



## Insects as human food

Gene DeFoliart discusses some nutritional and economic aspects

*During the past few years there has been a new upsurge of interest in insects as food. One factor that may be responsible is an increasing awareness in the western world that insects are traditional and nutritionally important foods for many non-European cultures. Other factors may be increased pride in ethnic roots and traditions, increased concern about environment and overuse of pesticides, and better communication among scientists who are interested in the subject. Edible insects may be closer now than ever before to acceptance in the western world as a resource that should be considered in trying to meet the world's present and future food needs.*

### Traditional use and economic importance in non-European cultures

Insects have played an important part in the history of human nutrition in Africa, Asia and Latin America (Bodenheimer, 1951). They were an equally important resource for the Indians of western North America, who, like other indigenous groups, expended much organization and effort in harvesting them (Sutton, 1988). Hundreds of species have been used as human food. Some of the more important groups include grasshoppers, caterpillars, beetle grubs and (sometimes) adults, winged termites (some of which are very large in the tropics), bee, wasp and ant brood (larvae and pupae) as well as winged ants, cicadas, and a variety of aquatic insects. Ordinarily, insects are not used as emergency food to ward off starvation, but are included as a planned part of the diet throughout the year or when seasonally available. Among the numerous examples that could be cited, the Yukpa people of Colombia and Venezuela prefer certain of their traditional insect foods to fresh meat (Ruddle, 1973), as do the Pedi of South Africa (Quin, 1959). Indeed, Quin reported that when *mopanie* caterpillars (*Gonimbrasia belina* Westwood) were in season, the sale of beef was seriously affected. In

the early 1980s, annual sales of *mopanie* entering commerce were estimated by the South African Bureau of Standards to be 1600 t; this did not include those privately collected and consumed (Dreyer and Wehmeyer, 1982). Currently, hundreds of tons of *mopanie* are exported annually from Botswana and South Africa to Zambia and Zimbabwe. A similar caterpillar trade, involving other species, exists further north in Africa.

The Yansi people of central Zaire are not atypical of other indigenous groups, and the importance with which they regard their caterpillars is indicated by some of their sayings: 'Caterpillars and meat play the same role in the human body', and, 'As food, caterpillars are regulars in the village but meat is a stranger' (Muyay, 1981). There are also children's songs about eating caterpillars. One of these contains the following verse: 'Father you have to give me some "milee" caterpillars. . . . Look at all the other children with milee caterpillars that their fathers gave them. . . . I'm going to bother you until you give me some' (Muyay, 1981).

With reference to *mumpa* caterpillars, which feed on *Julbernardia paniculata* and several other common trees in the *miombo* woodland of Zambia, Holden (1986) states:

One person can pick about 20 litres per day if the bush is rich in caterpillars, the value of which in 1985 was K20. Thus 7 days' picking should give K140 if all are sold and this is a month's salary for a general worker in Zambia. Not strange that people travel 200–300 km to pick caterpillars. And traders come from

Lusaka and the Copperbelt (900 km) to buy the foodstuff and sell it at a much higher price when they go back.

Chavunduka (1975) noted that in several areas of Zimbabwe, some families 'make a fairly good living from selling caterpillars'.

Insects are not only sold widely in the village markets of the developing world, but many of the favourites make their way to urban markets and restaurants. Conconi (1982), who has proposed the 'industrialization' of edible insects in Mexico, notes that in 1981 the demand for 'escamoles' (immature stages of the ant, *Liometopum apiculatum* Mayr.) was so great that the price per kilogram went up to 1000 pesos (>US\$2 at the then-prevailing exchange rate). She states (translation):

In Tlaxcoapan . . . they are sold in restaurants like El Prendes, Las Meninas, Delmonicos, and Bellinghaussen, where 2 tacos with 50 grams of ants cost 300 pesos. They are served fried or with black butter, but the best way is fried with onions and garlic.

Two other insects that are found in urban restaurants of Mexico, and were formerly exported to the United States and Europe, are the white maguery 'worm' (larva of the hesperiid, *Aegiale hesperiaris* Kirby) and *ahuahutle* or 'Mexican caviar' (eggs of several species of aquatic Hemiptera). However, both are in reduced numbers now – maguery larvae because of over-collecting, and *ahuahutle* because of urban pollution of alkaline lakes. At present, two Asian insects are being exported to Asian community food shops in the United States: these are the giant water bug (*Lethocerus indicus* L. & S.) from Thailand (Pemberton, 1988), and canned silkworm pupae [*Bombyx mori* (L.)] from South Korea.

### Nutritional value

#### Protein

In the dried form most frequently

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found in village markets of the developing world, insects are very high in crude protein, many species ranging above 60%. As to protein quality, Finke, DeFoliart and Benevenga (1989) reported that the house cricket [*Acheta domestica* (L.)], when fed to weanling rats, was superior to soy protein as a source of amino acids at all levels of intake. The Mormon cricket (*Anabrus simplex* Haldeman), a tettigoniid, was equivalent to soy protein. Other investigators have obtained similar results with a variety of insects in feeding trials with poultry. On the other hand, whole insects as a source of protein are of somewhat lower quality than vertebrate animal products because of the indigestibility of chitin (Phelps, Struthers and Moyo, 1975; Dreyer and Wehmeyer, 1982). Despite this, Dreyer and Wehmeyer conclude that, 'the consumption of *mopanie* caterpillars [*Gonimbrasia belina*] can to a substantial degree supplement the predominantly cereal diet with many of the protective nutrients'. Removal of chitin increases the quality of insect protein to a level comparable to that of products from vertebrate animals. Following alkali extraction, the true digestibility of protein concentrate obtained from whole dried adult honey bees (*Apis mellifera* L.) was increased from 71.5% to 94.3%, the protein efficiency ratio (PER) from 1.50 to 2.47, and the net protein utilization (NPU) from 42.5 to 62.0. This compares with values of 96.8%, 2.50 and 70.0, respectively, for casein (Ozimek *et al.*, 1985). In general, insect protein tends to be low in the amino acids, methionine/cysteine; but it is high in lysine and threonine, one or both of which may be deficient in the wheat, rice, cassava and maize-based diets that are prevalent in the developing world.

### Fat

Malnutrition in developing countries is as much, or more, a problem of calorie deficiency as of protein deficiency. Insects vary widely in fat (and, thus, energy) content. Isoptera (termites) and Lepidoptera (caterpillars) rank among the highest in fat. For example, Phelps *et al.* (1975) reported

a calorific value of 761 kcal ( $\approx 3196$  kJ)/100 g (dry, ash-free, weight basis) for the winged sexual forms of the African termite, *Macrotermes falciger* Gerstaecker, while the winged forms of another African species, *Macrotermes subhyalinus* Rambur were found to contain 613 kcal ( $\approx 2575$  kJ)/100 g (dry weight) (Oliveira *et al.*, 1976). Ashiru (1988) reported a calorific value of 611 kcal ( $\approx 2566$  kJ)/100 g for the caterpillar *Anaphe venata* Butler (Notodontidae) in Nigeria. Twenty-three species of caterpillars in Zaire, mostly Saturniidae, were found to average 457 kcal ( $\approx 1919$  kJ)/100 g dry weight, ranging from 397 to 543 kcal ( $\approx 1667$ – $2281$  kJ) (Malaisse and Parent, 1980).

Recent analyses of 94 of the insect species consumed in Mexico also yielded high fat and caloric values (Ramos-Elorduy and Pino, 1990). Excluding pork, soybeans [at 4660 kcal ( $\approx 19572$  kJ)  $\text{kg}^{-1}$ ] was the highest ranking non-insect food tested, plant or animal. Maize was found to have a value of 3700 kcal ( $\approx 15540$  kJ)  $\text{kg}^{-1}$ . Of the insects analysed, 50% had a higher caloric value than soybeans; 87% were higher than corn; 63% were higher than beef; 70% were higher than fish, lentils and beans; and 95% were higher than wheat, rye or teosinte. The five highest Lepidoptera (caterpillars) of 16 species examined averaged 6594 ( $\approx 27695$  kJ)  $\text{kg}^{-1}$ ; the five highest Coleoptera (beetle grubs) of 17 species examined averaged 5964 kcal ( $\approx 25049$  kJ)  $\text{kg}^{-1}$ ; the five highest Hemiptera (mixed nymphs and adults) of 14 species examined averaged 5646 kcal ( $\approx 23713$  kJ)  $\text{kg}^{-1}$ ; the five highest Hymenoptera (all ants, ranging from adults to immatures) of 24 species examined averaged 5361 kcal ( $\approx 22516$  kJ)  $\text{kg}^{-1}$ ; and the five highest Orthoptera (grasshopper nymphs and adults) of 20 species examined averaged 4168 kcal ( $\approx 17506$  kJ)  $\text{kg}^{-1}$ .

Cholesterol levels in insects vary from low (e.g. none in the edible leaf-cutter ant, *Atta cephalotes* Latr.) to approximately the levels found in other animals ( $\sim 1$  mg sterol  $\text{g}^{-1}$  tissue), depending on species and diet (Ritter, 1990). Insect fatty acids are

similar to those of poultry and fish in their degree of unsaturation, with some groups being rather higher in linoleic and/or linolenic acids, which are the essential fatty acids (DeFoliart, 1991).

### Vitamins and minerals

In Angola, the caterpillar, *Usta terpsichore* M. & W. (Saturniidae), was found to be a rich source of iron, copper, zinc, thiamin (vitamin B<sub>1</sub>) and riboflavin (B<sub>2</sub>); 100 g of cooked insect provided >100% of the daily requirement of each of these minerals and vitamins (Oliveira *et al.*, 1976). Winged adults of the termite, *Macrotermes subhyalinus*, are high in magnesium and copper, and the palm weevil larva, *Rhynchophorus phoenicis* F., in zinc, thiamin and riboflavin. In each case, 100 g of these insects provided more than the minimum daily requirement. In Zaire, Kodondi, Leclercq and Gaudin-Harding (1987) analysed three species of saturniid caterpillars prepared by the traditional techniques of smoking and drying, and found them to be high in riboflavin and niacin, but low in thiamin and pyridoxine (B<sub>6</sub>). Feeding trials confirmed that, except for thiamin and pyridoxine, the vitamins supplied by the caterpillars are sufficient to allow proper growth of young rats. The caterpillars studied by Malaisse and Parent (1980), also in Zaire, proved an excellent source of iron; of 21 species tested, 100 g of insects provided (average value) 335% of the minimum daily requirement.

In Mexico, *axayacatl* (a mixture of several species of aquatic Hemiptera), *ahuahutle* (eggs of the preceding), and *jumiles* (several species of edible stink bugs) are rich sources of riboflavin and niacin (Massieu *et al.*, 1958, 1959). *Sphenarium* grasshoppers are high in niacin, while *axayacatl* is a rich source of iron. The high content of iron and zinc in many edible insects is of particular interest. Iron deficiency is a major problem in women's diets in the developing world, particularly among pregnant women, and especially in Africa (Orr, 1986). Vegetarians everywhere are at risk of zinc deficiency.

## Fibre

Chitin comprises ~10% of whole dried insects. It is a carbohydrate polymer found in invertebrate exoskeletons, protozoa, fungi and algae, and is being called the polymer of the future because of its abundance, toughness and biodegradability (Goodman, 1989). Numerous applications of chitin and its derivatives (especially chitosan) are being found in medicine, agriculture and industry. In fact, chitin from shells of lobsters, crabs and crayfish has been approved by the Japanese for use in cereals as a source of fibre and calcium. If protein concentrates from dechitinized insects should become acceptable and produced on a large scale, the chitin by-product could be of significant value as a fibre source.

## Potential hazards

Some insects secrete toxins, produce toxic metabolites or sequester toxic chemicals from foodplants (Blum, 1978; Duffey, 1980; Wirtz, 1984). Defensive secretions that may be reactive, irritating or toxic include carboxylic acids, alcohols, aldehydes, alkaloids, ketones, esters, lactones, phenols, 1,4-quinones, hydrocarbons and steroids, among others. Phytochemicals sequestered by various insects include simple phenolics, flavin, tannins, terpenoids, polyacetylenes, alkaloids, cyanogens, glucosinolates and mimetic amino acids. Insects are also a source of injectant, ingestant, contactant and inhalant allergens (Wirtz, 1984; Gorham, 1991), and some insects serve as vectors or passive intermediate hosts of vertebrate pathogens such as bacteria, protozoa, viruses or helminths (Gorham, 1991). More attention should be directed toward assessing these risk factors in the edible insect groups. The long history of human use suggests, however, with little evidence to the contrary, that the insects intentionally harvested for human consumption do not pose any significant health problem.

## Relevance to environmentally compatible pest management and sustainable agriculture

As noted by Dufour (1987) in Colombia, insects used as food by indigenous

populations are often those that are dependably most abundant. Thus, many of the species used as food are important crop pests. Relative to efficiency of resource utilization and preserving environmental quality, a few examples will suffice to indicate the diversity of possibilities that exists. The question has been raised, for example, whether increased promotion and harvest of palm weevil (*Rhynchophorus*) and rhinoceros beetle (*Oryctes*) larvae as food might serve as a form of biological control of these pests (and the associated 'red-ring disease' of palms). Such a practice might result in the reduction of pesticides, as well as creating new economic opportunities for indigenous people (DeFoliart, 1990). In South Africa, Ledger (1987) suggested that serious consideration be given to attempting harvest of the brown locust, *Locustana pardalina* (Walker), as human and animal food (as indigenous people have done for centuries) in order to eliminate or reduce the use of insecticides on this pest. The idea was summarily dismissed as 'totally impractical' by agricultural officials. Nevertheless, local officials in Thailand launched a campaign to combine grasshopper harvest and sale with pest control when conventional control procedures proved unsuccessful (DeFoliart, 1989): whether or not successful pest control was achieved, the grasshoppers were an economic windfall.

In Mexico, Conconi and Pino (1979) suggest that some plants that are widespread and characteristic of arid regions, but of limited food value, such as mezquite, madrono and some cacti, could be used for cultivation of their associated insects, thus producing more protein of animal quality. The insects are many times higher in protein and fat than are the plants upon which they feed: for example, protein (on a dry weight basis) is 69.05% in the adult weevil, *Metamasius spinolae* Vaurie, compared with 5.21% in nopal, the cactus upon which it feeds; fat is 58.55% of the caterpillar of *Aegiale hesperiaris* Kirby compared with 3.60% in the maguey plant. When the cosmopolitan house cricket, *Acheta domesticus*, was maintained at temperatures > 30°C and fed

a diet of similarly high quality to that used in bringing beef animals to market size and condition, the food conversion efficiency of the crickets was estimated to be more than five times that of beef animals (Nakagaki and DeFoliart, 1991). When the high fecundity of the cricket is considered (1500 offspring per female cricket compared with four standing animals in the beef herd for each animal marketed), the true food conversion efficiency is closer to 15–20 times greater for the cricket than for beef.

Turk (1990) notes that at least 42 species of leguminous trees are fed upon by edible caterpillars in Africa. He suggests that management practices for these trees should be developed that would help preserve caterpillar production. Some of the trees are among those recommended (for reasons other than caterpillar production) by an advisory panel of the United States National Academy of Sciences (1979) for further development as food protein resources. In Zambia, where late bush-burning is very damaging to the forest, Holden (1986) noticed that there were very few late fires in the areas where the *mumpa* caterpillars are found: the people burn early to protect the caterpillars. He proposed research on management of the caterpillars not only because they are important as food, but because of their favourable impact on woodland management. That is, this practice would create an incentive for people to burn early and, thereby, enhance woodland regeneration. The reception by administrators for this proposal was: 'Serious researchers cannot come up with such things!' (Holden, 1986, in postscript added in 1991).

## Economic implications for industrialized countries

Processed insects for sale as cocktail snacks, etc., are apparently no longer imported into the United States (DeFoliart, 1988). A new product, however, tequila-flavoured lollipops, which contain an embedded beetle grub, are selling (at US\$0.95 each) as fast as they can be made, according to the Californian manufacturer. Several

processed insects are commercially available in Japan (Mitsuhashi, 1984; Kantha, 1988). The most widely eaten is *inago* (the grasshopper, *Oxya velox* F.), which is preserved by boiling in soy sauce. This product appears as a luxury item in supermarkets throughout the country, including Tokyo. Mitsuhashi (1984) states (translation): 'Catching inago is an activity that adds poetic charm to rice paddies in autumn'. He further describes an inago hunt at an elementary school in Tsukuba Science City in Ibaraki Prefecture, in which the fathers and mothers who participated collected 68 kg of inago in 2 h. Mitsuhashi suggests that with rice in overproduction, why not let inago feed on the excess, thus increasing the population of the grasshopper. Another product, cooked wasps, sells at Y1000 ( $\approx$  US\$8.00) per can ( $\approx$  65 g); mixed with cooked rice, this was a favourite dish of the late Emperor Hirohito (Mitsuhashi, 1988).

There is currently an effort to incorporate several insects that were important in aboriginal diets into the Australian cuisine (Irvine, 1989). In Canada, attempts are under way to apply industrial methods to the production of insects as food (Kok, Shivhare and Lomaliza, 1991). The French book, *Délicieux Insectes*, by Comby (1990), is selling so well that it is being translated into German and Italian editions.

Commercially grown insects available to fanciers (from bait and pet food stores) in the USA and Europe include the cricket, *Acheta domestica*, the mealworm, *Tenebrio molitor* L. (a beetle grub), and the greater waxmoth larva, *Galleria mellonella* (L.). More than 80 recipes based on these insects and honey bee pupae (*Apis mellifera*) are included in the tastefully executed cookbook, *Entertaining with Insects, or the Original Guide to Insect Cookery*, by Taylor and Carter (1976); unfortunately, the book is out of print. Dr Justin Schmidt, of the USDA's Carl Hayden Bee Research Laboratory, Tucson, Arizona, USA, has researched methods of harvesting honey bee drone pupae and the possibility of developing markets for the pupae (J. Schmidt, personal communication, 1991).

If insects become more widely accepted as a respectable food item in the industrial countries, the economic implications are obvious. They would form a whole new class of foods made to order for low-input small-business and small-farm production. International trade in edible insects would almost certainly increase. Although prospects for widespread acceptance are uncertain, there has been a notable increase in the number of articles in newspapers and magazines, and the subject is usually treated more seriously than in the past. In my contacts with the US public the response has been almost totally positive. For example, as a guest on radio call-in shows, I have repeatedly heard callers make comments such as 'We Americans shouldn't be foisting our food values on other people who need food', and 'Maybe we Americans would be better off if we were eating insects ourselves, instead of dousing the world in pesticides'. In addition, the *Food Insects Newsletter* (DeFoliart, 1988–1991), a desktop operation, has met with wider enthusiasm than anticipated, the mailing list having grown from 100 names with the initial issue in 1988 to > 1700 in early 1992. The *Newsletter* has proved to be a valuable source of information for university and secondary school teachers who want to incorporate the subject into their courses, as well as for newspapers, magazines, radio and television. With this increasing attention on the part of educators and the mass media, there is good reason to expect that the current momentum in public education on the subject of insects as human food will continue.

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