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A Comprehensive Look at the Possibilities of Edible Insects as Food in Europe – a Review

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Possibilities of edible insects use in European countries, are now an increasingly debated issue. Insects in Asian, African, Central American and South Central American cultures are mainly nutritional components. This review mainly describes the species of insects that are suitable as food in Europe and other developed countries. This comprehensive work addresses the issue of eating insects, especially considering the nutritionally important factors. Risks are also mentioned, as well as allergies, toxicity, and other aspects of the breeding and use of edible insects. Insects play and will play important roles in the future in various fields of research, exploitation, breeding, *etc*. This review provides a comprehensive current and future view of insects as a valuable foodstuff.

INTRODUCTION

Insects are gaining more and more attention worldwide due to many ways of their exploitation [*e.g.* Cerritos, 2011; Chae *et al*., 2012; Fontaneto *et al*., 2011; Mariod, 2011; Premalatha *et al*., 2011; FAO, 2012]. Many articles deal with insects in relation to developing countries, harvesting insects in nature and solving the problem of famine [*e.g.* De Foliart, 1992; Ramos-Elorduy *et al*., 2011], as in some cultures, insects present an important seasonal source of proteins and are a common part of the menu of a substantial part of human population, especially of Asian, African, Central American and South American cultures. In these areas, insects consumption is associated, by no means always, with a poor-man's subsistence [Katayama *et al*., 2008a]. However, insects are not only an emergency resource but are appreciated as palatable and tasty [Bukkens, 2005; Nonaka, 2009], and their popularity is also increasing in Westernized countries as a new, interesting food item [Comby, 1990; Menzel & D'Aluisio, 1998; Paoletti, 2005; Bednářová *et al*., 2013].

Despite the fact that social, economic and nutritional values of edible insects are often marginalized, more than 1500 species of edible insects in 300 ethnic groups in 113 countries [MacEvilly, 2000] have been recorded by various authors. To some ethnic groups insects provide 5–10% of protein, fat, calories, vitamins and minerals per year [MacEvilly, 2000]. But there is an apparent contradiction between the direct use of insects as food and the need for their conservation. Harvesting insects as food, like any other food hunting and collecting activities, has the potential to become a threat to both the target species and the environment. Ramos-Elorduy [2006] for example reported that the populations of some of the 30 edible insect species in the Mexican town of Tulancalo have declined because of over exploitation and this situation has led to a call for regulation of edible insects' exploitation in Mexico to ensure better management, production and conservation. In Europe, the situation is much more complicated because the long-lasting turn away from entomophagy has caused the loss of know-how of collecting and using freely living insects in kitchen, even with the villagers. Furthermore, potentially edible insects may contain higher than acceptable levels of chemicals due to frequent usage of pesticides, which also applies to some other parts of the world [Banjo *et al*., 2006].

From this point of view it is obvious that especially in Europe it is not possible to collect insects for eating purposes in nature. The aim of this review is to describe the benefits of entomophagy in Europe and state the species usable to such purpose.

Our interest in this work is to characterize edible insects in general, and the species bred in Europe for a long time. Breeding methods of these species are verified, and there is no secondary energy needed for their implementation. We do not mention the possibilities of collecting freely living insects

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TABLE 1. List of insect species commonly bred in Europe [Comby, 1990].

Insect species	Described by
Acheta domesticus	(Linnaeus, 1758)
Apis mellifera	(Linnaeus, 1758)
Bombyx mori	(Linnaeus, 1758)
Galleria mellonella	(Linnaeus, 1758)
Gryllus assimillis	(Fabricius, 1775)
Hermetia illucens	(Linnaeus, 1758)
Locusta migratoria	(Linnaeus, 1758)
Musca domestica	(Linnaeus, 1758)
Schistocerca gregaria	(Forskal, 1775)
Tenebrio molitor	(Linnaeus, 1758)
Zophobas atratus	(Fabricius, 1775)

in order to protect the endangered species, biotopes and biodiversity as a whole. Moreover, we do not mention species with a high nutritional or other potential, which would have to be imported to Europe, which would mean withdrawing the food sources from needy places and unecological transportation. Furthermore, we excluded all species of cockroaches due to disgust reasons, although breeding of many of them is at the highest level in Europe. Candidates meeting the above requirements are listed in Table 1.

HISTORY AND FUTURE OF ENTOMOPHAGY

Insect consumption is deeply rooted in human evolutionary history [Fontaneto *et al*., 2011]. Evidence is offered by stable carbon isotope analysis of dental enamel: grasses and sedges that use the C4 photosynthetic pathway are common in subtropical environments and tend to be enriched in 13C, whereas trees and shrubs are richer in 12C. The 13C/12C ratio in herbivores therefore reflects the plants they eat, and the same ratios in carnivores reflect the diet of their prey. Isotope analysis of the bones and dental enamel of australopithecines, significantly enriched in 13C, indicates a diet largely composed of animals such as insects, accustomed to foraging on Graminaceae [Sponheimer & Lee-Thorp, 1999]. Other proof may be the strontium/calcium (Sr/Ca) ratios in Paranthropus, which suggested that it consumed more animal foods than it was previously believed. Grazing herbivores have the highest Sr/Ca, followed by browsers and carnivores. Thus, Sr/Ca for both hominins is relatively high and provides no direct evidence for omnivory in either taxon. The consumption of underground resources or insects is one of the possible explanations for the highly elevated Sr/Ca in Australopithecus [Sponheimer *et al*., 2005]. To gain insect delicacies, prehistoric people used tools made from bones of larger animals. Plio-Pleistocene bone tools in the Sterkfontein Valley were for example used to dig for termites [Backwell & d'Errico, 2001]. By all accounts, which include archeological evidence as well as analysis of fossilized feces, humankind has evolved as an entomophagous species [Sutton, 1995; Ramos-Elorduy, 2009].

Over the time, however, cultures and religions developed, where eating insects or any form of animal protein is discouraged to prevent animal sacrifice [Meyer-Rochow, 2009] or because of disgust [Borkovcová *et al*., 2009]. The colonization also took its toll, and eroded entomophagy just as it eroded cultural diversity everywhere in various other ways [Yen, 2009]. The impact of globalization and the fascination among a large cross-section of population towards fast-food culture has further weaned away a large number of protein-hungry people of the third world from what until now was a rich and affordable source of animal protein for them – *i.e.* insects [Heinrich & Prieto, 2008].

On the other hand, it is clear from other research that people are increasingly aware of the vast possibilities of using insects as food or feed, but also their potential for a relatively long-term future human settlement in space. Diet problems during the extended residence in space, especially animal protein supply, are the key issues in CELSS (Controlled Ecological Life Support System). Silkworm, for example, contains quality protein and essential nutrients, and is rightly regarded an important component of the diet in different parts of the world. It also has a suitable ratio of amino acids and unsaturated fatty acids to meet the demands of human nutrition. Silkworm requires a shorter period of growth and less space than other animal species. Therefore, silkworm is a good space animal candidate. Space biology techniques can facilitate the space silkworm culture [Katayama *et al*., 2008 a,b]. Apart from *B. mori,* grasshoppers are considered to become the part of the menu for space utilization, as their nutritional value including minor components is known [Katayama *et al*., 2005].

INSECT PROCESSING PRIOR TO EATING, THE WAYS IN WHICH INSECTS ARE EATEN

Previously, insects were eaten alive [Ramos-Elorduy, 1996; Van Huis, 2003]. Later they were served in some cultures also cooked, roasted or boiled (either insects *per se* or insect additives to food) or using other culinary techniques [Yen, 2010]. As the time went by, in some parts of the world insects were given the position of sophisticated gourmet dishes, offered in experimental restaurants, having totally changed the look and presenting them as much more attractive and savory [Nonaka, 2009]. However, opinions differ on how the food from insect should look like. Eating insects whole or their body parts can be difficult for those brought up in Western societies. Some insect eaters on the contrary require visible insects in food, preferably whole bodies, which is an example of a unique Asian culture, whose people eat them for their delightful taste and also enjoy the process of collecting them [Nonaka, 2009]. On the other hand, people – especially in areas where insects were not consumed for a long time – prefer incorporating insects into the food in a way they are not visible – so they accept only the idea that the insects have a nutritional value. This shows that people especially in North America and Europe 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 insect transformation will facilitate its 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. Such dishes will be acceptable to most people [Mitsuhashi, 2010]. Some recipes of such dishes – from pulverized insects have been published [Taylor & Carter, 1995; Borkovcová *et al*., 2009], and the example of the tortilla obtained from the addition of *T. molitor* larvae powder to maize flour shows a new way of entomophagy. Although a little darker than the control, this supplemented tortilla had a good acceptance, a 2% increase in total protein and a 1% increase in the fat content. Furthermore, a considerable increase in essential amino acids was detected, it had a very good taste, color, and texture acceptability [Aguilar-Miranda *et al*., 2002]. If we want to put insects on the menu for nutritional reasons, then perhaps we should consider the addition of ground-up insects in prepared foods (such as flour or pastes) [Bednářová *et al*., 2013]. This raises the question of whether we will simply breed known species such as silkworms (*B. mori*), house flies (*M. domestica*) and mealworms (*T. molitor*). The answer is that we probably need to find out what other insects can provide that these species do not [Yen, 2010].

WHY USE INSECTS AS FOOD FOR HUMANS

Unconscious consumption

People around the world eat insects unknowingly, as it is almost impossible to avoid contamination by insects or their parts in food [Mitsuhashi, 2010] and many states had worked out lists with prescribed permissible levels of insect contamination in food (*e.g.* FDA, 2012]. Therefore, it is obvious that also the people who dislike insects have consumed insects or parts of them before, which contaminated food during food production or processing.

Traditions

For many nations and ethnic groups, especially in Asia, Africa, South America and Australia insects are an indispensable and really traditional food [*e.g.* De Foliart, 1992; Mitsuhashi, 1997; Ramos-Elorduy *et al*., 1997; Van Huis, 2003; Nonaka, 2009]. However, the availability of freely living edible insects is unpredictable, both in time and in location [Banjo *et al*., 2006]. Therefore, such ethnic groups must leverage current food supplies, as they lack the more sophisticated methods of preservation than drying in the sun or smoking over a fire. This readily available source of food is also used because of the sheer necessity [Marconi *et al*., 2002].

Famine

Human population is growing exponentially and according to the opinion of specialists, we are very close to the global food crisis and famine [De Foliart, 1992; Van Huis, 2003]. As people in rural areas suffer from under nutrition, especially protein-energy malnutrition (PEM), alternative-nutritional food source is needed – among other sources also insects with a high-fat content [Raksakantong *et al*., 2010]. Current field crop management practices and the potential of animals, used as a source of animal protein, are reaching their limits. The world is calling for a review of food and its resources obtaining methods [Borkovcová *et al*., 2009].

Good taste

The taste of insects depends on many factors – primarily the species of insects, stage of live-cycle and food received [Ramos-Elorduy, 1996; Borkovcová *et al*., 2009]. Given the large number of known species of edible insects and experience of native inhabitants, there is no problem all over the world to choose those, which conform to the current taste of eater. The dishes with a harmonious taste may represent true gourmet delicacies [Comby, 1990].

Nutritional aspects

Large numbers of known edible insect species at the same time also offer a choice of species regarding the nutritional requirements of consumers not only to replenish essential nutrients, but also microelements. For Australian Aborigines insects provide sugar (honey ants, sugar bags, and lerps) and fat (grubs, Bogong moths) [Yen, 2009]. Ants containing much iron can substitute chemical sources of this element [Ramos-Elorduy *et al*., 1997]. Insects can be an alternative for vegetarians, because to some of them insects, unlike livestock meat, can be acceptable and addition of animal foods greatly increases the amino acid score of food [Katayama *et al*., 2005].

NUTRITIONAL VALUE – THE CHEMICAL COMPOSITION OF EDIBLE INSECTS

The insects could be considered a good nutritional food source especially of fat and protein [Raksakantong *et al*., 2010; Bednářová *et al*., 2013, 2014], they have been found to be a rich source of vitamins and minerals, especially iron and zinc [Akinnawo & Ketiku, 2000]. However, the chemical composition of insects depends on many factors and may differ significantly even in the same developmental stage of one species [*e.g.* De Foliart, 1992; Bukkens, 1997, 2005; Ramos--Elorduy *et al*., 1997; Barker *et al*., 1998; Mziray *et al*., 2000; Finke, 2004; Wang *et al*., 2004; Babiker *et al*., 2007; Falade & Omojola, 2010; Kinyuru *et al*., 2010; Oonincx & Dierenfeld, 2011]. For example, the studies of wild insects show both seasonal variation as well as variations between different populations of the same species living in the same general area [Finke, 2004]. Nutrient content may also differ in commercially farmed species of insects. Moreover, the content of substances varies in adults and their larvae. Adults of *T. molitor* and *Z. atratus* contained more protein than the literature values reported for their larval counterparts, and one-half to one-third of the fat content of their larval stages. Macro mineral concentrations in beetles were similar to, or slightly lower than, published values for larval stages of these beetles, whereas trace mineral concentrations in the beetles studied were consistently higher than previously reported for both larval and adult stages [Oonincx & Dierenfeld, 2012]. Insect processing methods affected their nutrient potential, as evidenced by the changes in the protein digestibility and the vitamin content. Depending on the processing conditions, heat processing may reduce (when proteins are exposed to some heat treatments due to the formation of disulphide bonds in the protein [Stanley, 1989]) or increase (by unfolding the polypeptide chain and rendering the protein more susceptible to digestive enzymes [Opstvedt *et al*., 2003]) protein digestibility [Kinyuru *et al*., 2010]. Solar drying at 30°C of the toasted sample led to a much higher loss (64%) in the riboflavin content as compared to the fresh dried sample (46%). This trend was also observed for all other vitamins on the test samples under similar processing conditions. The rate of the vitamin destruction is accelerated by an increase in temperature and duration of heating. Therefore, optimal processing methods need to be investigated even as we promote the commercialization of these insects [Kinyuru *et al*., 2010].

Proteins

Insects are potentially an important energy efficient source of protein for humans, either through a direct consumption or as food supplements for stock (poultry, pigs and aquaculture) [De Foliart, 1989] and many nations have already been using it. For example, local communities in the Amazon region attain 8 to 70% of their dietary protein from insects and several other invertebrates such as spiders and earthworms [Paoletti & Dufour, 2005]. However, there are large differences in protein sources. Developed nations have a higher protein consumption *per capita* than developing nations – about 96 g/person/day, but a much greater proportion – 65% of it is derived from meat. On the contrary, the protein consumption in developing countries is much lesser – about 56 g/person/day and a still lesser portion – only 25% of it is animal protein [Yen, 2010]. The high protein content is an indication that the insects can be of value in man and animal ration and can eventually replace higher animal protein usually absent in the diet of rural dwellers in developing countries [Banjo *et al*., 2006]. The protein content varies by species of insects, but generally is of a good quality and high digestibility [Ramos-Elorduy *et al*., 1997]. Analyses showed that in egg, larva, pupa and adult stages, the raw protein content is generally 15–81%/dry basis. The protein content of some insects is also higher than that of chicken eggs, meat and fowl [Comby, 1990; De Foliart, 1992; Mitsuhashi, 1984; Hu, 1996; Ramos-Elorduy *et al*., 1997; Yang, 1998; Chen & Feng, 1999]. The content of essential amino acids is 10–30% of all amino acids (35–50%) [Chen *et al*., 2009]. The protein digestibility of insect protein reported values of 77–98% [Ramos-Elorduy *et al.*, 1997], especially after removing the exoskeleton [De Foliart, 1992]. This is only slightly lower than the values reported in other animal protein sources (egg 95%, beef 98% and casein 99%). Whole dried bees had the digestibility of 94.3% [Ozimek *et al.*, 1985] and the moth *Clanis bilineata* 95.8% compared to casein [Xia *et al.*, 2012]. Protein digestibility of fresh termites *Macrotermes subhylanus* was 90.49%, of the green form of grasshoppers *Ruspolia differens* 82.34% and of the brown form of grasshoppers *Ruspolia differens* 85.67% [Kinyuru *et al.*, 2010]. The digestibility of insect protein is higher than that of many vegetable-based proteins [Finke, 2004]. When calculating the protein content usable for insectivora it is necessary to take into account that estimates of the protein content (calculated as nitrogen x 6.25) may be misleading. Some of the nitrogen is contained within the N-acetylglucosamine subunit of the chitin polymer and may be unavailable to insectivores. This protein value may be corrected by subtracting the ADF-N /or nonprotein nitrogen from the total nitrogen before multiplying by 6.25 [Finke *et al*., 1989]. The amino acid composition of insects ranges from approximately 40 to 95% of all nitrogenous substances [Finke, 2004].

Fats

Mostly, the fat content of edible insects is between 10–50%. Reports and analyzed results [De Foliart, 1991; Lu *et al*., 1992; Chen & Feng, 1999; Feng *et al*., 1999; 2000a,b; 2001a,b,c; He *et al*., 1999] have shown that many edible insects are rich in fat; witjuti grubs have nearly 40% of fat (a composition similar to olive oil) [Naughton *et al*., 1986]. The fat content of insects depends on many factors such as species [Raksakantong *et al*., 2010], reproductive stages, season, age (life stage), or sex [Pennino *et al*., 1991], habitat and diet [Raksakantong *et al*., 2010]. For example, the fat content is higher in the larva and pupa stages; at the adult stage, the fat content is relatively lower [Chen *et al*., 2009]. Female insects contain more fat than male insects [Finke, 2004]. The content of essential fatty acids is higher as compared with animal fats [Chen *et al*., 2009]. Similarly, the fatty acid composition of related species is different, as there are many factors playing a role, too. Largely it is influenced by the host plant on which they feed [Schaefer, 1968; Bukkens, 1997]. For insects that feed on a single food plant, the values are probably typical for all members of the species, in contrast, the fatty acid content of generalist feeders such as the house cricket, *A. domesticus*, is likely to vary widely depending on the diet being fed [Finke, 2004]. Lipids are vital in the structural and biological functioning of the cells and help in the transport of nutritionally essential fat-soluble vitamins [Omotoso, 2006]. Especially those of the omega-3 long chain polyunsaturated fatty acids (LC-PUFA) have played an important role in human evolution, providing essential elements to build cerebral tissues [Crawford *et al*., 2000; Carlson & Kingston, 2007]. Edible insects contain a good quality fatty acid especially long chain omega-3 fatty acids such as alpha-linoleic acid, eicosapentaenoic acid [Yang *et al*., 2006]. The reason for insects containing long-chain PUFAs and different fatty acid compositions is linked with the diet and enzymatic activity in the insects. In the terricolous insects, the PUFAs detected were especially LA and ALA [Yang *et al*., 2006]. However, delta 9 desaturase was also isolated and characterized in the insects–enzyme, which was found in house cricket [Riddervold *et al*., 2002]. Insect fatty acid was Δ 12-desaturase genes, AdD12Des from house cricket (*A. domesticus*) and TcD12Des from the red flour beetle (*Tribolium castaneum*), responsible for the production of linoleic acid from oleic acid [Zhou *et al*., 2008]. One of the most important PUFA is DHA, which has been considered important for brain and eye development and also good cardiovascular health, and populations, which consume 0.5–0.7 g/day DHA have a lower incidence of heart disease [Özogul *et al*., 2007]. A few insect species are likely to be able to modify endogenously produced or dietary PUFAs to form the precursors to PGs (mammal prostaglandins) and related biologically active compounds [Stanley-Samuelson *et al*., 1988].

Carbohydrates

Carbohydrates in insects are formed mainly by chitin. The carbohydrate content of edible insects ranged from 6.71% in sting bug to 15.98% in cicada [Raksakantong *et al*., 2010]. The recent research showed that considerable amounts of polysaccharides might improve immune function of human body [Sun *et al*., 2007]. Chitin is a macromolecular compound that has a high nutritional and health value [Burton & Zaccone, 2007]. As a form of low-calorie food, chitin also has a medicinal value [Chen *et al*., 2009]. In most cases, the hard cover polysaccharide chitin of insects accounts for 5–20% of the dry weight. Chitin exists rarely in a pure form in nature but instead is usually in a complex matrix with other compounds (proteins, lipids and insignificant amounts of minerals). Some authors suggest the fiber in insects represents chitin because chitin (linear polymer of b-(1–4) N-acetyl-D-glucosamine units) is similar structurally to cellulose (linear polymer of b-(1–4)-D-glucopyranose units) and because the ADF (acid detergent fiber) fraction has been shown to contain nitrogen [Barker *et al*., 1998; Finke, 2002]. Finke [2007] states that the fiber content of insects (measured as ADF) consists not only of chitin but also of significant amounts of amino acids that are likely to represent cuticular proteins. Insects with "harder" cuticles do not seem to contain significantly more chitin than softer bodied insects but rather their ADF fraction seems to contain a much higher proportion of amino acids than softer bodied insects.

Although chitin presents problems of digestibility and assimilability in monogastric animals, it and its derivatives, particularly chitosan, possess properties that are of increasing interest in medicine, industry and agriculture. If the time should come when protein concentrates from insects are acceptable and produced on a large scale, the chitin byproduct could be of a significant value. A significant contribution of chitin can be presented for example by significantly reducing serum cholesterol, acting as a hemostatic agent for tissue repair, enhancing burn and wound healing, acting as an anticoagulant, protecting against certain pathogens in the blood and skin, serving as a nonallergenic drug carrier, providing a high tensile strength biodegradable plastic for numerous consumer goods, enhancing pollutant removal from waste-water effluent, improving washability and antistatic nature of textiles, inhibiting growth of pathogenic soil fungi and nematodes and boosting wheat, barley, oat, and pea yields by as much as 20% [Goodman, 1989; Chen *et al*., 2009].

Mineral elements

Analysis of mineral elements showed that edible insects are rich in nutritious elements such as potassium and sodium (*e.g.* cricket nymph), calcium (*e.g.* cricket adult), copper (*e.g. Usta terpsichore,* mealworm adult), iron (*e.g.* axayacatl – a mixture of several species of aquatic Hemiptera, giant mealworm), zinc (*e.g.* cricket nymph), manganese (*e.g.* cricket adult) and phosphorus *(e.g.* cricket adult) [Oliveira *et al*., 1976; Van Huis, 2003; Finke, 2004; Sun, 2008]. The mineral composition in general probably largely reflects the food sources of insects, both those which are present in the gastrointestinal tract and those which are incorporated into the insect's body as a reset of the food it consumed [Finke, 2004]. For example, the calcium content of wax worms, house crickets, mealworms and silkworms can all be increased 5 to 20-fold when fed a high calcium diet. This increase in calcium appeals to be solely due to the residual food in the gastrointestinal tract with little of the calcium being incorporated into the insect's body [Finke, 2004]. All insects contain high levels of phosphorus, which results in a calcium: phosphorus ratio of less than one. For most monogastric animals, phosphorus from animal sources is virtually 100% available, while plant-based phytate phosphorus is approximately 30% available. For insects prepared for human consumption, some of the elevated levels of iron and copper are likely the reset of metal that has leached from the cookware [Finke, 2004].

Vitamins

Studies dealing with the vitamin content in insects are insufficient, yet it is known that edible insects contain mainly carotene and vitamins B1, B2, B6, D, E, K and C [De Foliart, 1991; Lu *et al*., 1992; Chen & Feng, 1999; Feng *et al*., 1999, 2000a,b; 2001a,b,c]. As far as the A vitamin (retinol) is concerned, the data differ not only in dependence on the species, but also on the origin of analyzed insects, methods used and ways of preparation. High performance liquid chromatography (HPLC) of larval and pupal stages of the honey bee (*A. mellifera*) failed to detect any trace of retinol (vitamin A) or retinyl palmitate contrary to previous reports based on Carr-Price colorimetry. Bee brood is not a source of retinol for dietary or cosmetic purposes [Skinner *et al*., 1995; Barker, *et al*., 1998]. Commercially raised insects appear to contain little or no beta-carotene, most wild-caught insects contain a variety of carotenoids (astaxanthin, alpha-carotene, beta-carotene, lutein, lycopene, teaxanthin and others), which they accumulate from their food. Most species of vertebrates can convert some of these carotenoids to retinol, so insects containing high levels of carotenoids may be a significant source of vitamin A for insectivorous vertebrates [Finke, 2004]. Insects appear to be a good source of most B-vitamins, but a number of insects appear to contain low levels of thiamin. These low levels are likely an effect of heat processing, although the low levels seen for house crickets and superworms are for raw, whole insects [Finke, 2004].

Energy balance

With a daily growing world population, there are now more than 3.7 billion people suffering from malnutrition, mainly due to lack of protein and energy from food.

Associated with the declining availability of land, water and energy resources *per capita* [Pimentel, 2004], we need to conserve and manage these resources to produce more food. Animal husbandry competes for these vital resources, as the land is occupied by the production of feed and cannot be used to produce food for humans [Steinfeld *et al*., 2006]. Livestock production is very expensive because it requires a large input of water, grain and fodder as well as human effort and energy from fossil resources [Pimentel, 2004]. Livestock now consume more human edible protein than they produce: livestock consume 77 million tons of protein in feedstuff that is potential for human nutrition to produce 58 million tons of protein [De Foliart, 1995; Ramos-Elorduy, 2008]. Utilization of insects as a protein source could benefit insect conservation through habitat protection [Steinfeld *et al*., 2006]. Insects are essential agents feeding on organic matter in nature, and they efficiently exploit all organic sources. It is also important that insects are able to recycle organic waste and provide nutrients for farm animals [St-Hilaire *et al*., 2007; Myers *et al*., 2008; Diener *et al*., 2009]. Hence, insects could be used as efficient biotransformers to convert abundant, low cost organic wastes into animal biomass rich in proteins and suitable for use in animal nutrition [Ramos-Elorduy, 1999, 2005]. In a world as it is today [WHO/FAO/UNU, 2002], insects can contribute to human nutrition. Raising insects using waste biomass is already being implemented and managed today, with minimal infrastructure [Ramos-Elorduy *et al*., 2002]. Furthermore, insect culture requires little areas [Pimentel, 1980]. Many of the edible insect species do not compete with human beings for food resources, and according to Pimentel [2004], 99% of the world's food is produced on land. Insect farming requires little water, which is significant because water shortages already exist throughout the world and are likely to increase. Hence, insects are nicknamed "Minilivestock" [Paoletti & Dreon, 2005].

Fats provide the majority of the energy necessary for sustaining life. Immature stages of holometabolous insects have high quantities of polyunsaturated fat. The energy contents of edible insects vary according to the species and region found. Energetic values for livestock are 165–705 kcal/100 g, and vegetables 308–352 kcal/100 g, while edible insects provide 217–777 kcal/100 g, and insects raised on organic wastes provide 288–575 kcal/100 g. Furthermore, early stages of poultry, fish, ostrich, and pig, raised on feed enriched with insects, had conversion efficiency values of 1.24:1 – 2.83:1. On the contrary, Pimentel & Pimentel [1983] present the efficiency of conversion by chickens when they are nourished with 2.3 kg of grain per 1 kg of chicken The energetic cost of collecting edible insects is lower than that for vertebrates. Hence, insects may efficiently provide the necessary energy for the vital functions of our organism. Some species of edible insects have mostly the polyunsaturated fat type [De Foliart, 1992], as they feed on vegetables with largely unsaturated fats [Krause & Mahan, 2003].

THE RISKS, ALLERGIES AND TOXICITY OF EDIBLE INSECTS

Even when eating edible species of insects and handling with them, problems may arise. Consumption of inappropriate developmental stages, wrong culinary preparation, handling without protective equipment or collection of insects in unsuitable areas may result into adverse reactions.

Risks

Bouvier [1945] observed in D.R. Congo that consuming grasshoppers and locusts whole, without removing legs, may lead to intestinal constipation, caused by the large spines on the tibia. Often the only way to relieve the patient in such situation is surgical removal of the locust legs. Autopsies of monkeys, that died during locust invasion also proved, that the consumption of locusts was fatal for the same reason.

Toxicity

The comparatively high activity of relatively heat-resistant thiaminase was detected and characterized from the African silkworm pupae *Anaphe* spp. [Nishimune *et al*., 2000]. Epidemics of an acute ataxic syndrome occur annually in the rainy season in parts of south-western Nigeria, characterized by intention tremors, ataxia and varying levels of impaired consciousness, following a carbohydrate meal [Adamolekun *et al*., 1997]. Enzyme reaction can decrease cellular free thiamin concentration, carbohydrate metabolism or energy production can be impaired.

Thiaminase activity in Japanese silkworms (*B. mori*) is less than one-third that of *Anaphe* spp. The results indicate the need for thorough heat treatment for detoxification of the African silkworm, making the worm a safe source of high quality protein [Nishimune *et al*., 2000]. Another problem is the pesticide applications against locusts and grasshoppers, which can cause problems because of their toxic residues [Van Huis, 2003; Yen, 2009].

Allergy

Allergy, a potentially life-threatening condition, has at its heart an overly zealous T-helper type 2 response to environmental antigens. We are constantly flooded by potential allergens, both airborne and ingested. Inhalation and/or contact with airborne particulate insect products has resulted in sensitivity to insect proteins and is manifested by such common entities as dermatitis, conjunctivitis, rhinitis, asthma [Freye *et al*., 1996], contact urticaria [Bernstein *et al*., 1983] or rhinoconjunctivitis [Schroeckenstein *et al*., 1990]. In most cases, allergies to insects are associated with a job where employees deal with insects.

In clinical practice in relation to insects, most often reported allergic reactions are to chitin which is the second most abundant biopolymer in nature [Rop *et al*., 2009], where it protects crustaceans, parasites, fungi, and other pathogens from the adverse effects of their environments, hosts, or both [Elias *et al*., 2005]. Chitin is not commonly deemed a potential allergen but can cause sensitization through frequent exposure [Burton & Zaccone, 2007] and is a recognition element for tissue infiltration by innate cells implicated in allergic and helminth immunity and this process can be negatively regulated by a vertebrate chitinase [Reese *et al*., 2007]. Allergic reactions have been documented primarily in various types of mealworm and Orthoptera, both contact and respiratory form [Linares *et al*., 2008]. Combined allergies to more species of insects are common [Bleßmann-Gurk *et al*., 2007]. Those studies demonstrate that inhaled particulates from Tm exoskeletons are potent sensitizers and elicit IgE-mediated occupational asthma [Bernstein *et al*., 1983] and confirm the fact that beetles of the Tenebrionid family are potentially significant allergens for workers exposed to grains or grain products [Schroeckenstein *et al*., 1990].

Exposure to chitin (from dust mites, mould, shellfish or insects) might be the primary external determinant in allergy development. Intermittent low-level exposure could induce allergy in genetically-predisposed individuals. Understanding the potential allergenic role of chitin is important, not only because of its abundance in the environment but also because of its commonplace use in dental and surgical appliances, biomedical materials and cosmetic products. Indeed, various studies indicate that chitin and related molecules can accelerate wound healing [Muzzarelli, 1997], as chitin has the ability to alternatively activate macrophages, which in turn could be beneficial for stimulating tissue repair [Kodelja *et al*., 1997]. Remedies based on these molecules are widely used today [Muzzarelli, 1997].

On the other hand, chitin might recruit polymorphonuclear leukocytes and trigger allergic reactions. Most toxicological tests are performed on animals, which might have more efficient chitinase activity than humans, and more studies will be required to address the genetic basis of differences in chitinase functions and allergy [Kodelja *et al*., 1997]. Moreover, chitinase plays a key role in the innate immunity to parasites and other infectious agents. It is thus reasonable to hypothesize that, when produced in a dysregulated fashion, they also play an important role in the pathogenesis of allergy and/or asthma [Elias *et al*., 2005].

The prototypic chitinase, acidic mammalian chitinase, was also induced during TH2 inflammation through an IL-13–dependent mechanism. It was also shown to play an important role in the pathogenesis of TH2 inflammation and IL-13 effector pathway activation and demonstrated to be expressed in an exaggerated fashion in human asthmatic tissues. The finding that chitinases contribute to host antiparasite responses and asthmatic TH2 inflammation supports the concept that asthma might be a parasite independent antiparasite response [Elias *et al*., 2005; Burton & Zaccone, 2007; Sutherland *et al*., 2009].

Chitin is a recognition element for tissue infiltration by innate cells implicated in allergy and helminth immunity, and this process can be negatively regulated by vertebrate chitinases. Acidic mammalian chitinase (AMCase) and chitotriosidase (ChT) have chitinolytic activity, but little is known about their roles in nasal polyps. Nasal polyps appear to have elevated levels of chitinases, and the presence or growth of chitin-containing pathogens might enhance chitinase expression, resulting in a nasal polyp formation and growth in susceptible individuals [Park *et al*., 2009].

OTHER ASPECTS OF THE BREEDING AND USE OF INSECTS

Insects in many aspects appear to be strategic "raw material" and with good management they have the potential to provide much good to humankind. However, it is necessary to be aware of certain attributes of this phenomenon, take into account the negatives and work with positives.

Rejection of insects

Many people still dislike insects. This abhorrence is not inherent however. It is formed during infancy by the people surrounding the child [Mitsuhashi, 2010]. Whatever is not generally consumed in society is often thought to be disgusting to eat. There is a general antipathy to ingesting anything, not thought of as food [Harris, 1998]. Some people refuse insects such as unclean. However, most insects, especially 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 [Mitsuhashi, 2010].

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 [De Foliart, 2005; Gullan & 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% were neutral, and only 20% considered them acceptable [Rich, 2006].

Expressions of disgust at the idea of eating, handling, or even seeing meat have often been reported in studies of vegetarianism. In-depth interviews showed that vegetarians reject red meat and especially blood; some equate animal and human. The sickly sweet smell of the blood, which they believe is awful, bothers them. Meat eaters were also asked about eating the flesh of certain animals not normally eaten in the UK, such as horse, alligator, kangaroo, ostrich, dog cat, monkey, rat, *etc*. Many respondents had tried some of these. Meat eaters are not much put off by the idea of eating almost any animal with the very marked exception of household pets and to some extent horses [Hamilton, 2006].

PEST OR FOOD?

The central idea is to view some species as potentially sustainable resources for feeding human populations and not as pests [Cerritos, 2011]. The supreme irony is that all over the world monies worth billions of rupees are spent every year to save crops that contain no more than 14% of plant protein by killing another food source (insects) that may contain up to 75% of high quality animal protein. Each year, a large number of grasshopper species invade agrosystems worldwide, causing major economic losses and damages. Chemical and biological methods are used for controlling the population size of these species; however, the efficiency of these control methods is limited, as they usually lead to an increase in the size of the population, and they cause drastic ecological damage as well. An ideal alternative method for the control of these species is mechanical capture, where the removal of this biomass of insects can be used as human food, particularly because grasshoppers are edible and have a high nutritional value [Cerritos, 2011]. Wild harvesting of crop pests as human food is a possibility [Banjo *et al*., 2006] which can reduce pesticide use [Gullan & Cranston, 2005]. One of the questions worth exploring is the practicality of harvesting pest insect species as food—would it protect crops as well as reduce the use of insecticides? Whether this is economically feasible needs to be addressed. Pest outbreaks can be unpredictable, and the mode of collection will depend on the target species [Yen, 2010].

Products

Insect products and by-products probably account for the lion's share of insect commercialization. One of the most famous products is the silk and therefore sericulture.

Among fine fabrics made of natural products such as wool, cotton, linen, and leather, silk is usually the most highly prized [Kampmeier & Irwin, 2009]. Other products also include honey, royal jelly, bee pollen, and propolis. These products are all sold as a good food source to deal with a variety of ailments from anorexia to insomnia to cardiovascular diseases, and to promote wound healing [Kampmeier & Irwin, 2009].

Implements for research

Insects provide critical basic tools for studying a great many aspects of biology. Human and animal protein products derived from insect cell lines are marketed for a number of purposes, including drug screening and clinical trials [Kampmeier & Irwin, 2009].

CONCLUSIONS

Insects play a key role in the diet of many nations. Their high nutritive value is mainly determined by a high content of protein, essential fatty acids, vitamins, minerals and other bioactive substances. However, the West refuses entomophagy as disgusting. The main aspects of the possible accepting will certainly be created by food safety, the change in the approach of developed society and other factors.

Most insects have high food conversion efficiency compared with conventional livestock. Cultivating insects for protein is less environmentally damaging than cattle ranching. Insects can also serve as a valuable animal feed, due to their composition.

Insects may form the potential for a colonization of space by man in distant future. However, if we shall consider using insects as a food source for humans in future, we must respect the issue of nature preserving, especially in the tribal societies and the overproduction of food in developed society.

Insects provide critical basic tools for studying a great many aspects of biology. Human and animal protein products derived from insect cell lines are marketed for a number of purposes, including drug screening and clinical trials.

Despite the establishment of many breeding centers and other systems designed for the use of insects by humans, animals and other purposes, however, further scientific research will be required. These issues are, and will be subject of work of many scientists from different areas.

REFERENCES

1. Adamolekun B., McCandless D.W., Butterworth R.F., Epidemic of seasonal ataxia in Nigeria following ingestion of the African silkworm *Anaphe venata*: Role of thiamine deficiency? Metab. Brain Dis., 1997, 12, 251–258.
2. Aguilar-Miranda E.D., Lopez M.G., Escamilla-Santana C., Barba De La Rosa A.P., Characteristics of maize flour tortilla supplemented with ground *Tenebrio molitor* larvae. J. Agr. Food Chem., 2002, 50, 192–195.
3. Akinnawo O., Ketiku A.O., Chemical composition and fatty acid profile of edible larva of Cirina forda (Westwood). Afr. J. Biomed. Res., 2000, 3, 93–96.
4. Babiker E.E., Hassan A.B., Eltayeb M.M., Solubility and functional properties of boiled and fried Sudanese tree locust flour as a function of NaCl concentration. J. Food Technol., 2007, 5, 210–214.
5. Backwell L.R., D'errico F., Evidence of termite foraging by Swartkrans early hominids. Proc. Natl. Acad. Sci. USA, 2001, 98, 1358–1363.
6. Banjo A.D., Lawal O.A., Songonuga E.A., The nutritional value of fourteen species of edible insects in southwestern Nigeria. Afr. J. Biotechnol., 2006, 5, 298–301.
7. Barker D., Fitzpatrick M.P., Dierenfeld E.S., Nutrient composition of selected whole invertebrates. Zoo Biol., 1998, 17, 123–134.
8. Bednarova M., Borkovcova M., Mlcek J., Rop O., Zeman L., Edible insects – species suitable for entomophagy under condition of Czech Republic. Acta Univ. Agric. Silvic. Mendel. Brun., 2013, 61, 3, 587–593.
9. Bednarova M., Borkovcova M., Komprda T., Purine derivate content and amino acid profile in larval stages of three edible insects. J. Sci. Food Agric., 2014, 94, 71–76.
10. Bernstein D.I., Gallagher J.S., Bernstein I.L., Mealworm asthma: clinical and immunologic studies. J. Allergy Clin. Immun., 1983, 72, 475–480.
11. Bleßmann-Gurk B., Hoffmann B., Bayerl C., Allergische Kontakturtikaria bei einem Reptilienhalter. Aktuelle Derm., 2007, 33, 166 (in German).
12. Borkovcova M., Bednarova M., Fiser V., Ocknecht P., Kuchyne hmyzem zpestrena, 2009, 1st ed., Lynx: Brno, Czech Republic. 136 p. ISBN 975–80–86787–37–4.
13. Bouvier G., Quelques questions d'entomologie vétérinaire et lutte contre certains arthropodes en Afrique tropicale. Acta Trop., 1945, 2, 42–59 (in French).
14. Bukkens S.G.F., The nutritional value of edible insects. Ecol. Food Nutr., 1997, 36, 287–319.
15. Bukkens G.F., Insects in the human diet: Nutritional aspects, 2005, In M.G. Paoletti, ed. Ecological implications of minilivestock, p. 545–577. Enfield NH, Science Pub., USA
16. Burton O.T., Zaccone P., The potential role of chitin in allergic reactions. Trends Immunol., 2007, 28, 419–422.
17. Carlson B., Kingston J.D., Docosahexaenoic acid biosynthesis and dietary contingency: Encephalization without aquatic constraint. Am. J. Hum. Biol., 2007, 19, 585–588.
18. Cerritos R., Grasshoppers in agrosystems: Pest or food? CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources, 2011, 6, 1–9.
19. Chae J., Kurokawa K., So Y., Hwang H.O., Kim M., Park J., Jo Y., Lee Y.S., Lee B.L., Purification and characterization of tenecin 4, a new anti-Gram-negative bacterial peptide, from the beetle Tenebrio molitor. Dev. Compar. Immunol., 2012, 36, 540–546.
20. Chen X., Feng Y., Chen Z., Common edible insects and their utilization in China. J. Entomol. Res., 2009, 39, 299–303.
21. Chen X.M., Feng Y., The Edible Insects of China, 1999, 1st ed., Science and Technology Publishing House: Beijing, China.
22. Comby B., Délicieux insectes. Les protéines du futur, 1990, 1st ed., Editions Jouvence: Geneve, Switzerland. p. 105–119.
23. Crawford M., Galli C., Visioli F., Renaud S., Simopoulos A.P., Spector A.A., Role of plant-derived omega-3 fatty acids in human nutrition. Ann. Nutr. Metab., 2000, 44, 263–265.
24. De Foliart G.R., The Human used of insects as food and feed. Bull. Entomol. Soc. Am., 1989, 35, 22–35.

25. De Foliart G.R., Insect fatty acids: similar to those or poultry and fish in their degree of unsaturation but higher in the polyunsaturates. Food Insects. Newsl., 1991, 4, 1–4.
26. De Foliart G.R., Insects as human food. Crop Prot., 1992, 11, 395–399.
27. De Foliart G.R., Edible insects as minilivestock. Biodivers. Conserv., 1995, 4, 306–321.
28. De Foliart G.R., Overview of Role of Edible Insects in Preserving Biodiversity, 2005, In M.G. Paoletti, ed. Ecological implications of minilivestock, p. 123–140. Enfield NH, Science Pub., USA
29. Diener S., Zurbrügg C., Tockner K., Conversion of organic material by black soldier fly larvae: Establishing optimal feeding rates. Waste Manag. Res., 2009, 27, 603–610.
30. Elias J.A., Homer R.J., Hamid Q., Chun G.L., Chitinases and chitinase-like proteins in TH2 inflammation and asthma. J. Aller. Clin. Immun., 2005, 116, 497–500.
31. Falade K.O., Omojola B.S., Effect of processing methods on physical, chemical, rheological, and sensory properties of Okra (*Abelmoschus esculentus*). Food Bioprocess Tech., 2010, 3, 387–394.
32. FAO, Assessing the Potential of Insects as Food and Feed in assuring Food Security, 2012, *in:* Summary Report of Technical Consultation Meeting (eds. P. Vantomme, E. Mertens, A. van Huis, H. Klunder). Rome, Italy .
33. Feng Y., Chen X.M., Ye S.D., Wang S.Y., Chen Y., Wang Z.L., Records of four species edible insects in Homoptera and its nutritive elements analysis. Forest Res., 1999, 12, 515–518.
34. Feng Y., Chen X.M., Wang S.Y., Ye S.D., Chen Y., The nutritive elements analysis of bamboo insect and review on its development and utilization value. Forest Res., 2000a, 13, 188–191.
35. Feng Y., Chen X.M., Wang S.Y., Ye S.D., Chen Y., The common edible insects of Hemiptera and its nutritive value. Forest Res., 2000b, 13, 612–620.
36. Feng Y., Chen X.M., Wang S.Y., Ye S.D., Chen Y., Three edible Odonata species and their nutritive value. Forest Res., 2001a, 14, 421–424.
37. Feng Y., Chen X.M., Wang S.Y., Ye S.D., Wang Z.L., Studies on the nutritive value and food safety of Ericerus pela eggs. Forest Res., 2001b, 14, 322–327.
38. Feng Y., Chen X.M., Ye S.D., Wang S.Y., Chen Y., Wang Z.L., The common edible species of wasps in Yunnan and their value as food. Forest Res., 2001c, 14, 578–581.
39. FDA, Levels of natural or unavoidable defects in Foods that present no health hazards for humans, first ed. Silver Spring, Maryland, 2012.
40. Finke M.D., De Foliart G.R., Benevenga N.J., Use of a four-parameter logistic model to evaluate the quality of the protein from three insect species when fed to rats. J. Nutr., 1989, 119, 864–871.
41. Finke M.D., Complete nutrient composition of commercially raised invertebrates used as food for insectivores. Zoo Biol., 2002, 21, 269–285.
42. Finke M.D., Encyclopedia of Entomology, 2004, 1st ed., Kluwer Academic Press: Dordrecht, The Netherlands.
43. Finke M.D., Estimate of chitin in raw whole insects. Zoo Biol., 2007, 26, 105–115.
44. Fontaneto D., Tommaseo-Ponzetta M., Galli C., Risé P., Glew R.H., Paoletti M.G., Differences in fatty acid composition between aquatic and terrestrial insects used as food in human nutrition. Ecol. Food Nutr., 2011, 50, 351–367.
45. Freye H.B., Esch R.E., Litwin C.M., Sorkin L., Anaphylaxis to the ingestion and inhalation of Tenebrio molitor (mealworm) and *Zophobas morio* (superworm). Aller. Asthma Proc., 1996, 17, 215–219.
46. Goodman W.G., Chitin: A Magic Bullet? Food Insenct. Newsl., 1989, 3, 6–7.
47. Gullan P.J., Cranston P.S., The Insects: An Outline of Entomology, 2005, 3rd ed., Blackwell Publishing Ltd.: Oxford, UK, cap. The importance, diversity and conservation of isects. 505 p.
48. Hamilton M., Disgust reactions to meat among ethically and health motivated vegetarians. Ecol. Food Nutr., 2006, 45, 125–158.
49. Harris M., Good to Eat: Riddles of Food and Culture, 1998, 3rd ed., Waveland Press: Long Grove, IL, USA, 289 p.
50. He J.Z., Tong Q., Huang X.H., Zhou Z.H., Nutritive composition analysis of moths of Dendrolimus houi Lajongquiere. Entomol. Knowledg., 1999, 36, 83–86.
51. Heinrich M., Prieto J.M., Diet and healthy ageing 2100: Will we globalise local knowledge systems? Ageing Res. Rev., 2008, 7, SI, 249–274.
52. Hu C., Resource Insects and Utility, 1996, 1st ed. China Agriculture Press, Beijing, p. 219–228.
53. Kampmeier G.E., Irwin B.E., Encyclopedia of Insects, 2009, 2nd ed., Academic Press Inc: Burlington, MA, USA, cap. Commercialization of insects and their products, p. 220–227..
54. Katayama N., Yamashita M., Wada H., Mitsuhashi J., Space agriculture task force; entomophagy as part of a space diet for habitation on Mars. J. Space Technol. Sci., 2005, 21, 1–10.
55. Katayama N., Ishikawa Y., Takaoki M., Yamashita M., Nakayama S., Kiguchi K., Kok R., Wada H., Mitsuhashi J., Entomophagy: A key to space agriculture. Adv. Space Res., 2008a, 41, 701–705.
56. Katayama N., Yamashita M., Kishida Y., Liu C., Watanabe I., Wada H., Azolla as a component of the space diet during habitation on Mars. Acta Astronaut., 2008b, 63, 1093–1099.
57. Kinyuru J.N., Kenji G.M., Njoroge S.M., Ayieko M., Effect of processing methods on the *in vitro* protein digestibility and vitamin content of edible winged termite (*Macrotermes subhylanus*) and grasshopper (*Ruspolia differens*). Food Bioprocess Tech., 2010, 3, 778–782.
58. Kodelja V., Müller C., Tenorio S., Schebesch C., Orfanos C.E., Goerdt S., Differences in angiogenic potential of classically *vs* alternatively activated macrophages. Immunobiology, 1997, 197, 478–493.
59. Krause M., Mahan L.M., Food, Nutrition and Diet Therapy, 2003, 11th ed., W. B. Saunders Co.: St. Louis, CA, USA.
60. Linares T., Hernandez D., Bartolome B., Occupational rhinitis and asthma due to crickets. Ann. Allerg. Asthma Immunol., 2008, 100, 566–574.
61. Lu Y., Wang D.R., Han D.B., Zhang Z.S., Zhang C.H., Analysis of the patterns and contents of amino acids and fatty acids from *M. annandalei* (Silvestri) and *M. barneyi* Light. Acta Nutr. Sin., 1992, 14, 103–106.
62. Marconi S., Manzi P., Pizzoferrato L., Buscardo E., Cerda H., Hernandez L.D., Paoletti M.G., Nutritional evaluation of terrestrial invertebrates as traditional food in Amazonia. Biotropica, 2002, 34, 273–280.
63. Mariod A.A., Insect oils: Nutritional and industrial applications. Int. News Fats, Oils Rel. Mat., 2011, 22, 266–268.

64. MacEvilly C., Bugs in the system. Nutr. Bull., 2000, 25, 267–268.
65. Menzel P., D'Aluisio F., Man Eating Bugs: The Art and Science of Eating Insects, 1998, 1st ed., Ten Speed Press: Berkeley, CA, USA, 192 p.
66. Meyer-Rochow V.B., Food taboos: Their origins and purposes. J. Ethnobiol. Ethnomed., 2009, 5, 1–10.
67. Mitsuhashi J., Edible Insects of the World, 1984, 1st ed. Kokin Shoin, Tokyo, Japan, 270 p.
68. Mitsuhashi J., Insects as traditional foods in Japan. Ecol. Food Nutr., 1997, 36, 187–199.
69. Mitsuhashi J., The future use of insects as human food. Proceedings of the forest insects as food: humans bite back, Chiang Mai, Thailand, 19–21 February 2010, Durst, P.B., Johnson D.V., Leslie R.N., Shono K., Eds., RAP Publication: Bangkok, Thailand, 2010, pp.115–122.
70. Morris B., Insects and Human Life, 2004, 1st ed., Oxford International Publishers Ltd.: Oxford, UK, 317 p.
71. Muzzarelli A., Human enzymatic activities related to the therapeutic administration of chitin derivatives. Cell. Mol. Life Sci., 1997, 53, 131–140.
72. Myers H.M., Tomberlin J.K., Lambert B.D., Kattes D., Development of black soldier fly (*Diptera: Stratiomyidae*) larvae fed dairy manure. Evniron. Entomol., 2008, 37, 11–15.
73. Mziray R., Imungi J., Karuri E., Changes in ascorbic acid, beta-carotene, and sensory properties in sun-dried and stored *Amaranthus hybridus* vegetables. Ecol. Food Nutr., 2000, 39, 459–469.
74. Naughton J.M., O'Dea K., Sinclair A.J., Animal foods in traditional Australian Aboriginal diets: polyunsaturated and low in fat. Lipids, 1986, 21, 684–690.
75. Nishimune T., Watanabe Y., Okazaki H., Akai H., Thiamin is decomposed due to Anaphe spp. entomophagy in seasonal ataxia patients in Nigeria. J. Nutr., 2000, 130, 1625–1628.
76. Nonaka K., Feasting on insects. J. Entomol. Res., 2009, 39, 304–312.
77. Oliveira J.F.S., de Carvalho J.P., de Sousa R.F.X.B., Simao M.M., The nutritional value of four species of insects consumed in Angola. Ecol. Food Nutr., 1976, 5, 91–97.
78. Omotoso O.T., Nutritional quality, functional properties and antinutrients compositions of the larva of *Cirina forda* (Westwood) (Lepidoptera: Saturniidae). J. Zhejiang Univ.-Sc. B, 2006, 7, 51–55.
79. Oonincx D.G.A.B., Dierenfeld E.S., An investigation into the chemical composition of alternative invertebrate prey. Zoo Biol., 2012, 31, 40–54.
80. Opstvedt J., Nygard E., Samuelsen T.A., Venturini G., Luzzana U., Mundheim H., Effect on protein digestibility of different processing conditions in the production of fish meal and fish feed. J. Sci. Food Agr., 2003, 83, 775–782.
81. Ozimek L., Sauer W.C., Kozikowski V., Ryan J.K., Jorgensen H., Jelen P., Nutritive value of protein extracted from honey bees. J. Food Sci., 1985, 50, 1327–1329.
82. Özogul Y., Özogul F., Alagoz S., Fatty acid profiles and fat contents of commercially important seawater and freshwater fish species of Turkey: A comparative study. Food Chem., 2007, 103, 217–223.
83. Paoletti M.G., Dreon A.L., Minilivestock Environment, Sustainability, and Local Knowledge Disappearance, 2005, In M.G. Paoletti, ed. Ecological implications of minilivestock, Enfield NH, Science Pub., USA, 648 p.
84. Paoletti M.G., Dufour D.L., Edible Invertebrates among Amazonian Indians: A Critical Review of Disappearing Knowledge, 2005, In M.G. Paoletti, ed. Ecological implications of minilivestock, Enfield NH, Science Pub., USA, 648 p.
85. Park S.K., Kim H.I., Yang Y.I., Roles of vascular endothelial growth factor, Angiopoietin 1, and Angiopoietin 2 in nasal polyp. Laryngoscope, 2009, 119, 409–421.
86. Pennino M., Dierenfeld E.S., Behler J.L., Retinol, alpha-tocopherol and proximate nutrient composition of invertebrates used as feed. Int. Zoo Yearbk., 1991, 30, 143–149.
87. Pimentel D., Energy and land constraints in food production. Science, 1980, 190, 754–761.
88. Pimentel D., Pimentel M., Energy use in food processing for nutrition and development. Food Nutr. Bull., 1983, 7, 36–45.
89. Pimentel D., Livestock production and energy use. Enc. Energy 2004, 3, 671–676.
90. Premalatha M., Abbasi T., Abbasi S.A., Energy-efficient food production to reduce global warming and ecodegradation: The use of edible insects. Renew. Sust. Energ. Rev., 2011, 15, 4357–4360.
91. Raksakantong P., Meeso N., Kubola J., Siriamornpun S., Fatty acids and proximate composition of eight Thai edible terricolous insects. Food Res. Int., 2010, 43, 350–355.
92. Ramos-Elorduy J., Insect Consumption as a Mean of National Identity, 1996, 1st ed.; Deep Publications: New Delhi, India. p. 9–12.
93. Ramos-Elorduy J., Moreno J.M.P., Prado E.E., Perez M.A., Otero J.L., De Guevara O.L., Nutritional value of edible insects from the state of Oaxaca, Mexico. J. Food Compos. Anal., 1997, 10, 142–157.
94. Ramos-Elorduy J., Insects as intermediary biotransformers for obtaining proteins, 1999, *in:* Homo sapiens: An Endangered Species: Towards a Global Strategy for Survival (eds. F. Dickinson-Bannack, E. Garcia-Santaella). CINVESTAV-IPN, Merida.
95. Ramos-Elorduy J., González E.A., Hernández A.R., Pino J.M., Use of *Tenebrio molitor* (*Coleoptera: Tenebrionidae*) to recycle organic wastes and as feed for broiler chickens. J. Econ. Entomol., 2002, 95, 214–220.
96. Ramos-Elorduy J., Insects: A Hopeful Food, 2005, In M.G. Paoletti, ed. Ecological implications of minilivestock, Enfield NH, Science Pub., USA, 648 p.
97. Ramos-Elorduy J., Threatened edible insects in Hidalgo, Mexico and some measures to preserve them. J. Ethnobiol. Ethnomed., 2006, 2, 51.
98. Ramos-Elorduy J., Energy supplied by edible insects from Mexico and their nutritional and ecological importance. Ecol. Food Nutr., 2008, 47, 280–297.
99. Ramos-Elorduy J., Anthropo-entomophagy: Cultures, evolution and sustainability. J. Entomol. Res., 2009, 39, 271–288.
100. Ramos-Elorduy J., Moreno J.M.P., Vázquez A.I., Landero I., Oliva-Rivera H., Camacho V.H.M., Edible Lepidoptera in Mexico: Geographic distribution, ethnicity, economic and nutritional importance for rural people. J. Ethnobiol. Ethnomed., 2011, 7, 1–22.
101. Reese T.A., Liang H.E., Tager A.M., Luster A.D., Van Rooijen N., Voehringer D., Locksley R.M., Chitin induces accumulation in tissue of innate immune cells associated with allergy. Nature, 2007, 447, 92–96.

102. Rich B.R., A feasibility study into the commercialisation of witchetty grubs. A Report for Rural Research and Development Corporation, 2006, 1st ed., RIRDC Publication: Kingston, Australia, 58 p.
103. Riddervold M.H., Tittiger C., Blomquist G.J., Borgeson C.E., Biochemical and molecular characterizaton of house cricket (*Acheta domesticus, Orthoptera: Gryllidae*) Δ9 desaturase. Insect Biochem. Molec. Biol., 2002, 32, 1731–1740.
104. Rop O., Mlcek J., Jurikova T., Beta glucans in higher fungi and their health effect. Nutr. Rev., 2009, 67, 624–631.
105. Schaefer C.H., The relationship of the fatty acid composition of *Heliothis zea* larvae to that of its diet. J. Insect Physiol., 1968, 14, 171–178.
106. Schroeckenstein D.C., Meier-Davis S., Bush R.K., Occupational sensitivity to *Tenebrio molitor* Linnaeus (yellow mealworm). J. Allergy Clin. Immun., 1990, 86, 182–188.
107. Skinner M., Jones K.E., Dunn B.P., Undetectability of vitamin A in bee brood. Apidologie, 1995, 26, 407–414.
108. Sponheimer M., Lee-Thorp J.A., Oxygen isotopes in enamel carbonate and their ecological significance. J. Archaeol. Sci., 1999, 26, 723–728.
109. Sponheimer M., De Ruiter D., Lee-Thorp J., Späth A., Sr/Ca and early hominin diets revisited: New data from modern and fossil tooth enamel. J. Hum. Evol., 2005, 48, 147–156.
110. St-Hilaire S., Cranfill K., Mcguire M.A., Mosley E.E., Tomberlin J.K., Newton L., Sealey W., Sheppard C., Irving S., Fish offal recycling by the black soldier fly produces a foodstuff high in omega-3 fatty acids. J. World Aquacult. Soc., 2007, 38, 309–313.
111. Stanley D.W., Protein Reactions During Extrusion Processing in Extrusion Cooking. Extrusion Cooking, 1989, 1st ed., American Association of Cereal Chemists: St. Paul, Minn, USA.
112. Stanley-Samuelson D.W., Jurenka R.A., Cripps C., Blomquist J.G., De Renobales M., Fatty acids in insects: Composition, metabolism, and biological significance. Arch. Insects Biochem., 1988, 9, 1–33.
113. Steinfeld H., Gerber P., Wassenaar T., Castel V., Rosales M., deHaan C., Livestock's Long Shadow, Environmental Issues and Options, 2006, 1st ed., FAO: Rome, Italy, cap. Livestock as a major player in global environmental issues, 24 p.
114. Sun L., Feng Y., He Z., Ma T., Zhang X., Studies on alkaline solution extraction of polysaccharide from silkworm pupa and its immunomodulating activities. Forest Res., 2007, 20, 782–786.
115. Sun S.S.M., Application of agricultural biotechnology to improve food nutrition and healthcare products. Asia Pac. J. Clin. Nutr., 2008, 17, 87–90.
116. Sutherland E.R., Lehman E.B., Teodorescu M., Wechsler M.E., Body mass index and phenotype in subjects with mild-to-moderate persistent asthma. J. Allergy Clin. Immunol., 2009, 123, 1328–1334.
117. Sutton M.Q., Archaeological aspects of insect use. J. Archaeol. Method. Th., 1995, 2, 253–298.
118. Taylor R.L., Carter B.J., Entertaining with Insects, or: The Original Guide to Insect Cookery, 1995, 2nd ed., Salutek Publishing: Yorba Linda, CA, USA.
119. Van Huis A., Insects as food in sub-Saharan Africa. Insect Sci. Appl., 2003, 23, 163–185.
120. Wang D., Bai Y., Li J., Zhang Ch., Nutritional value of the field cricket (*Gryllus testaceus* Walker). Entomologia Sin., 2004, 11, 275–283.
121. WHO/FAO/UNU., Protein and amino acid requirements in human nutrition. Joint FAO/WHO/UNU Expert Consultation on Protein and Amino Acid Requirements in Human Nutrition, 2002, 1st ed., WHO Press: Geneva, Switzerland.
122. Xia Z., Wu S., Pan S., Kim J.M., Nutritional evaluation of protein from *Clanis bilineata* (*Lepidoptera*), an edible insect. J. Sci. Food Agric., 2012, 92, 1479–1482.
123. Yang G.H., Utility of Chinese Resource Insects and its Industrialization, 1998, 1st ed., China Agriculture Science Press: Beijing, China, p. 5–54.
124. Yang L., Siriamornpun S., Li D., Polyunsaturated fatty acid content of edible insects in Thailand. J. Food Lipids, 2006, 13, 277–285.
125. Yen A.L., Edible insects: Traditional knowledge or western phobia? J. Entomol. Res., 2009, 39, 289–298.
126. Yen A.L., Edible insects and other invertebrates in Australia: future prospects. Proceedings of the Forest Insects as Food: Humans Bite Back, Chiang Mai, Thailand, 19–21 February 2010, Durst, P.B., Johnson, D.V., Leslie, R.N., Shono, K., Eds., RAP Publication: Bangkok, Thailand, 2010, pp. 65–84.
127. Zhou X., Horne I., Damcevski K., Haritos V., Green A., Singh S., Isolation and functional characterization of two independently-evolved fatty acid Δ12-desaturase genes from insects. Insect Mol. Biol., 2008, 17, 667–676.

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