 1933). In another example, Spencer and Gillen (1899) described a *witchetty* grub ceremony at Emily Gap near Alice Springs in Central Australia. But the site is not known for the grub that feeds in the roots of the *witjuti* bush (*Acacia kempeana*). Instead, Emily Gap is a very important location for the traditional Arrernte owners because it is where *arlperenye* (the green stink beetle) decapitated the *ayeparenye* (the caterpillar that feeds on tar vine, *Boerhavis* spp), *ntyarlke* (the caterpillar that feeds on pigweed, *Portulaca olearacea*) and *utnerrengatye* (the caterpillar that feeds on the emu bush, *Eremophila longifolia*), and spilled their innards everywhere. It is the place where the caterpillars that are considered the main creative ancestors of Alice Springs originated (Central Land Council 2007a,b). These three caterpillars were food items and were ritually gutted before eating. A hole was dug and the guts were squeezed into the hole and buried; this gutting process is called *werlaneme* and had to be done according to Arrernte Law because these *tyape* (edible caterpillars) were very sacred to the area and the Arrernte people (Central Land Council 2007b). Interestingly, the scientific identities of these three species are still uncertain.

Documenting information from traditional owners requires acknowledgement that some sensitive information cannot be made public. For example, information on whether a particular insect is edible and how it is collected is often forthcoming, but information on Aboriginal understanding of the biology and mythology (which can be associated with creation and movement across the country) may not be.

Consultation with Aboriginal communities is essential because they will, in many cases, have important information on edible insects, may retain some ownership of land involved and they could be an important contribution to small local economies (Vantomme *et al.* 2004). Aboriginal involvement would involve gaining community support, provision of training, support services (developing a business plan, funding, site selection, species and plant), marketing and issues associated with intellectual and cultural property (Miers 2004).

Controlled mass production including economical mass harvest methods

Two factors work against mass harvest of edible insects from the wild in Australia: unreliability of supply and the potential for habitat destruction. As outlined earlier, Australian Aborigines were able to utilize edible insects in a sustainable manner because of low population densities and tracking resources by moving across the country. There are questions as to whether harvesting for tourism and restaurants is sustainable because motorized transport has increased the area that is searched for food and at a much higher rate. There is unsubstantiated anecdotal evidence that sugarbags (native bees) have declined in the southern parts of Australia; whether this is due to better access or due to other environmental factors, remains to be determined.

The mass harvesting of pest insects is another matter. Whether this is economically feasible needs to be addressed. Pest outbreaks can also be unpredictable, and the mode of collection will depend on the target species. Collecting plague locusts would be difficult because of the vast areas that they cross in a short time, and access to some of these areas can be difficult. Locust control in Australia is based on spraying hopper beds to reduce adult numbers, and this may prevent collection of adults. Some pests of agricultural crops or horticulture could be mass collected by light or chemical (pheromone) traps. Initially it would be necessary to determine if these species are of entomophagous value to humans.

There has been limited study on mass rearing of edible Australian insects (Rich 2006), and the techniques are better developed for snails (Berg 2006, 2003) and crayfish (Piper 2000). There is certainly an opportunity to research mass rearing of selected insects other than the known iconic species as well as determining more efficient ways of rearing *bardi* and *witjuti* grubs. This research needs to be conducted in conjunction with research on food quality and safety. While discussion has focused on using the products within Australia, the value of international export markets needs to be kept in mind.

If minilivestock enterprises are to be established in Australia, it is necessary to consider the design, location and integration of these enterprises with other production systems. These need to be considered in relation to their purpose and how they operate (for example recycling systems for converting organic wastes into high protein feed supplements for humans, poultry, pigs and fish), and how farmers could augment their main income with minilivestock operations. New ventures should be considered, such as the possibility of using appropriate termites to produce compost from sawmill waste in certain locations, and at the same time harvest termites as animal feed (D. Ewart, personal communication, 2008).

Conservation

Besides reliability of supply, the other main argument for developing mass rearing facilities for edible insects is habitat conservation. While much of Australia is semi-arid or arid (but still with considerable vegetative cover), forests and woodlands have been severely depleted since European settlement. Many woodlands were cleared for agriculture, while some of the remaining forests are still used for timber production. The major threats to Australian forests and woodlands include alienation and fragmentation, altered hydrology regimes, stock grazing and other forms of activities that affect the understorey and ground layers and inappropriate fire regimes.

A survey of entomophagy in Central Africa found that forest caterpillars (Lepidoptera) and grubs (Coleoptera) provided high nutritive value and were a main source of protein, and unlike those from agricultural land, they were free of pesticides. Gathering (by hand or chopping off branches or felling trees) was probably not as much of a threat as logging, bushfires or other forms of forest disturbance (FAO Département des Forêts 2004). The situation in Australia is different in that more forest has been cleared or alienated than in Central Africa, and although not many insects are being harvested, the effects (especially digging for fish bait) could be quite severe. Also, unlike Central Africa, Australian commercial forests are sometimes sprayed with chemicals (insecticides, fungicides and herbicides).

Mass rearing of insects, even if it is only for recreational fishing, would help the conservation of Australian forests. As part of environmental restoration in Australia, there are numerous tree-planting programmes to replace lost forests (and also part of carbon-trading schemes). These programmes range from those with purely conservation goals (planting endemic species with a structure that imitates natural conditions) to purely commercial agroforests. There is a need to consider whether some of these programmes can be integrated into a system that will also involve the production of edible insects.

Conclusions and recommendations

The consumption of insects is not a major component of diet in Australia today. It is confined to some groups of Aborigines (where it is in decline due to preference for processed western foods), as part of the bush tucker tourism experience and in a very small number of restaurants. There are commercial operations involving the mass rearing of freshwater crayfish and *Helix aspera* for human consumption. There is high demand for edible insects as bait in recreational fishing.

There are enormous opportunities to develop and expand entomophagy in Australia on three levels: (1) human consumption of selected species; (2) as a nutritive supplement in food for humans; and (3) as food for fish, poultry and other animals. Most edible Australian insects are difficult to collect in large numbers (and often in isolated locations that make transport to markets an issue), are unpredictable in their occurrence and inappropriate harvesting could result in significant damage to both their population numbers and their habitats.

Mass rearing of edible insects would be the most appropriate solution to increase their availability. This involves research in raising insects from different habitats (leaf feeders, wood and root feeders, honeydew feeders, etc.) and species that can be highly mobile (for example *Bogong* moths). Mass rearing and preparation of edible insects is a research area that could facilitate more cross-continental collaboration. For example, the Asmat in Papua rear the palm weevil (*Rhynchophorus ferrugineus*) in rotting trunks of sago palm to enable the collection of large quantities (Paoletti 1995); can this idea be applied to edible trunk and root grubs in Australia?

If wild harvesting of edible insects and other invertebrates is to be undertaken, then there needs to be further research on the distribution and population dynamics of these groups so they can be harvested without destroying forests and other environments (Paoletti *et al.* 2000; Paoletti 1995).

The list of widely adopted edible insects in Australia is relatively small (for example *witjuti* and *bardi* grubs, *Bogong* moths, honey ants). This is partly due to taxonomic impediments and the actual number of species of Lepidopteran and Coleopteran larvae eaten (at the moment collectively lumped into the *witjuti* and *bardi* categories) could be quite large. There is an urgent need to document further information from Australian Aborigines because this disappearing traditional local knowledge could be lost forever (Paoletti *et al.* 2000). There could be more edible species in Australia, and it is necessary to learn how the various Aboriginal groups found, collected and cooked them.

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Review of the nutritive value of edible insects

Chen Xiaoming, Feng Ying, Zhang Hong and Chen Zhiyong[1]

Insects have not been fully used and developed as a food source. Based on analysis and study, the nutritive value of edible insects was reviewed. The results showed that insects have rich protein (20-70 percent), amino acid (30-60 percent), fat (10-50 percent), fatty acid, carbohydrate (2-10 percent), mineral elements, vitamins and other activated elements that promote human health. As protein sources, the nutritive value of edible insects is as good as other animals or plants. Insects are characterized by rich species diversity and large populations, therefore as nutritive resources, edible insects can be widely used and have great development potential. In promoting insects as human food, relative nutritive values should be taken into consideration to provide the maximum benefit to human consumers.

Keywords: amino acid, carbohydrate, fat, fatty acid, protein, trace elements

Introduction

Insects represent a significant biological resource that is still not fully utilized around the world. There are many species and vast numbers of insects. Insect bodies are rich in protein, amino acids, fat, carbohydrates , various vitamins and trace elements. Therefore insects offer an important nutritional resource for humans and are worthy of development (Chen and Feng 1999; Yang 1998; Hu 1996; DeFoliart 1992; Mitsuhashi 1992; Comby 1990; Ramos-Elorduy and Pino 1989; Zhou 1982; Zhou 1980).

During human evolution, it was customary in many countries and regions to eat insects. In ancient China it was common to consume insects as food. According to the famous entomological historian Zhou Shu-wen, the Chinese began to eat insects more than 3 000 years ago (Zhou 1982), moreover many old documents detail the eating of insects; some insects were even sent to the king and high officials as tribute. Until now, in many regions of China, especially in areas where minority groups live, people are still accustomed to eating insects.

Besides being a delicious food commodity, the nutritive value of edible insects has attracted the attention of nutritionists, health workers and physicians. Many insects not only have high nutritive value, but are also considered to have health-enhancing properties, such as Chinese caterpillar fungus, ants, termites and silkworms; some have been processed into health foods.

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Other countries have also paid considerable attention to edible insects. As early as 1885, the English entomologist Vincent M. Holt published *Why not eat insects?* (Holt 1885). Since then many entomologists have made further studies on the nutritive value of insects, identification of edible insects, customs related to eating insects and other aspects. The French entomologist Bruno Comby wrote *Delicieux insectes* (Comby 1990); Professor G.R DeFoliart of the University of Wisconsin has edited *The Food Insects Newsletter*; Japanese entomologist Jun Mitsuhashi published *Edible insects of the world* (Mitsuhashi 1992); Japanese entomologist Dr Umeiya Kenji described edible insects and medical insects in *Insect resources of Asia*; and in 1989 Dr Julieta Ramos-Elorduy of the National Autonomous University of Mexico investigated and analysed the nutritive elements of edible insects in Mexico, with excellent results (Ramos-Elorduy and Pino 1989).

Zhou (1982) and Zhou (1980) conducted research on insects of ancient China and both wrote books on historical entomology in China. In these books, Chinese edible insects are discussed. Zhou (1982) in particular describes the nutritive value and eating customs of edible insects in ancient China. In recent years, *Resource insects and utility* (Hu 1996) and *Utility of Chinese resource insects and their industrialization* (Yang 1998) have also addressed some edible insects. In *The edible insects of China* (Chen and Feng 1999), 11 orders, 54 families, 96 genera and 177 species are recorded. The value of edible insects has made scientists pay much greater attention to the subject.

Protein and amino acids of edible insects

Protein is the basis of all organism activity and constitutes many important materials such as enzymes, hormones and haemoglobin. Protein is an important component of antibodies as it bolsters the immunity function of the body. It is the only material to produce nitrogen for maintaining acid and alkali balance, transforming genetic information and transporting important materials in the human body. As a nutritive element that produces heat, it can supply energy.

Insect bodies are rich in protein. In nearly 100 analysed edible insects (Chen and Feng 1999; Yang 1998; Hu 1996; DeFoliart 1992; Mitsuhashi 1992; Comby 1990; Ramos-Elorduy and Pino 1989), at egg, larva, pupa or adult stages, the raw protein content is generally 20-70 percent. Raw protein content is 66.26 percent in Ephemeroptera larvae, 40-65 percent in Odonata larvae, 40-57 percent in Homoptera larvae and eggs, 42-73 percent in Hemiptera larvae, 23-66 percent in Coleoptera larvae and 20-70 percent in Lepidoptera larvae. Protein content of Apidae, Vespidae and Formicidae in the Hymenoptera Order is also high (38-76 percent). According to analysed data, the protein content of insects is higher than most plants; the protein content of some insects (e.g. larvae of *Ephemerella jianghongensis* [66.26 percent], *Sphaerodema rustica* Fabricius [73.52 percent]) is higher than that of commercial meat, fowl and eggs (Table 1).

Protein is composed of more than 20 types of amino acid that benefit the human body; among them eight are necessary for human nutrition as they cannot be synthesized in the human body (Jin 1987). Analysis of nearly 100 types of edible insects has shown that necessary amino acid content is 10-30 percent, covering 35-50 percent of all types of amino acids, which is close to the amino acid model proposed by the World Health Organization and FAO (Table 1).

Table 1. The protein and amino acid content of edible insects in some insect orders (% dry weight)

Order	Protein			Amino acids			Necessary amino acids			N amino acids/ amino acids		
	high	low	ave.	high	low	ave.	high	low	ave.	high	low	ave.
Ephemeroptera			66.26			65.97			23.81			36.09
Odonata	65.45	46.37	58.83	51.70	36.10	46.03	19.08	13.04	16.12	36.91	34.05	35.69
Isoptera				58.27	33.96	44.03	20.88	12.77	16.74	40.05	35.73	38.04
Orthoptera	65.39	22.80	44.10	57.51	20.23	38.87	19.92	7.98	13.95	39.45	34.64	37.05
Homoptera	57.14	44.67	51.13	53.19	32.59	42.45	21.92	12.38	16.34	41.21	35.42	38.21
Hemiptera	73.52	42.49	55.14	59.68	38.09	48.72	22.18	14.73	18.65	42.72	34.77	38.41
Coleoptera	66.20	23.20	50.41	62.97	13.27	39.74	28.17	4.45	17.13	50.49	26.65	42.79
Magaloptera			56.56			53.31			19.51			36.60
Lepidoptera	68.30	14.05	44.91	61.84	13.27	32.88	25.60	4.45	13.92	47.23	26.65	40.35
Diptera			59.39									
Hymenoptera	76.69	12.65	47.81	81.27	21.0	45.18	33.62	8.42	16.23	46.41	30.56	35.78

Sources: Yang (1998); Hu (1996); Mitsuhashi (1992); DeFoliart (1991); Comby (1990); Ramos-Elorduy and Pino (1989); and the authors.

Fat in edible insects

Fat is an important component of the human body, storing and supplying energy as well as supporting and protecting different organs. Fat can also help in the absorption of vitamins. Phosphate, carbohydrate and cholesterol are components of many tissues and cells; combined with protein, they can form fat protein and cell membranes. Recent studies show that phosphatide is good for the brain and liver, reduces blood fat, produces clean cholesterol, helps cells and skin to grow and postpones senility (Jin 1987). Fatty acids can be separated into saturated fatty acid and unsaturated fatty acid. Unsaturated fatty acid can help human growth, protect the skin and reduce the formation of thrombi and clotting of blood platelets.

According to reports and analysis (Feng *et al.* 2001 a,b,c; 2000 a,b; 1999; Chen and Feng 1999; He *et al*. 1999; Lu 1992; DeFoliart 1991), many edible insects are rich in fat (Tables 2 and 3). During edible larvae and pupae stages, their fat content is higher; during the adult stage, the fat content is relatively lower. The fat content of edible insects is between 10 and 50 percent; the fat content of *Oxya chinensis* (Thunberg) of Orthoptera only reaches 2.2 percent; some larvae and pupae of Lepidoptera have higher fat content, such as *Pectinophora gossypeilla* Saunders (49.48 percent) and *Ostrinia furnacalis* Gunnee (46.08 percent). The fatty acid of edible insects is different from animal fat; it has higher fatty acid that the human body needs, such as that found in the larvae and pupae of *Dendrolimus houi* Lajonquiere, larvae of *Musca domestica* Linnaeus, *Chilo Fuscidentalis* Hampson and some ants.

Therefore, the fat of edible insects has good nutritive value. Edible insects have similar fat materials, such as phosphatide, which has health benefits.

Table 2. Fat content of some edible insects (% dry weight)

Order	Fat		
	high	low	average
Odonata	41.28	14.23	25.38
Orthoptera			2.2
Homoptera	30.60	24.85	27.73
Hemiptera	44.30	9.73	30.43
Coleoptera	35.86	14.05	27.57
Lepidoptera	49.48	5.0	24.76
Diptera			12.61
Hymenoptera	55.10	7.99	21.42

Sources: Lu *et al*. (1992); DeFoliart (1991); and the authors.

Table 3. Fatty acids of some edible insects (%)

Species	Saturated fatty acids		Unsaturated fatty acids		
Macrotermes annandalei (Silvestri)	18.54	9.98	51.14	13.01	0.65
Macrotermes subhyalinus	33.0	1.4	9.5	43.1	3.0
Oxya chinensis (Thunberg)	25.0	26.1	27.1	2.3	
Locuta migratoria migratorioides (R. & F.)	25.5	5.8	47.6	13.1	6.9
Melanoplus sanguinipes (Fabricius)	11.0	4.0	19.0	20.2	43.0
Schistocerca gregaria (Forska) male adult	40.3	6.7	31.7	7.5	3.6
Schistocerca gregaria (Forska) female adult	34.6	5.8	37.6	10.2	6.2
Rhynchophorus phoenicis (Fabricius)	36.0	0.3	30.0	26.0	2.0
Tenebrio molitor L.	23.6	1.4	44.7	24.1	1.5
Antheraea pernyi Guérin-Méneville pupa		2.37	27.81	24.74	24.87
Dendrolimus houi Lajonquiere pupa	3.038	4.40	29.77	9.96	22.24
Dendrolimus houi Lajonquiere adult	36.64	7.84	32.82	6.0	8.79
Galleria mellonella L.	39.6	3.1	47.2	6.5	
Musca domestica L. larva	12.7	2.3	18.2	32.5	3.3
Polyrhachis dives Smith	21.14	2.29	62.44	1.39	1.21

Sources: Lu *et al*. (1992); DeFoliart (1991); and the authors.

Carbohydrates of edible insects

Carbohydrates are important nutritive elements in the human body. They are the main heat source, can reduce consumption of protein and help detoxification. They are also important constituent materials of the human body. They can combine with protein and fat and their compounds have important physiological functions (Jin 1987).

Edible insects have rich protein and fat, but less carbohydrate (Table 4). Types of edible insects differ and their carbohydrate contents also vary (1-10 percent). An unusual source is insect tea, the excrement of insects, which has higher carbohydrate content (16.27 percent). Recent research has revealed that insects have considerable amounts of polysaccharide that can enhance the immunity function of the human body (Sun *et al*. 2007).

Table 4. Carbohydrate content in some insect orders (% dry weight)

Order	Carbohydrate		
	high	low	average
Odonata	4.78	2.36	3.75
Orthoptera			1.20
Homoptera	2.80	1.54	2.17
Hemiptera	4.37	2.04	3.23
Coleoptera	2.82	2.79	2.81
Lepidoptera	16.27	3.65	8.20
Diptera			12.04
Hymenoptera	7.15	1.95	3.65

Sources: Yang (1998); Hu (1996); and the authors.

Chitin is a macromolecular compound that has high nutritive and health food value. Chitin can be made into a health food that has medicinal value for it can stop bleeding, prevent thrombus and help wounds to heal; it can be made into a medicinal film and can also be used in making cosmetics. The body and skin of edible insects are rich in chitin; different forms of edible insects have different chitin content (5-15 percent), such as *Bombyx mori* L. dried pupa (3.73 percent), defatted pupa (5.55 percent) and *Dendrolimus houi* Lajonquiere pupa (7.47 percent) and adult 17.83 (percent) (Chen and Feng 1999; He *et al*. 1999). The scientific study of the chitin of insect bodies is just beginning, with potential for many human uses.

Inorganic salts and trace elements in edible insects

Inorganic salts and trace elements are important components of the human body. They are necessary materials to maintain normal physiological functions (Jin 1987).

According to analysed results (Table 5), edible insects have rich trace elements such as potassium (K), sodium (Na), calcium (Ca), copper (Cu), iron (Fe), zinc (Zn), manganese (Mn) and phosphorus (P). Many edible insects are also high in calcium, zinc and iron. Therefore, edible insects can supply necessary nutritive elements for human body functions.

Table 5. Trace element content of some edible insects (% dry weight)

Species	K	Na	Ca	Mg	Cu	Zn	Fe	Mn	P
Gomphus cuneatus Needham	2 620	590	4 180	880	64.3	124.8	728.9	74.8	1 470
Lestes paraemorsa Selys	2 930	2 020	2 160	970	64.8	147.7	1198	58.9	2 470
Crocothemis servilia Drury	3 330	2 310	1 510	950	50.6	103.8	461.6	27.2	1 420
Darthula hardwicki (Gray)	2 120	610	280	4 500	56.9	544.3	100	13.6	
Ericerus pela Chavaness, egg	6 300	89.51	353.7	1 200	23.6	164.2	133.1	26.74	6 000
Cyclopelta parva Distant	4 720	1 680	480	1 530	2.4	155.8	119.7	19.9	8 200
Eusthenes saevus Stal.	610	780	280	260	45.4	78.0	98.3	16.3	1 520
Cyrtotrachelus buqueti Guérin-Méneville	2 620	650	270	1 050	38.4	306.1	64.7	21.0	5 190
C .longimanus Fabricius	1 740	510	390	480	22.9	127.1	66.3	25.9	2 920
Holotrichia oblita (Faldermann)			397.22	455.78	18.86	101.33	1313.7	46.50	
Anomala corpulenta Motschulsky			434.94	297.04	26.82	84.51	2 299.5	61.61	
Protaetia aerata (Erichson)			187.47	303.65	35.56	97.48	338.54	20.03	
Aromia bungii Faldermann			131.56	220.54	23.97	98.76	102.5	15.47	
Anoplophora nobilis Ganglbauer			133.56	105.2	10.42	95.42	105.33	9.56	
Apriona germari (Hope)			150.68	254.36	25.46	102.34	96.56	20.47	
Pectinophora gossypeilla (Saunders)			113.40	163.21	33.40	87.01	36.78	0	
Corcyra cephalonica Stainton			148.66	156.81	17.13	78.29	264.81	6.87	
Ostrinia furnacalis (Gunnee)			140.53	184.06	14.84	91.78	70.26	4.56	
Papilio machaon L.	1 250	90.5	384	279	1.5	3.5	18.0	0.9	457
Chilo fuscidentalis Hampson	2 620	740	880	1 060	11.1	109	57.1	41.8	1 690
Antheraea pernyi Guérin-Méneville	13 390	620	790	3 800	19.01	141.8	0.01	8.73	690
Musca domestica L.	15 600	2 700	1 200	12 300	59	570	520	406	17 900
Polyrhachis dives Smith female adult			613.34	172.36	32.66	155.42	378.36	104.35	
Polyrhachis dives Smith male adult			585.28	163.78	27.08	148.83	391.56	101.89	

Sources: Hu (1996); Rong *et al.* **(**1987); and the authors.

Vitamin content of edible insects

Vitamins are one group of organic compounds that are necessary for metabolism in human bodies. As vitamins cannot be synthesized in the human body, they must be supplied constantly by food.

Studies on vitamins in edible insects are insufficient. But according to analysed results (Feng *et al*. 2001 a,b,c; 2000 a,b; 1999; Chen and Feng 1999; He *et al*. 1999; Lu 1992; DeFoliart 1991), edible insects have vitamin A, carotene, vitamins B_1, B_2, B_6, D, E, K, C, etc. For example, the vitamin A content of *Macrotermes annandalei* Silvestri reaches 2 500 IU/100 gram, vitamin D reaches 8 540 IU/100 gram, vitamin E reaches 1 116.5 mg/100 gram and the vitamin C content of insect tea reaches 15.04 mg/100 gram. Edible insects are rich in vitamins for human health and nutrition.

Conclusion

Edible insects are rich in protein and amino acid, especially essential amino acids for the human body. They are one source of good protein. They can supply rich fat, fatty acid, nutritive elements, vitamins and carbohydrates, especially high unsaturated fatty acid, which has excellent nutritive value. There are other substances in insects that are good for human health; for example, antibacterial protein and peptide, enzymes and hormones. Certain insects constitute superior health food. As a nutritional resource, edible insects and their industrialization should be focused on in future studies.

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Common edible wasps in Yunnan Province, China and their nutritional value

Feng Ying ,Chen Xiaoming, Sun Long and Chen Zhiyong[1]

Wasps belong to the Order Hymenoptera and feed on other insects. They have been consumed by humans for a long time, both in China and abroad. They are common edible insects in Yunnan Province. Research indicates that there are 12 species of edible wasps in Yunnan: Vespa velutinia auraria *Smith,* V. tropica ducalis *Smith,* V. analis nigrans *Buysson,* V. variabilis *Buysson,* V. sorror *Buysson,* V. basalis *Smith,* V. magnifica *Smith,* V. mandarinia mandarinia *Smith,* V. bicolor bicolor *F.,* Provespa barthelemyi *(Buysson),* Polistes sagittarius *Saussure and* P. sulcatus *Smith.*

The larvae and pupae of wasps are nutritious and rich in protein and amino acids. The average protein and amino acid content is 52.96 and 44.77 percent, respectively. The average amount of seven types of amino acids necessary for human nutrition is 16.62 percent, constituting 37.12 percent of total amino acids. Among the edible insects, wasps can play an important future role in human nutrition.

Keywords: amino acid, nutrition, *Polistes*, protein, *Provespa*, *Vespa*

Introduction

Wasps belong to the Order Hymenoptera and feed on many kinds of other insects, including various agricultural and forestry insect pests. Therefore wasps can be an important element in biological control programmes (Li 1993). The apitoxin excreted by female wasps can alleviate thrombus and can be used as a medicine.

Wasp larvae and pupae are also edible. Records show that it has been customary for Chinese people to eat wasps since ancient times. Wasp collecting and cooking techniques are documented in a book from the Tang Dynasty (618-907) (Zhou 1982). Wasps are also eaten in other countries, such as Mexico, Japan and Thailand (Wen 1998; Satoshi *et al.* 1996; Mitsuhashi 1992). The larvae and pupae of wasps are commonly eaten in Yunnan Province, southwestern China; in summer and autumn they are sold with the nest in local markets. Dishes of cooked wasps are also served in restaurants. Research on edible wasps is insufficient despite their popularity in China. The amino acids of *Vespa velutina auraria* Smith and *V. tropica ducalis* Smith were analysed by Wang *et al.* (1998). The analysis of edible wasps in Yunnan is the subject of this paper and is based upon Chinese studies of edible insects conducted by scientists over many centuries.

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Plate 1. Wasp larvae and pupae soup (steamed larvae and pupae of wasps with bamboo shoots and vegetables), Ruili, Yunnan *(Courtesy Feng Ying)*

Materials and methods

Specimens were investigated and collected in Kunming, Shimao, Dali, Honghe and Xishuangbanna prefectures of Yunnan Province. Protein was analysed using the Kjeldahl quantitative determination method. Amino acids were analysed by an automatic amino acid analyser.

Results and analysis

Eating practices and common species

Wasps are common edible insects in China. Eating wasps has been practised throughout China since ancient times and is particularly common in Yunnan Province. The Han, Dai and other minority groups have consumed wasps and offered them to guests for a long time. Local people collect wasp nests to sell at the markets. When a wasp dish is prepared, the larvae and pupae are removed from the nest. In this way, the insects can be kept clean and fresh. The most common way to prepare wasps is deep-frying or frying with chicken eggs, similar to cooking methods employed for edible insects in general. The Dai people who live in Jinghong and Ruili towns of Yunnan Province prefer to steam and mix the insects with vinegar and other seasonings.

There are 12 species of edible wasps in Yunnan, belonging to two insect families. Vespidae accounts for ten species: *Vespa velutinia auraria* Smith, *V. tropica ducalis* Smith, *V. analis nigrans* Buysson, *V. variabilis* Buysson, *V. sorror* Buysson, *V. basalis* Smith, *V . magnifica* Smith, *V. mandarinia mandarinia* Smith, *V. bicolor bicolor* F. and *Provespa barthelemyi* Buysson. The remaining two species are in the Polistidae Family: *Polistes sagittarius* Saussure and *P. sulcatus* Smith.

Protein and amino acid content

The protein content of four wasp species larvae was analysed by the authors. Results showed that the protein content of larva of *V. basalis* Smith, *V. mandarinia mandarinia* Smith, *Polistes sagittarius* Saussure and *P. sulcatus* Smith was 53.18, 54.59, 46.17 and 57.88 percent, respectively. The average of these four species of larvae is 52.96 percent, higher than the protein content of pork (21.42 percent), milk (28.04 percent) and eggs (48.83 percent) (INFS 1998). These results clearly show that wasp larvae are very rich in protein.

Plate 2. Fried wasp larvae and pupae, Ruili, Yunnan *(Courtesy Feng Ying)*

Table 1 presents the results of amino acid analysis for six species of wasp larvae. The contents of 16 types of amino acids of *V. basalis* Smith, *V. mandarinia mandarinia* Smith, *P. sagittarius* Saussure, *P. sulcatus* Smith, *Vespa velutina auraria* Smith and *V. tropica ducalis* Smith were 43.91, 52.20, 36.11, 45.02, 49.03 and 42.44 percent, respectively. The average content of amino acids was 44.77 percent. The contents of the seven essential amino acids for the human body were 15.15, 24.43, 12.57, 16.08, 16.78 and 14.68 percent, respectively. The average amount of these seven essential amino acids was 16.62 percent, constituting 37.12 percent of total amino acids.

Table 1. The amino acid content of six species of wasp larvae (%)

Amino acid	*V. basalis* Smith†	*V. mandarinia mandarinia* Smith†	*P. sagittarius* Saussure†	*P. sulcatus* Smith†	*V. velutin auraria* Smith‡	*V. tropica ducalis* Smith‡
Aspartic acid	3.36	3.30	2.96	3.32	4.53	4.32
Threonine*	1.75	1.74	1.52	1.86	2.12	1.94
Serine	1.91	1.82	1.59	2.02	3.15	2.05
Glutamic acid	7.47	6.89	6.23	6.88	5.91	5.70
Glycine	3.58	3.29	2.50	3.97	3.90	3.70
Alanine	3.41	3.41	2.59	4.01	3.54	3.34
Cystine	ND	ND	ND	ND	ND	ND
Valine*	2.59	2.59	2.37	3.00	3.38	3.24
Methionine*	0.90	0.35	0.48	0.88	1.35	0.53
Isoleucine*	2.64	2.38	2.04	2.83	2.91	2.32
Leucine*	3.54	3.24	2.81	3.61	3.65	3.51
Tyrosine	2.51	2.14	1.78	2.17	3.69	2.29
Phenylal-anine*	1.87	5.53	1.77	1.98	1.98	1.78
Lysine*	1.86	8.60	1.58	1.92	1.39	1.36
Histidine	1.07	1.11	1.09	1.14	1.53	0.58
Arginine	1.73	1.71	1.64	1.82	3.14	3.04
Tryptophane*	Untested	Untested	Untested	Untested	Untested	Untested
Proline	3.72	4.10	3.16	3.62	2.89	2.79
Total	**43.91**	**52.20**	**36.11**	**45.02**	**49.03**	**42.44**

*The essential amino acids. ND = not detected.

Sources: † data from the authors; ‡ Wang *et al.* 1998.

The highest protein content was in four larvae of *P. sulcatus* Smith (measured at 57.88 percent). The lowest was in *P. sagittarius* Saussure, at 46.17 percent. The highest content of amino acids was in six larvae of *V. mandarinia mandarinia* Smith, at 52.20 percent. The seven essential amino acids for the human body constituted 24.43 percent, comprising 46.41 percent of total amino acids. The lowest content of amino acids was in *P. sagittarius* Saussure.

Discussion

A total of 177 species of edible insects have been recorded in China (Chen and Feng 1999). Among them, wasps are widely eaten by many Chinese people. This paper discussed 12 species of wasps. In fact more than 12 wasp species are eaten and the others need to be studied scientifically. Based upon the results presented here, the protein and amino acid content of wasps in the larval stage is higher than in common foods, such as eggs and pork.

Protein is one of three important nutrients for the human body. It consists of 20 amino acids, among them eight types of essential amino acids only obtained from food. The amino acids of different protein may have a complementary function (Dai 1994). Therefore, larval wasps can effectively supplement protein supply by complementing other animal protein sources.

Adult wasps and wasp nests also contain amino acids – even higher than in larvae and pupae (Wang *et al*. 1998). Adult wasps do not taste as good as larvae and pupae and it must be noted that they contain apitoxin. Nevertheless, the adults and nests of wasps have been used in traditional medicine and as a health food by local people since yesteryear in China. In this context, scientific research needs to focus on wasp utilization in medicine and health care.

Wasps also have a positive role in the control of forest pests, as they feed on other insects. Protection and sustainable utilization must be considered in the exploitation of this insect. One promising approach is through artificial feeding of wasps.

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Teak caterpillars and other edible insects in Java

Dwi Retno Lukiwati[1]

*Teak (*Tectona grandis*) is a versatile wood that is excellent for building, furniture making and also fine carving. Among the defoliating insects frequently encountered in plantations is the teak caterpillar or* enthung jati *(*Hyblaea puera *Cramer; common name: teak defoliator), which is the sole genus of the Family Hyblaeidae. An estimated 2 000 insect species are consumed around the world; some people do not just eat insects, they relish them. The quantity of insects harvested from forests or agricultural areas varies greatly according to species and the prevalence of their food plants. Many insect species are lower in fat and higher in protein compared to beef, lamb, pork, or chicken. Crickets (*Brachytrupes portentosus *Lichtenstein), grasshoppers (*Valanga nigricornis *Burmeister and* Patanga succincta *L.), dragonflies (Order Odonata, species* Pantala flavescent *F.), red palm weevils (*Rhynchophorus ferrugineus *F.,* Chalcosoma atlas *L.) and bees (*Xylocopa latipes *Drury) are especially palatable, nutritious and easily obtained in Indonesia.*

Keywords: teak caterpillars, bees, crickets, cooking methods, dragonflies, grasshoppers, palm weevils

Introduction

Teak (*Tectona grandis*) is a versatile wood that is excellent for building, furniture making and also fine carving. In Javanese, the name for teak, *kayu jati*, also means “real wood”. Most of the teak can be found growing in villagers’ forest gardens called *kebun*, especially in traditional teak-producing areas, such as Wonogiri, Blora, Cepu (Central Java), Bojonegoro, Lamongan and Ngawi (East Java) on Java island. One of the defoliating insects frequently encountered in plantations is the teak caterpillar.

Teak caterpillars as a food source

The teak caterpillar or *enthung jati* (*Hyblaea puera* Cramer) is the sole genus of the family Hyblaeidae (Intachat 1997). Some people can consume teak caterpillar cocoons, but others break out in an allergic rash when they eat this seasonal delicacy. For a snack, the teak

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caterpillar cocoons are fried in coconut oil or African palm oil and seasoned with salt. Teak caterpillar cocoons were abundant in 2007 owing to rain in October, which allowed the leaves of the deciduous teak to bud early. As soon as the teak has a full cover of leaves the caterpillars attack, and as soon as the cocoons appear the cocoon collectors enter the forest. The entire neighbourhood participates, young and old, men, women and children. They forage and collect each curled teak leaf containing the tiny cocoon (Sari 2007). Frequently, and especially if large quantities are harvested, some are sold at local markets at US$3/ kilogram). Consuming teak caterpillar cocoons is believed to enhance vitality.

Other selected edible insects

An estimated 2 000 insect species are consumed around the world. There are 1 462 recorded species of edible insects (Price 2008). In fact, most insects are edible, but there are a few species that are especially palatable, nutritious and easily obtainable in Indonesia. Some insect groups and their use as food are described hereunder (LIPI 1980).

Grasshoppers (Order Orthoptera)

The short-horned grasshopper (*Valanga nigricornis* Burmeister, local name *belalang kayu*) is found in rubber plantations or rice paddy fields, and also in teak plantations at the end of the rainy season.

Rice grasshoppers (*Patanga succincta* L., local name *belalang patanga*) occur in lowlands (0-600 metres), underbrush, maize and paddy fields at the beginning of the dry season. This species is lower in fat and higher in protein compared to beef, lamb, pork, or chicken (Table 1).

Grasshoppers belong to the Phylum Arthropoda, Order Orthoptera and Family Acrididae, as evidenced by the ring-like segments of their bodies, their jointed appendages and their exoskeletons. Grass-feeding species of grasshoppers are the most numerous in grasslands (Pfadt 1994). They are often roasted, after first removing the wings and legs. Seasonings such as onion, garlic, chili, or soy sauce may be added. According to Ramos-Elorduy and Pino (1990), the nutritive value of the five highest Orthoptera (grasshopper nymphs and adults) of 20 species examined, averaged 4 168 kcal/kilogram.

Table 1. Nutritive value of livestock compared to rice grasshoppers* (%)

Animals	Protein	Fat
Cattle	15.8	24.3
Sheep	14.6	30.5
Pigs	13.0	33.3
Poultry	20.5	4.3
Patanga succincta* L.*	**24.4**	**1.5**

* Paul and Southgate (1978).
** Dwi Retno Lukiwati (1991).

Crickets (Order Orthoptera)

The cricket *Brachytrupes portentosus* L. is called *gangsir* in Javanese. It has a brown or dark-brown body colour and is found in the dry sandy soil of lowlands (0-600 metres) dominated by agricultural crops and plantations in the dry season. The adult lays its eggs in the ground. Egg production of this species is about 100-160 eggs per period. Cricket intestinal contents are removed prior to cooking. According to Price (2008), 100 grams of cricket contain 121 calories, 12.9 grams of protein, 5.5 grams of fat, 5.1 grams of carbohydrates, 75.8 milligrams (mg) of calcium, 185.3 mg of phosphorus, 9.5 mg of iron, 0.36 mg of thiamin, 1.09 mg of riboflavin and 3.1 mg of niacin.

Dragonflies (Order Odonata)

The name for the dragonfly (*Pantala flavescent* Fabricius) in Javanese is *capung ciwet*. It has a red and yellowish body colour and yellow spotted wings. They are found in lowlands and uplands (0-2 800 metres), especially among swamp plants.

Weevils and beetles (Order Coleoptera)

Among the most important of the larval stem borers is the red palm weevil (*Rhynchophorus ferrugineus* F.) or *ulat sagu* in Javanese. Larvae of this weevil are associated with dead sago palm trees or other dead trees. The larvae have soft bodies and can be fried without removing the gut content.

Scarab beetles (*Chalcosoma atlas* L.) or *kumbang tanduk* are found in lowland and upland areas (0-1 700 metres). The caterpillars of *Chalcosoma atlas* are known as *uret* in Javanese. They feed on debris on the ground and the roots of plants. *Uret* contain a good amount of fat and can be fried without additional oil for a snack.

Drury bee (Order Hymenoptera)

Drury bees (*Xylocopa latipes* Drury) or *tawon endas* feed on the pollen and nectar of flowers. They have a full black body colour. Nests are commonly found underground or in cavities in bamboo or trees and are made by the female bees. Usually the larvae and pupae are taken from the nests and eaten. They are fried with butter or fried with onion and salt.

How to prepare a batch of edible insects

Edible insects must be killed, cleaned and cooked before being eaten. Normally they can be eaten after roasting or frying with coconut oil, mixed with cassava leaves, cooked with salt and a few hot peppers, or simply fried with salt and onions.

The desired quantity of live insects should be rinsed in water and allowed to dry. This is easy to do with larvae or pupae/cocoons, but fairly difficult with winged insects. For winged insects, the gut content, head, hind legs and wings are removed and the insects are placed into a colander and covered with wire screening or cheesecloth. The insects are again rinsed and dried by shaking the colander until all the water drains out. The insect bodies are placed in a plastic bag and kept in a freezer for 15 minutes (but not allowed to freeze). The insects are then taken out of the freezer and rinsed again, after which they are ready for cooking. Two recipes are provided below:

Fried grasshoppers (*belalang goreng*)

Ingredients
- 2 cups of grasshoppers
- 1 cup of wheat flour
- 1 egg
- salt, pepper, garlic
- coconut oil or African palm oil

Method
Soak the grasshoppers in boiling water for one minute and then dry them. Mix and stir the egg, salt, pepper, garlic and add a little water; then dip the grasshoppers individually in the mix and fry them in hot coconut oil. Serve with hot coffee or tea.

Hot sweet teak cocoons (*kering enthung*)

Ingredients
- 2 cups of teak cocoons
- salt, *salam* leaf (*Eugenia polyantha*), a slice of crushed galangal (*Alpinia* spp., a relative of ginger), coconut sugar
- 3 shallots, 3 onions, 5 chilies raw and chopped
- sweet soy sauce

Method
Rinse the cocoons with boiling water. Fry all ingredients (except the cocoons) in a tablespoonful of oil until the aroma rises. Add a little water and keep stirring until the sugar caramelizes and then add the cocoons. Serve with warm white aromatic rice.

Conclusion

Edible insects are generally abundant, nutrient-rich and marketable; they contribute significantly to the livelihoods of many rural families in Indonesia, although historically data have not been collected on them. Very little research has been done on edible insects in Indonesia, but they have considerable development potential.

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Edible insects in Papua, Indonesia: from delicious snack to basic need

Euniche Ramandey and Henk van Mastrigt[1]

The Indonesian province of Papua occupies the western portion of New Guinea; it is equatorial in latitude and consists of lowland, hill and mountain habitats up to 5 000 metres. Local people inhabit villages up to 2 300 metres. About 60 to 100 insect species, representing ten insect Orders, are eaten by indigenous people. Consumption focuses on larger insects that do not need special equipment for capture and which are edible raw or after some roasting. Among large insects, preferences vary from tribe to tribe, probably based upon taste, abundance and custom. Among lowland people, Rhynchophorus bilineatus *is the most commonly eaten insect. Its larvae are used as subsistence food and are sold in local markets. In mountainous areas a wider diversity of insects is consumed, but their collection is more incidental and exclusively for subsistence purposes. In Papua, there is broad indigenous knowledge of edible insects, which is reflected by insect names in the local language, traditions and insect habitats. In the lowlands, edible insect populations are on the decline because of loss of sago forests. In mountainous areas, incidental edible insect collection is expected to continue and could be promoted as additional scientific information becomes available.*

Keywords: entomophagy, New Guinea, protein, *Rhynchophorus*, subsistence, tribal groups

Introduction

Ethnoentomology is still a young science and little research has been published on the use of insects or insect products in Papua as food, medicine or for other purposes. Nevertheless, knowledge and use of insects as food is widespread among indigenous tribes.

Papua Province of Indonesia occupies the western part of New Guinea, bordered to the east by the independent state of Papua New Guinea. Including its surrounding islands, the province has an area of 421 981 square kilometres and a human population of about 2.7 million. It is the easternmost part of Indonesia, situated between 130º and 141º east longitude and 9º north and 2º25’ south latitude. There is a wide variety of habitats in this huge area, broadly divided into lowland (up to 800 metres) and mountainous areas (800- 5 000 metres). Lowlands mainly consist of sago forests, mangrove forests and swamps in the coastal areas. In the Merauke area and in the Birdshead Peninsula there are extensive grasslands. Lowlands generally have a greater number of alternative animal protein resources apart from insects, such as salt- and freshwater fish, wild pigs, birds, couscous (a marsupial) and lizards.

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Mountainous zones, with primary and secondary forests and many garden plots close to villages, generally have fewer animal protein resources with wide variation from area to area. In some locations insects are very important protein resources, especially when fewer alternatives are available. The indigenous people in mountains raise pigs and chickens, but typically restrict consumption of these valuable animals to weddings, exchanges and traditional ceremonies. Insects, especially grasshoppers, leaf and stick insects, cicadas and large moths and their caterpillars, remain an important protein source in the daily diet of many Papuan populations.

Precise data about numbers of insects in Papua are not available. Petocz (1987) approximated between 50 000 and 100 000 insect species in New Guinea, including about 30 000 Coleoptera and 5 000 Lepidoptera. The number of described species of insects in Papua has not been quantified yet. Based on Parsons (1999) and our own data, there are approximately 800 butterfly species in total. Recent surveys of various insect Orders (beetles, damsel flies and dragonflies, butterflies and moths) have shown that the number of recognized species is likely to increase considerably in the years to come.

Data sources

Besides the information provided by Tommaseo-Ponzetta and Paoletti (2005) and Duffels and van Mastrigt (1991), the data in this paper are based on observations by the authors and other members of the Entomological Group in Papua, and the results of interviews with indigenous people. The first author surveyed the life cycle of *Rhynchophorus bilineatus* larvae during her studies at Cenderawasih University (2001-2005); the second author has been working as a missionary in Papua since 1974, has visited many areas and villages all over Papua, and has built up a collection of insects, especially Lepidoptera.

Edible insects

General

Many insects are edible; however, consumption focuses on larger insects that can be collected and eaten without the use of special equipment. Insects that are edible in a raw state or that require minimal cooking are preferred. A summary of edible insects in Papua is provided in **Appendix 1**.

Seasonal conditions influence consumption. Insects that occur in small numbers are rarely utilized; however, insects that emerge in large numbers in a short time, either dependent on weather or other natural circumstances, are often collected and consumed by local people. Examples include Cerambycid beetles, which congregate during the pandan (*Pandanus conoideus*) fruiting season, one-day flies (Ephemenoptera) at the beginning of the rainy season, and *Cosmopsaltria waine* (Homoptera), which has – exceptionally for *Cosmopsaltria* – a two-year life cycle.

Records

In lowlands (areas along Papua's coastline), by far the most important edible insects are the larvae of *Rhynchophorus bilineatus*, the sago beetle (Plate 1). The larvae are collected one month after palm trees (*Metroxylon sagu*) are cut down for production of sago starch (Ramandey 2007; 2004). Normally they are consumed raw or after some roasting. Children in boarding houses in Jayapura and in the interior (for example Moanemani) receive parcels from their home villages containing live sago grubs, which are consumed raw with great relish. The consumption of the sago beetle larvae by the Citak and Asmat people has been documented extensively and found to vary according to both everyday and ritual life. Tommaseo-Ponzetta and Paoletti (2005) mention *Rhyncophorus ferrugineus* and add that possibly two species of Curculionid grubs are collected.

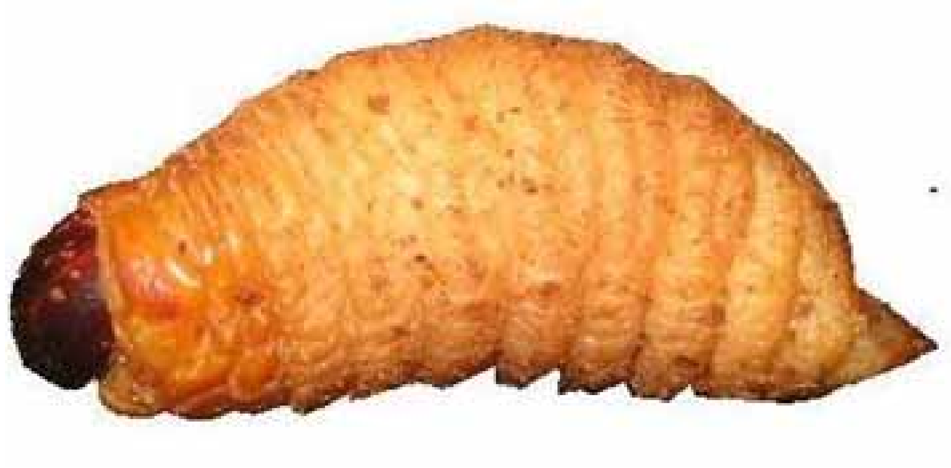

Plate 1. Sago larva (*Rhynchophorus bilineatus*) *(Courtesy E. Ramandey)*

In the southern lowlands, north of Merauke (in Tanahmerah, Mindiptana and Iwur) a one-day fly or mayfly (Ephemenoptera) is collected by the Muyu people and other tribes seasonally, after they emerge and die in enormous numbers above rivers and creeks. Mosquito nets are used to collect the floating insects, which are then packed in wild banana leaves and roasted on embers or just heated in a pan before consumption. At the end of the 1970s, the second author heard stories about enormous numbers of white butterflies dropping in rivers and being collected by local people for consumption. Recently it has become clear that the white butterflies were members of Ephemenoptera. In other parts of Indonesia one-day flies (in Indonesian *laron*) are collected during rainy evenings by putting a basin of water beneath the light of a gas lamp.

Information was obtained from the Ayamaru area in the Birdshead Peninsular of Papua about the occurrence and consumption of beetles in the pandan fruiting season, when fruits are collected by local people and processed. Within a few hours, discarded fruit seeds attract hundreds of beetles that consume traces of fruit on the seeds. The authors have not seen specimens of the beetles collected by local people, but after inspection of the KSP (Collection of Papuan Insects in Jayapura), Cerambycidae species were pointed out, probably in the genera *Xixuthrus*, *Osphryon* and *Macrotoma*. Further information must be obtained to be sure of the exact taxonomic identity of the consumed species. Apart from these beetles, various Sphingidae caterpillars are collected from the leaves of *keladi* (*Colocasia* sp.), the food plant visited most frequently by Sphingidae, to be consumed after some roasting by local people.

During visits from 1984 to 1989 to Timeepa (3º58' south latitude, 135º47' east longitude) and Modio (4º03' south latitude, 135º47' east longitude), the second author discovered that cicadas and moth caterpillars are an important food source for the Mee people in the Mapia area, at the foothills of the Kobowre Mountains (formerly the Weyland Mountains), at 1 400 and 1 280 metres above sea level respectively (van Mastrigt 2007).

The wild pig is hunted and has been domesticated. The population of wild birds around these villages is sparse, probably due to excessive hunting. Women and children catch forest rats, small fish, shrimp and crabs, and occasionally insects, such as cicadas and caterpillars of a Saturnid moth, *Syntherata apicalis* Bouvier, which congregate in communal silk nests.

The Mee people are knowledgeable about the life cycle of cicadas (Hemiptera) and recognize many distinct species for which they have different names in their local language, all ending with "-tege" (*kegaitege*, *pepatege*, *uwaitege*, *ditege* and *enijatege*), except for *waine*. In the Mee language outside the Mapia area *waine* is used for all *Cosmopsaltria* species, while in the Mapia area this name refers to a single species of cicada. The *waine* is easily recognized by the indigenous people by its sound. It is a seasonal species that occurs every other year (emerging in odd numbered years) in large numbers in the dry season (September to November). All kinds of adult cicadas are eaten by the Mee people in the Mapia area, but they most favour the *waine*, especially when collected early in the morning as the adult cicadas emerge from the underground pupae. The insect known as *waine* was new to science and has since been described as *Cosmopsaltria waine* Duffels (Duffels and van Mastrigt 1991).

In other parts of Papua, in the central mountain range indigenous people also consume various cicadas, but there is no location where the knowledge and exploitation of *Cosmopsaltria* is as developed as in the Mapia area. In the Star Mountains (near the Papua New Guinea border) the Ngalum people recognize three different kinds of cicada in their local language, although the number of *Cosmopsaltria* found in the area is probably twice that number.

At Sumbole, Landikma local people consume the complete nests of bees including wax, honey and larvae (personal observation, van Mastrigt). Beetles (Coleoptera) are eaten in many areas. As mentioned earlier, species of the Cerambycidae Family associated with the pandan fruit are consumed in the Birdshead Peninsula. *Xylotrupes gideon* (Dinastynae, Scarabaeidae) is eaten by inhabitants of the Arfak Mountains in the Birdshead Peninsula and at Walmak (about 140º east longitude) on the north side of the central mountain range.

At Langda, close to Mt Goliath (also about 140º east longitude, but at the south side of the mountain range), people collect *Cotilis* spp. (Cetoniinae, Cetoniidae) on high flowering trees, which are skewered on a small stick like sate and roasted before consumption. At least five species of the larvae of *Batocera* spp. and *Dihamnus* spp., Blattodea, found in decayed wood, *Palyzosteria* (?) sp. are part of the diet of the Langda people (Tommaseo-Ponzetta and Paoletti 2005).

Adult *Rosenbergia mandibularis* (Cerambycidae) are collected by the Maribu people (Sentani, Jayapura) from the breadfruit (*sukun)* tree (*Artocarpus communis*) and eaten after roasting. In the Pass Valley (close to the Baliem Valley) children play with the green shield bugs, called *babukulit* (*Nezara viridula* L., Pentatomidae) and eat them raw or roasted. According to the local children, it is the most delicious of the various insects that they consume, including grasshoppers (Orthoptera), cicada (Hemiptera) and some beetles (Coleoptera, including *Behrensiellus glabradus* Pascoe). Their knowledge of beetles is evident in the use of local names such as *fulug* (Passalidae), *fua* (Lucanidae), *bomboli* (snout beetle in general), *singgabit* (*Rhynchophorus richteri*) and *gulangge jangge* (*Behrensiellus glabradus*) (Menufandu 2007a,b).

Tommaseo-Ponzetta and Paoletti (2005) recorded seven local names for insects consumed by indigenous people at the Bime Valley (4º25’-4º30’ south latitude; 140º12’-140º15’ east longitude):

- *dunkala,* the yellow caterpillar of *Acherontia achesis,* as well as several other sphingid caterpillars used as food, Sphingidae (Lepidoptera);
- *due*, the larvae of Melolonthinae beetles, at least six edible species of Scarabeidae;
- *dyk dyk*, adults and larvae of Passalidae;
- *bulutnamgme*, larvae of Cerambycidae, at least three edible species (all Coleoptera);
- *wisin*, larvae of Tettigoniidae, at least five species have been indicated as edible;
- *pho*, adults of Gryllidae (both Orthoptera), with at least three edible species; and
- *philipalala*, the adults of *Extatosoma* sp. (?) Podacanthinae (Phasmatodea).

A wide range of edible insects is found at Borme (900 metres elevation) on the north side of the Star Mountains. Phasmida, Mantodea, Orthoptera and Coleoptera, and many larvae and adults of various species of moths (Lepidoptera) are common food for the indigenous people. During our first visit to Borme in 1998 it became clear that this area has few mammals and birds, probably due to hunting. Cicadas were not seen or heard during a one-week stay in September 1998. In 2006, a few cicadas were collected, but they were uncommon and therefore of little significance in the local diet.

We observed a local woman returning from the forest with two frogs and some spiders as additional food for her family. While collecting moths at light traps for scientific purposes, we noticed that many of the large-bodied species were consumed, in our absence, by local people. Many kinds of caterpillars and adults are eaten, especially of the larger moths – all Sphingidae and Saturniidae, many Geometridae and Noctuidae and a single Uraniidae (*Nyctalemon patroclus goldiei*).

The relationship between the behaviour of the people at Bime and Borme (two different tribes) is probably not only due to the same habitat and circumstances (villages at close proximity in the eastern part of the central mountain range), but also attributable to the large migration of Bime people to Borme in 1977 after a strong earthquake affected Bime villages and gardens.

Some tribes in the Merauke District of Papua consume many kinds of caterpillars of moths, many beetles and other insects; specific data must be collected from field surveys.

Some interesting information about insect eating in Papua New Guinea has come to light and it seems safe to assume that the same customs would be found among indigenous people in Papua, as the localities in Papua New Guinea are close to the border with Papua.

The Maring people who inhabit the northern slopes of the central range in the Western Highlands of Papua New Guinea are reported to use at least seven unidentified species of insects for food, one species for medicinal purposes and one for decorative purposes (Rappaport 1967).

The large longicorn beetle *Batocera wallacei* is often consumed by schoolchildren who roast the whole insect on fire embers, before removing the legs and wing casings and consuming the fat-filled abdomen. The Simbai people living just north and at slightly lower elevations than the Maring, decorate ceremonial headdresses with the reflective green elytra of Cetonid beetles. Several hundred insects are required to make one headdress (C. Davenport, personal observation).

Parsons (1999) reports that the gregarious larvae of *Papilio lagleizei* are a popular human food item in various parts of Papua New Guinea and are found in village markets at Garaina Central Province, Karimui in Simbu Province and Koinambe in the Western Highlands.

Trade and farming

People collect insects for a number of reasons:

- As an important seasonal food source, particularly in areas where game and/or agricultural resources are limited;
- Incidental, opportunistic collecting of a minor food source during other activities such as gardening or hunting of mammals and birds;
- As recreation by children, who play with and consume many kinds of beetles;
- For ceremonial purposes such as making headdresses and other body decorations; and
- For medicinal purposes.

Most insects collected by indigenous people are solely for their own consumption and are not found in local markets in the mountainous interior of Papua. In some lowland markets the larvae of the sago beetle (*Rhynchophorus bilineatus*) are offered for sale; at the Sentani Market (Plates 2-3), near Jayapura, the price of a bag of 100 to 120 larvae is IDR20 000 (US$1.00 = IDR9 455 [October 2009]), equivalent to the price of 3 kilograms of rice or 20 eggs.

In the last decade, the area of sago forest has been reduced considerably through felling and the establishment of oil-palm plantations, which will inevitably impact on the trade and consumption of sago beetle larvae. In spite of the importance and popularity of this food source, there has been no research or field work to develop husbandry of these insects.

Plate 2. Sago larvae for sale at Sentani Market, near Jayapura *(Courtesy E. Ramandey)*

Local differences and preferences

Caution must be exercised in generalizing information relating to any one ethnic group to the entire island of New Guinea. For instance, earthworm collection and human consumption is reported by P. Agnoletto (personal communication) from the nomadic Bisoro people in the upper reaches of the Salumei River, a Sepik tributary, in Papua New Guinea, but has not yet been documented in the western half of the island (Tommaseo-Ponzetta and Paoletti 2005).

In the western part of the island, reports about the exploitation of food insects by a few widely dispersed ethnic groups should not be generalized because they are dependent on various localized factors such as elevation, forest cover, customs and traditions, concentration of insect species and seasonal patterns of availability and alternatives, as well as individual taste.

In the lowlands only a few insects are known to be consumed regularly. This may be due to the strong influence of customs such as dietary taboos rather than the absence of edible species of insects.

In some mountainous areas, cicadas are the most favoured insects; in other areas grasshoppers, leaf and stick insects are preferred. This preference appears to be influenced by availability. In localities where grasshoppers, leaf and stick insects are popular for consumption (Baliem Valley and Borme), cicadas are less abundant; the reverse is true in the Mapia area and the high Star Mountains (1 400-2 500 metres).

Language is an important parameter of the relationship between local people and insects. This knowledge is often conveyed by traditional stories and by the number of local words for certain families or genera of insects. Detailed knowledge (often correct, but sometimes wrong) includes awareness of factors such as life cycles, habitat preference, edibility, toxicity and beauty.

Regrettably, this indigenous knowledge of nature is being lost as younger generations, exposed to many new influences, do not have such an interest in their environment as their parents and grandparents, with the consequence that the number of names in local languages for particular animals is decreasing quickly.

Future expectations

Urbanization will proceed in lowland areas; more people will become employees and the income of local people will increase, with the consequence that gardening and farming will receive less attention. Land (including sago forests) will be sold and converted to oil-palm projects or cleared and used for other commercial and social purposes. It may be assumed that the utilization of wild sago palms and the associated collection of *Rhynchophorus bilineatus* larvae will become much less common, although the larvae are considered to be a real delicacy by the local people.

In the mountainous areas the importance of insects as necessary food will also decrease. However, incidental, recreational and seasonal collecting are so strongly ingrained in the daily life of indigenous people that this will continue for the foreseeable future.

No surveys of the behaviour of migrants from other islands of Indonesia (about half of the population in Papua) have been carried out. Many of them come from cultures with traditions of collecting and eating insects (such as Homoptera, Orthoptera and Ephemenoptera). However, it seems that these traditions are rarely continued in their new environment.

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Appendix 1. Edible insects in Papua, with locations

Blattodea: Bime	1 species
Phasmida (stick and leaf insects)	
4 Families: Borme/Bime	5-8 species
Orthoptera (grasshoppers)	
Tettigoniidae: Borme/Bime	>5 species
Gryllidae: Bime	>3 species
Mantodea	
Mantidae: Borme	3-5 species
Hemiptera	
Pentatomidae: Pass Valley *Nezara viridula*	1-2 species
Homoptera	
Cosmopsaltria sp. (Cicada) Mapia (Kobowre Mountains), Baliem Valley, Star Mountains	>7 species
Coleoptera	
Scarabaeidae and Cetoniidae	>10 species
Curculionidae *Rhynchophorus* sp. – larvae	2(?) species
Cerambicidae: Bime	>5 species
Sentani *Rosenbergia mandibularis*	1 species
Passalidae: Bime	>1 species
Ephemenoptera (one-day flies): Mindiptana, Tanahmerah, Iwur	1 species
Lepidoptera	
All large moths of five Families: Borme	
Sphingidae – all large-sized species + caterpillars	>25 species
Saturniidae – all species + caterpillars (3 genera)	± 10 species
Noctuidae – all large imagines	>10 species
Uraniidae – *Nyctalemon patroclus goldiei*	1 species
Geometridae – Ennominae	>5 species
Hymenoptera – nest with bees: Sumbole, Landikma	1-2 species
Total	**> 95 species**

The future use of insects as human food

Jun Mitsuhashi[1]

Shortages of food, especially animal protein, are predicted for the twenty-first century so it will be necessary to look for new sources of animal protein. In this context, insects are suitable, although most people in developed countries dislike or hesitate to consume them – probably because they are repulsed by the appearance of insects, not their taste. Insects can be accepted favourably in the future by processing and mixing them with other foodstuffs. Edible insects may be used as space-travel food in the distant future. For long voyages to other planets, their cell culture will provide animal protein in a spacecraft, within which the area for the production of foodstuffs will be limited. If humans ever live in huge airtight domes on other planets, food production will have to be developed within the confines of the domes. Breeding of large livestock will not be practicable because of space limitations. The alternative will be to use insects to provide a source of animal protein. For such purposes, species such as silkworms, termites and flies have been suggested, taking into account the effective recycling of organic substances.

Keywords: animal protein, cell culture, flies, silkworms, space food, termites

Introduction

Increases in world population will require the production of vast amount of foods in the latter half of the twenty-first century. However it will be difficult to increase productivity to a level that satisfies food demand, mainly because of limited availability of new farm land. This will lead to shortages of food, especially animal protein. When total food resources are insufficient, it is unwise to feed livestock with grain and other foodstuffs, which can be consumed directly by humans. Therefore, it becomes necessary to look for new sources of animal protein such as insects, which are rich in nutrients. Most insects are edible, although there are some toxic species, and they can thrive on a diet that humans cannot consume. Some insects are even scavengers, such as saprophagers or coprophagers. The latter can contribute to recycling of animal waste.

Insect eating: the cultural context

Many people dislike or hesitate to consume insects; they indicate that insects are dirty, harmful or inspire fear. However, this is not true for most insects, especially edible insects. Some of the major edible insects, such as grasshoppers, and lepidopteran or coleopteran larvae, mostly eat fresh plant leaves or wood and are therefore cleaner and more hygienic than crabs or lobsters, which eat carrion. Although, insect-eating campaigns are becoming active in some developed countries (Table 1), many people still despise insects. This abhorrence is not

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inherent however. It is formed during infancy by the people surrounding the child. This is evidenced by some infants at insect-eating events who clearly enjoy insects. Therefore, insect hatred should be viewed as a prejudice that can potentially be eliminated. It is probable that people are repulsed by the image of insects, but not by their meat.

People who dislike insects have consumed insects or parts of insects before, which contaminated food during food production or processing. It is almost impossible to avoid contamination by insects or their parts in food. In fact, the Food and Drug Administration of the United States has prescribed permissible levels of insect contamination in food (FDA 1998). Therefore, people are regularly eating insects unconsciously, without serious complications. This shows that people can eat insects if they do not know what they are eating, with the exception of individuals who have allergic reactions.

These factors suggest that transforming insects will facilitate their consumption in the future. In practice, dried insects may be crushed or pulverized, and raw or boiled insects ground or mashed, making their insect form unrecognizable. They simply become masses of protein and lipids that can be mixed with other foodstuffs such as grain, ground meat and mashed potatoes to make a variety of dishes (Table 2). Such dishes will be acceptable to most people. Some recipes of such dishes have been published (Ramos-Elorduy, 1998; Tayler and Carter, 1992).

Table 1. Organizations that host insect-eating events

Country	Organization
Australia	New South Wales Entomological Society.
Canada	Alberta State Museum; Ontario Joint Entomological Meeting; L'Insectarium de Montreal.
Japan	Tokyo Tama Zoo, Insectarium, Tokyo.
Republic of South Africa	South African Entomological Society.
United States	Audubon Zoo Insectarium, LA; Buffalo Museum of Natural History, NY; Cincinnati Zoo, OH; Crowley's Ridge State Park, AK; Garfield Park Nature Center, OH; Invertebrate in Captivity Conference, AZ; Iowa State Univ., Department of Entomology, IA; Los Angeles Museum of Natural History, CA; New York Entomology Soc., NY; Northwest College, WY; Oregonridge Nature Center, OR; Pennsylvania State Univ., Department of Entomology, PA; Purdue Univ., Department of Entomology, IN; San Francisco Zoo, CA; Smithsonian Institution, Museum of Natural History, DC; State Botanical Garden, GA; Univ. Illinois, Department of Entomology, IL.

Table 2. Examples of foodstuffs and cuisine

Insect	Treated form	Other ingredients to be added	Form to be eaten
Mealworms	Dry flour	Maize flour	Tortilla
Crickets	Dry flour	Wheat flour, buttermilk, baking powder	Bread
Grasshoppers	Ground	Miso, sugar, minced walnut	Paste
Wasp larvae	Minced	Wheat flour, soybean flour, mashed potato, vegetables	Wasp ball
Any insect	Ground	Minced meat, wheat flour, onion, mashed potato, egg	Insect burger

If and when insects are used as a major food resource, large quantities will be required. Naturally occurring insects may not meet demand; if too many wild insects are collected, ecosystems will be damaged. Insects used as foodstuffs should be raised. Clean and uniform insects will be produced through artificial rearing. This will contribute to sustaining ecosystems and avoiding overexploitation of wild insects. Several industrial plants are producing insects on a large scale, such as for projects to eradicate screwworms and fruit flies. The facility for the mass production of melon fly, *Bactrocera cucurbitae* in Okinawa, Japan is shown in Plate 1. In this plant, 40 million matured larvae are produced every week. Most of the procedures for raising larvae are controlled automatically. This system could be a model for the mass production of edible insects in the future.

Plate 1. A plant producing sterile melon flies for their eradication: (1) larvae, (2) adults, (3) main building, (4) part of the automated rearing system, (5) feeding trays for larvae *(Courtesy Jun Mitsuhashi)*

Insects as space-travel nourishment

In the more distant future, the use of insects as space-travel food is suggested. This application may be considered in two contexts: (1) consumption of insects by humans during long duration space travel; and (2) consumption by people colonizing other planets.

In the first case, during long space voyages, there may be a need to produce food within the spacecraft where space is limited and large animals cannot be kept. Small animals like insects will be a suitable animal protein source. The species used should satisfy the following criteria: (1) it can be reared in a small space; (2) it has a high reproduction rate; (3) it is easy to reproduce; and (4) it is easy to handle. Thus, *in vitro* cultured insect cells, instead of entire insects, could provide animal protein efficiently in a spacecraft. The cells, which constitute insect bodies, could be cultured in an artificial culture medium *in vitro* (i.e. cell culture). Initially, insects would be surface-sterilized and the tissue to be cultured excised from the insect bodies aseptically. The tissue would be cut into small pieces and placed in culture flasks with a liquid medium. The medium would consist of minerals, amino acids, sugars, vitamins and growth-promoting substances (Table 3). In the flasks, cells contained in the explanted tissue would emerge from the tissue and scatter around it. Such liberated cells would multiply by mitosis, if the culture condition is suitable. When cell density in the flask increases to a particular level the multiplication rate can be expected to decrease. Some of these cells would then be transferred to another flask to decrease cell density. This removal of cells would stimulate cell multiplication again. By repeating these procedures, the cell population, which multiplies continuously, will be obtained. Such a cell population is called a continuous cell line (Plate 2).

These techniques have been developed already and many insect continuous cell lines have been created (Mitsuhashi 2002). However, there are some insect groups whose cells cannot be cultured with present techniques. This problem should be solved in the near future.

In order to culture cells in a liquid medium under zero gravity in a spacecraft, culture vessels may be fixed on a rotation drum, which creates gravity by centrifugal force. Or, when people travel to other planets, an artificial gravity vehicle may be used. The cell culture procedures can be controlled automatically by computer (Plate 3). The system does not occupy a large space – a major consideration for spacecraft. By using several hundred-litre jars or thousand-litre tanks, large volumes of cells could be grown and harvested. When the cell density reaches saturated state, the cells could be collected by centrifugation of the culture and used as a protein source.

The advantages of using insect cultures compared to cell cultures of livestock such as cattle or swine are that insect cell culture does not require special equipment for controlling carbon dioxide gas concentration in the culture vessel, and also does not require strict control of temperature. Therefore, use of (insect) continuous cell lines is easier and more efficient.

Table 3. A simple culture medium (MM-SF)

Material	g/1 000 ml	Material	g/1 000 ml
NaCl	7	$NAHCO_3$	0.12
KCl	0.2	$CaCl_22H_2O$	0.2
$MgCl_26H_2O$	0.1	NaH_2PO_4	0.2
Glucose	4	TC-yeastolate	5
Lactalbumin hydrolysate	6.5		
pH: 6.5			

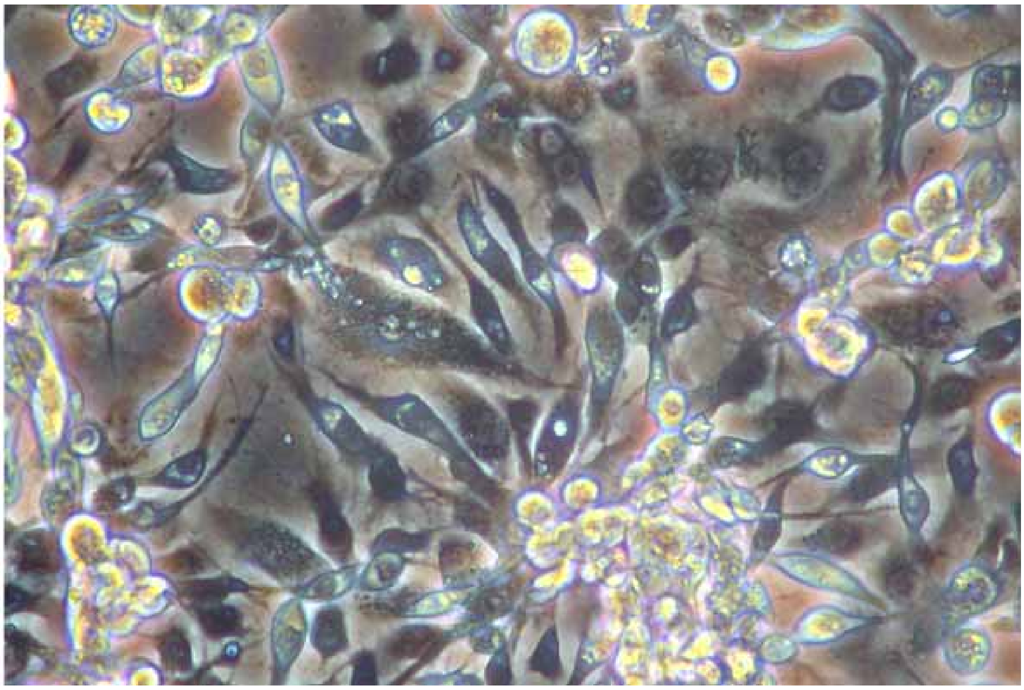

Plate 2. A continuous cell line obtained from the diamondback moth, *Plutella xylostella (Courtesy Jun Mitsuhashi)*

Plate 3. A model of a programmed cell culture system with glass jars *(Courtesy Jun Mitsuhashi)*

The second scenario for insects as space-travel nourishment relates to human colonization of other planets, likely living in air-tight domes. Within the domes, subsistence agriculture will have to be developed to supply food. One of the challenges is providing animal protein. Breeding of large livestock will not be practicable because of space limitation. The alternative is to use insects to provide a source of animal protein (Katayama *et al.* 2008; 2005). Silkworms, termites and flies offer potential for this purpose. The commercial silkworm (*Bombyx mori*) is a well-studied insect and people of many countries have eaten silkworm larvae, pupae and adults for centuries. Dried silkworm pupae contain roughly 50 percent protein and 30 percent lipids and are known to be rich in nutrients. It is commonly said that three silkworm pupae are equivalent to one hen's egg. The silkworm has been completely domesticated and is easy to rear (sericulture). Silkworms eat mulberry leaves, but an artificial diet has also been developed. Furthermore, an automatic rearing system has been devised.

Termites are eaten widely in tropical Asia, Africa and South America. There are many species of termites and they contain high levels of protein and lipids, although contents vary in different species. Termites consume wood and produce protein. Therefore, they can be used not only for human food, but also for breaking down woody waste.

Fly larvae have not been consumed commonly by humans to date, although some people eat fly larvae in Thailand (Kuwabara 1997), China (Chen and Feng 1999; Hoffman 1947) and even in Europe (Ramos-Elroduy 1998). The larvae or pupae of the house fly (*Musca domestica*) are nutrient rich. They contain 50-60 percent protein and 10-20 percent lipids on a dry matter basis. When fly larvae or pupae are used as food, vast numbers of flies are needed because of their small size. The reproduction rate of flies is very high; the house fly, for example, lays 500 eggs. If there are no predators, parasites or disease agents $2x250^{25}$ larvae are produced after a year (26 generations). If one larva weighs 25 milligrams, over a year this amounts to a theoretical gross amount of $5x10^{46}$ million tonnes of larvae. In order to rear vast numbers of flies, industrial plants similar to those used for mass production of screwworms or melon flies (Plate 1) will be necessary. Species belonging to Muscidae, Calliphoridae or Sarcophagidae are preferable, because of their size and feeding habits. The larvae of some species belonging to these families thrive on organic waste, especially on dead animal flesh and excreta. If these waste materials are used as part of the fly diet, they will contribute to recycling of organic substances. This would be particularly important within domes on another planet.

Conclusion

The examples of past and present utilization of insects as human food set the stage for the next and perhaps the most important application in light of food demand generated by increases in world population. Space travel and the colonization of other planets present a huge challenge in terms of the provision of foodstuffs. Food derived from insect rearing and insect cell culture represents the most feasible solution to feeding humans traveling in spacecraft or living in domed structures on other planets.

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Cultural and commercial roles of edible wasps in Japan

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*Insects such as long-horned beetle caterpillars and wasps are consumed in the mountainous areas of Japan. Although insect eating has generally declined in Japan, the collection and eating of wasps (*Vespula *spp. and* Vespa *spp.) can still be found. In particular, yellow-jacket wasp larvae and pupae (*Vespula *spp.) are preferred in the mountainous areas of central Japan, where they are treasured as an autumn delicacy. The larvae and pupae are also available commercially at high prices. Insect materials used in canned foods are imported from other countries to satisfy demand. Communal management has begun to maintain the populations and habitat of* Vespula *spp. as a food resource.* Vespa *spp. are also collected for subsistence use and for commercial sale by local people who must use special protective gear for collection. Culturally and commercially, wasps are regarded as an important food resource for the sustainable development of rural mountain villages.*

Keywords: insect eating, traditional food, *Vespa*, *Vespula*

Introduction

Edible insects are important cultural resources in Japan that reflect the country's rich biodiversity. However, increases in demand could lead to competition and overexploitation, resulting in their future decline. Insect habitats are also likely to be impacted in areas affected by overdevelopment. It is necessary to raise awareness on the importance of edible insects in order to ensure that they are exploited sustainably and to promote their proper use and conservation.

There were once many edible insects in Japan, although consumption of most has declined. Among those still utilized as food, wasps are a popular food in mountainous regions. They are highly valued, not only for personal consumption, but also for commercial purposes. In some areas, resource management has been carried out to preserve their habitats as well as to maintain population numbers (Nonaka 2007; 2005).

This study focuses on traditional wasp-eating practices in Japan. The data are based on the author's 20 years of fieldwork in Japan that focused on insect consumption, collection methods and regional variations.

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The custom of eating insects in Japan

In a report submitted in 1919, 55 edible insect species were listed in Japan (Miyake 1919). After the Second World War, this number decreased owing to environmental and social changes (Nonaka 1987). However, some insects such as grasshoppers and wasps are still popular as food, although there are regional differences in their consumption; regions where this food custom remains common are declining. Grasshoppers are collected in Japan's many paddy fields, which are very common because rice is a staple component of the Japanese diet and the country's most important agricultural product. More than 70 percent of Japan's land area is classified as mountainous and insects are consumed primarily in the uplands. Long-horned beetle caterpillars were popular among people living in mountainous areas 50 years ago when fuelwood was used for cooking and heating. Many senior citizens recall that they were very sweet and tasty. Nowadays, there are fewer opportunities to catch caterpillars as a result of decreased use of fuelwood.

Wasps are one category of insects that continue to be commonly collected and eaten. In Japan, two species of *Vespula* and three species of *Vespa* are eaten. Some people wonder why people in Japan enjoy collecting and eating wasps, as they are so dangerous. It is hard to imagine how the wasps are collected. When an Australian entomologist observed the practice in an area where the activity is still common, he was incredulous when he saw people collecting the nest and removing the wasps. He was astonished as he watched the way in which collectors handled the wasps and cooked them.

Collection methods

Species of *Vespula* are commonly found in fields and mountainous regions. They appear during summer and autumn and build their nests underground. The nests are not easy to locate.

In order to find the nests, unique and skillful methods have been established in regions where *Vespula* are popular, particularly in central Japan. The worker wasps are attracted with bait (Plate 1). They carry the balls of meat, with tiny ribbons attached, back to the nest. The ribbons make it easier to follow the wasps and locate the nest. The chase begins as the team follows the tagged wasps. Members of the team display great skill and close teamwork as they climb up trees and run up and down hills trying to determine the wasps' route. When the entrance to the nest is discovered, smoke is used to sedate the wasps inside. The nest is dug out while the wasps are sedated. By digging the whole nest out, one can determine its weight.

Plate 1. *Vespula flaviceps* starting to carry a meat ball with tiny ribbons attached back to the nest *(Courtesy Kenichi Nonaka)*

A similar method is used for giant hornets (*Vespa mandarinia*), which are the largest wasps in Japan. A meatball with a tiny ribbon attached is not required in this case, because the worker wasps are much larger and can be tracked more easily. Protective suits, which have to be specially ordered, are essential when collecting the hornet nest during the day time, because these insects are very dangerous (Plate 2). Some people tie a tiny white ribbon around the waist of the worker wasp while it is eating the bait. Others, wary of attacks, prefer to collect wasps at night when the workers are sleeping.

Plate 2. Collectors wearing protective suits against *Vespa mandarinia* approaching the nest *(Courtesy Kenichi Nonaka)*

Cooking

The harvested nests are brought home and prepared for cooking by members of the family. The larvae and pupae are removed one by one. This process is time-consuming, but the time is used to share the experience, recalling how the wasps were collected, and imagining how the wasps must have lived. They are usually boiled with soy sauce or fried with salt. The whole family gathers to remove the live larvae from the combs, taking great care not to crush them in the process. It takes considerable time and effort to do this, but it provides an opportunity for the family to interact with each other. The larvae are boiled to a hard consistency with soy sauce, sugar and sake. The cooked wasp larvae are then mixed with rice (Plate 3).

Plate 3. Mixed rice with *Vespula flaviceps* (Courtesy Kenichi Nonaka)

A variety of dishes are prepared using species of *Vespula.* Wasps simply boiled with soy sauce are good with rice and also make good accompaniments for sake. Mixed rice is a popular dish. *Gohei-mochi*, or skewered rice cake, is made by mashing up rice and reforming it into a flat oval shape, which is then grilled with a sauce. *Hebo-gohei-mochi* is another kind of *gohei-mochi*, which is prepared using a sauce made from mashed *Vespula*. Various kinds of sushi are also made using *Vespula*. Recipes for wasp larvae dishes vary greatly from household to household, bringing a varied autumn feast to the dinner table.

Hornets are much larger than *Vespula* and their meat is cooked in different ways. The intestines are removed before they are cooked. *Vespa* can be used in sukiyaki and tempura, popular Japanese dishes. A type of liquor made with hornets is reported to have health properties.