The Human Use of Insects as Food and as Animal Feed

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Edible insects are a food resource that continues to be tapped extensively by populations in the rural Third World, while continuing to be ignored by food and agricultural scientists. The unfounded Western aversion to insects as food should no longer stand in the way of attempts, through advocacy, research, and extension, to increase the contribution that insects can make to human nutrition.

MOST EUROPEANS AND NORTH AMERICANS are barely, if at all, aware that insects have played an important role in human nutrition. The older literature contains numerous accounts provided by explorers, naturalists, anthropologists, and assorted travelers describing the use of insects as food by the indigenous peoples of most of the world.

The desert locust, *Schistocerca gregaria* (Forskål) (Orthoptera: Acrididae), well-known as a destroyer of crops, was itself in earlier times a major source of food in northern Africa and the Middle East. Künckel d'Herculais (1891; vide Bodenheimer 1951, 205-206) gave the following account from Algeria:

> The natives are well disposed to carry out orders for the destruction of the locusts, since they use them for food. Around Tougourt every tent and house has prepared its store of locusts, on the average about 200 kilo to each tent. Sixty camel loads (9000 kilo) are the quantities of locusts accumulated daily in the Ksours of the Oued-Souf. They are a valuable resource for the poor population. To preserve them, they are first cooked in salt water, then dried in the sun. The natives collect and prepare such considerable stocks that apart from their own needs, they have some for trading on the markets of Tougourt, Temacin, etc. I have in my hands now two boxes of freshly prepared locusts and I convinced myself that they are quite an acceptable food. The taste of shrimps is very pronounced; with time they lose their quality.

Although few insects other than the desert locust were used as food in northern Africa, hundreds of species have been used in central and southern Africa, Asia, Australia, and Latin America. The reported total approximates 500 species in more than 260 genera and 70 families of insect. The actual numbers are probably far greater than the numbers reported, however, for two reasons, both attributable to the well-known Western coolness toward the idea of insects as food.

In his study of the food habits of the Yukpa of Colombia and Venezuela, Ruddle (1973, 95) stated: "Foraging for insects has generally been overlooked by most visitors to the region. Those scholars who have noted the phenomenon have done so only imprecisely, unfortunately with little regard for the procurement of specimens for zoological identification." This statement applies to other regions, as well. Thus, for many countries we know from the published literature only that "termites," "locusts," "grasshoppers," "caterpillars," or "insects" are used as food, but frequently we can only guess at the precise number and identity of the species used.

Where careful studies have been conducted, the number of insect species used has proven surprisingly large. Previous investigators of Yukpa food habits mentioned fewer than a dozen varieties of insect and the specific identity of only one, but Ruddle's data indicate that 25-35 species are eaten, 13 of which could be identified to species. Most of the others belonged to one or another of nine genera. In Zaire, one of the better studied countries from the standpoint of food insect use, Bequaert (1921) and other early observers provided information on 14 species, including the caterpillars of six species of Lepidoptera. In a recent careful study confined only to caterpillars and only to the southern part of Zaire, however, Malaisse & Parent (1980) distinguished 35 species that are used as food.

In Mexico, prior to studies initiated in the mid-1970s by J. R. E. de Conconi (National Autonomous University of Mexico), fewer than 20 species had been reported as food. Her group (de Conconi et al. 1984) reported 101 species that are regularly consumed—fresh, roasted, or fried—in Mexico; the total known has since been increased to more than 200 (J. R. E. de Conconi, personal communication, 1986). Current information suggests that 30 species or more are used by indigenous populations in many Third World countries, although the specific identity of relatively few of the species is known.

Also, where careful studies have been conducted, the *volume* of insects consumed as a percentage of the total animal proteins has been shown to be appreciable. In 1961, Gomez et al. estimated that insects furnished 10% of the 48,000 metric tons of animal proteins produced annually in Zaire, compared with 30% from game, 47% from fishing, 1% from fish culture, 10% from grazing animals, and 2% from poultry. Insects furnished between 26 and 37% of the animal protein consumed in four of the country's 25 districts and between 22 and 64% in 29 of its 137 territories. It is interesting (and revealing) that in projecting the country's future protein needs, Gomez et al. assumed that the contribution of insects would be maintained but did not consider the possibility that it could be increased. Although data from elsewhere in Africa are more fragmentary, it appears probable that the variety and volume of insect consumption in Zaire is not atypical of that in most countries of central, southern, and eastern Africa.

Among the Tukanoan Indians in the Colombian Vaupes region, Dufour (1987) found that the more than 20 species used provided up to 12% of the crude protein from animal sources in men's diets

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and 26% in women's diets during one season of the year, May–June, and probably 5–7% over the entire year. The insects also contributed substantial amounts of animal fat to the diet—up to 20% during certain seasons of the year. According to Dufour (p. 395), insects "were often used to dampen fluctuations in the availability of fish and game."

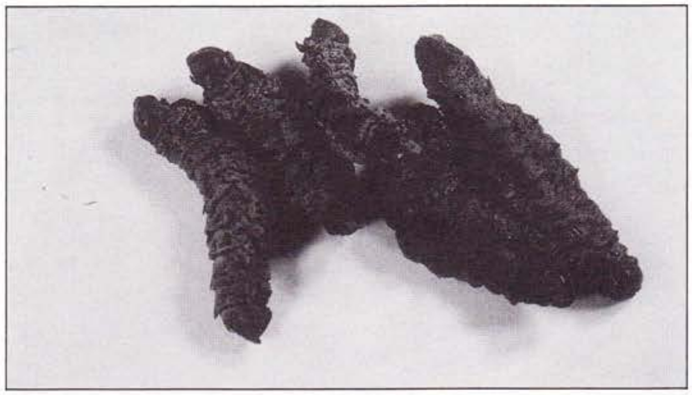
Denevan (1971) in Peru, Chavunduka (1975) in Zimbabwe, and other investigators have similarly recognized the quantitative importance of insects to indigenous diets although precise data were not obtained. Chavunduka credits insect consumption as averting many potential cases of kwashiorkor (protein-calorie malnutrition) among the young in remote rural areas of Zimbabwe. Posey (1987, 193), noting that gathered foods are frequently eaten "on the spot," emphasizes that "unless researchers follow on routine gathering ventures, constantly recording and weighing the gathered foods, importance of many gathered products may be grossly underestimated."

The second factor leading to a general underestimate of the magnitude of food insect use was also commented upon by Ruddle (1973, 94) in his study of the Yukpa: "The fact that many people regard entomophagy [eating insects] as either a curiosity or a relict of barbarism may, unfortunately, persuade the indigenous population to withhold information from investigators." Meyer-Rochow (1973) in a comparative study of the food habits of three ethnic groups of Melanesians in Papua New Guinea made the same point in a somewhat different fashion. Kiriwinians living on the coast of the Trobriand Islands denied eating any insects and referred to the inland people as insect eaters. Meyer-Rochow noted, however, that the coastal people know well which insects are edible, and they were seen indulging especially frequently in the yellow leaf ant, *Oecophylla smaragdina* F. (Hymenoptera: Formicidae). These studies and others suggest that the extent and importance of food insect use has been, and largely continues to be, underestimated in many geographic areas.

It should be understood that in those cultures in which the use of insects as food is traditional, the insects are highly prized and much sought after, not used merely to ward off starvation. They are incorporated as a regular part of the diet when in season or throughout the year if available. The proportionally small quantitative contribution of insects to the diet, compared with foods of plant origin, has undoubtedly been dictated primarily by limited supplies rather than by any deficiencies in palatability.

The Pedi of South Africa prefer certain insects to meat (Quin 1959), as do the Yukpa of Colombia and Venezuela (Ruddle 1973). Malaisse & Parent (1980) state that in the search for animal proteins in the Kipushi Territory of Zaire, caterpillars are indisputably the first supplement chosen. Villagers are knowledgeable about the hosts of the edible species and the season when each is ready for harvest. This knowledge among indigenous peoples of the host plants and seasonal history of local food insects has been noted by writers in other tropical countries.

In South Africa, the caterpillars of the saturniid, *Gonimbrasia belina* Westwood, known as *masonja* or "mopanie worms" are a special favorite. The Pedi not only prefer *masonja* to meat, but, according to Quin, prefer a quarter pound of these caterpillars to a pound of fresh beef. When *masonja* are available for sale, they seriously affect the sale of beef. There are up to three generations per year of the mopanie caterpillar in South Africa and a good picker in an average infestation can collect 18 kg of larvae in an hour (although there is a large loss in weight, especially of fat, during processing and drying). Considering the ecological deterioration and reduced availability of food insects in South Africa and noting the existence of a fairly extensive trade in roasted, dehydrated mopanie worms, Quin recommended expansion of the *masonja* industry as probably the most feasible remaining way of meeting the need and demand for insect foods, not only in the northern Transvaal where he worked but also in Zimbabwe and Botswana.



Dried "mopanie worms," caterpillars of the saturniid, Gonimbrasia belina, *as purchased in a village market in Zimbabwe. Courtesy of R. J. Phelps, University of Zimbabwe, Harare.*

Dreyer & Wehmeyer (1982) report that mopanie caterpillars have made impressive gains in sales in recent years and that a mopanie cannery has been established at Pietersburg in northern Transvaal. The South African Bureau of Standards estimates annual sales through agricultural cooperative markets at about 40,000 bags, each containing 40 kg of traditionally prepared, dried caterpillars. This amounts to 1600 metric tons, and the volume entering reported channels of commerce presumably is only a fraction of the volume actually consumed. One can't help but wonder what the ecological and nutritional maps of Africa might look like today if more effort had been directed toward developing some of these caterpillar, termite, and other food insect resources.

Considering the popularity of edible insects, it is not surprising that scores of species have been, and are, prominent items of commerce in the town and village markets of Africa and other tropical and semitropical regions of the world. In several areas of Zimbabwe, some families "make a fairly good living from selling caterpillars" (Chavunduka 1975, 219). In southern Mexico, food insects are not only prominent in the marketplaces of the rural towns and villages, but some are sold in the finest restaurants in the largest cities and exported abroad to Europe and the United States (Eerde 1981, de Conconi 1982).

In the recent and elegant cookbook, "The Taste of Mexico," (1986), Patricia Quintana, executive chef of the Mexican Bureau of Tourism, and William Orme describe several recipes based on insects. In a 1974 survey in Mexico City (de Conconi et al. 1984, 63) in which 12,300 people were interviewed, 93% considered that insect foods are "in the future" and that commercially produced food insect products should be developed. The fact that food insects serve not only as a direct source of needed nutrients available to the

Grasshoppers of the genus Sphenarium *in a village market in Oaxaca state, southern Mexico. As sold here, they have been mixed with onion, garlic, and chili powder, boiled (during which they turn pinkish brown in color), sun-dried and fried. Photo courtesy of Dr. Julieta Ramos Elorduy de Conconi, National Autonomous University, Mexico City.*

A close-up of Sphenarium *grasshoppers (Chapulines) showing the different measures by which they are sold. At 1984 prices the smallest container held 50 pesos' worth, the largest container 500 pesos' worth. Photo courtesy of Dr. Julieta Ramos Elorduy de Conconi, National Autonomous University, Mexico City.*

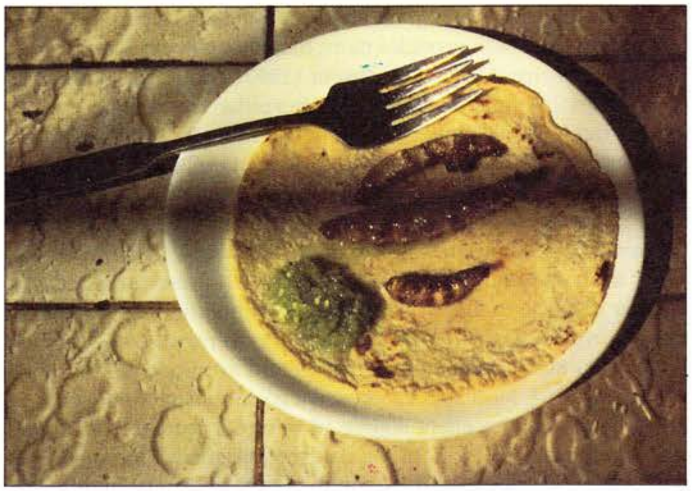
poorest of the poor in cultures retaining strong elements of the gatherer society but also add importantly to the rural economy should be a matter of great interest to individuals, organizations, and agencies concerned with alleviating world hunger and in developing greater food self-sufficiency among rural populations at risk of malnutrition.

There are several factors that threaten a reduction in the availability and use of insects as food in the developing world. In addition to acculturation toward Western attitudes already mentioned, they include ecological deterioration in such forms as tropical forest destruction and water pollution (aquatic food insects are of particular importance in Asia), and lack of government recognition and support. Malaisse & Parent (1980, 17) state that in Zaire "the degradation of the rainforests and their transformation into bushy arboreal savannah, which is occurring presently at an accelerated rate, will be accompanied by a noticeable reduction in the number of species of edible caterpillars" (translation). Similarly, the production of *ahuahutle* (Mexican caviar) and *axayacatl*, which are composed of the eggs and the nymphs and adults, respectively, of several species of aquatic Hemiptera, is much reduced as the result of land-filling and lake pollution as Mexico City has expanded (J. R. E. de Conconi, personal communication, 1986). These hemipterans formerly bred in tremendous numbers and for centuries were the basis of aquatic farming.

Relative to the need for government recognition, the reduction of insects to a relatively minor role in the diet of the Pedi (South Africa) was rated by Quin (1959) among the factors, both accultural and ecological, that had by then placed the Pedi between bare existence and starvation. Quin (p. 275) concluded that "the recognition and encouragement of their traditional foods and feeding habits could be the means of alleviating, and perhaps even solving, the great problem of malnutrition and disease among these people." Meyer-Rochow (1973, 676) came to a similar conclusion: "If the new Papua and New Guinea government can be persuaded not to accept the European attitude toward insects as human food, it would act to the benefit of vast numbers of natives. Instead of wasting resources in destroying certain insects often regarded as crop pests, the insects themselves should be used. Quite often they represent a higher nutritional value than the vegetable that they have been eating. . . ." Of the three Melanesian groups studied by Meyer-Rochow, the Chauve who inhabit the central New Guinea highlands, and among whom malnutrition and starvation are fairly widespread, ate the greatest variety of insects.

It is interesting, however, that the Kiriwinians who live on the Trobriand Islands and who raise pigs and chickens, harvest yam, taro, sweet potato, and coconut "and live on a balanced diet of fruits, vegetables, fish and meat" also eat a wide variety of insects. This again makes the point mentioned earlier that in general, indigenous peoples eat insects not because they have to, but because they like them. Gope & Prasad (1983) conducted proximate analyses on eight of the nearly 20 species found in a preliminary survey to be commonly used as food by the various tribes in Manipur State in northeastern India. They conclude that insects represent the cheapest source of animal protein in Manipur and their consumption should be encouraged because many of the people cannot afford fish or animal flesh. Dufour (1987, 395) notes that "the widespread practice of entomophagy warrants further attention in any evaluation of availability of protein resources" in the Amazonian ecosystem. Government recognition of these traditional insect foods would help provide respectability and would provide legitimacy for the research and extension needed to enhance their use.

Despite the erosive influences of acculturation and environmental destruction, food insect use continues to be widespread, as shown in the following statements by individuals in a position to know the current situation in various countries. In a personal communication, K. Ruddle (1987), now based in Japan (National Museum of Ethnology, Osaka) and involved primarily in Third World aquaculture and coastal fisheries research, states: "Insects are widely consumed here in Asia. Despite great modernization and the like they are widely appreciated here in Japan, particularly in



Tortillas served in a restaurant in Mexico City, with white agave worms (gusano blanco del maguey), larvae of the skipper butterfly, Aegiale hesperiaris. *Courtesy of L. B. Huebner, University of Wisconsin, Department of Entomology.*

Tortillas served in a restaurant in Mexico City, with red agave worms (gusano rosado del maguey), larvae of the cossid, Xyleutes redtenbachi. *Courtesy of L. B. Huebner, University of Wisconsin, Department of Entomology.*

rural areas—often as a snack to accompany alcohol. Insect consumption rates are high in Southeast Asia, particularly among the Thais, Laotians (the market in Vientiane is full of stalls with edible insects), Burmese, and Kampucheans. . . . The Malawians [of Africa] consume plenty of a wide variety of insects." In Ruddle's opinion, "Insects can make a potentially enormous contribution to solving problems of human nutrition." He has also considered attempting to produce insects as low-cost feed for pond fish on small farms.

R. J. Phelps, a U.S.-trained medical entomologist at the University of Zimbabwe, states (personal communication, 1987), relative to possible efforts toward greater development of food insect resources: "The time may well be ripe in this country. . . . Certainly, dried caterpillars of saturniid moths are sold on the local market, and consumption of termites, locusts and tettigoniids by the vast majority of the population continues in spite of the presence of western cultures. In fact, many people of European background eat termites here, although not in the quantities that the local people do."

G. S. Ibingira, former ambassador to the United Nations from Uganda, writes (personal communication, 1987): "The more I see both people and chickens getting 'crazy' over these insects when they are in season here, the more I remain convinced that we are on to something of great significance for many African societies. . . . Specifically, I particularly commend [for development] two insects: winged termites and cone-headed grasshoppers. They are great delicacies among many tribes in Uganda and other Eastern and Central African countries." The cone-headed grasshopper referred to is probably *Ruspolia* (*=Homorocoryphus*) *nitidula* (Scopoli) (family Tettigoniidae) which occurs widely in East Africa and at least as far south as Zimbabwe (Chavunduka 1975). The grasshopper is known as *nsenene* in Uganda (Owen 1973). The introduction of electric street lights into the towns of East Africa has revolutionized *nsenene* collecting as the insects are attracted in vast numbers to the lights. Of this species in the city of Kampala, Owen wrote (p. 134), "the streets may be completely blocked to traffic by people who come in from rural areas to collect *nsenene*."

Correspondence from former Peace Corps volunteers has also yielded valuable information showing continued wide use of insects, including in a number of countries for which there has been either no published record or none in the past half century.

Nutritional Importance of Insects in the Developing World

Despite the benefits reaped from the "green revolution" and the fact that a number of Third World countries that were formerly grain importers are now net exporters, protein-energy malnutrition continues to plague the poor in much of the developing world. Many cannot afford more than the barest subsistence diet. Key nutrients also include a number of vitamins and minerals, deficiencies of which occur routinely. It is important to note that insects are high in protein, high in energy, and high in various vitamins and minerals.

Mexico. In Mexico, the emphasis in nutritional studies has been on protein content and quality, with proximate analyses for approximately 65 insect species and amino acid profiles for 11. Crude protein content was above 50% in 40 species on a dry weight basis (de Conconi et al. 1984) and ranged as high as 82%. Digestible protein ranged as high as 64% (de Conconi 1982, 101), being between 78 and 99% of crude protein. In common with results obtained on insects elsewhere by biochemical analysis, Mexican insects are low in methionine, cysteine, and tryptophan (see later under feeding trial results, however). Hemipterans and ants (Hymenoptera) are relatively high, however, in methionine and the former in tryptophan compared with many insects.

Corn, a high-energy grain, has a caloric value of 320–340 kcal/100 g. By comparison, caloric values for nine Mexican insect species (calculated from proximate analyses by de Conconi et al. [1981]) ranged from 377 kcal/100 g of insect material (dry weight) for *ahuahutle* to 516 and 513 kcal/100 g, respectively, for larvae of *Xyleutes redtenbachi* Hamm and *Laniifera cyclades* Druce, two species of moth. Cravioto et al. (1951) analyzed mineral and vitamin content of several Mexican insects and found *axayacatl* a particularly rich source of iron and riboflavin—100 g of insect providing 267% and 119%, respectively, of the daily allowances recommended by the Food and Agriculture Organization.

Angola. Oliveira et al. (1976) conducted analyses of the nutritional value of four species cooked according to traditional methods in central Angola (Table 1):

Macrotermes subhyalinus (Rambur) (Isoptera: Termitidae) is a termite with wide distribution; it is common in the north and east of Angola. The reproductive form or alate, known as *juinguna*, is consumed after the wings have been removed and the body fried in palm oil.

Imbrasia ertli Rebel (Lepidoptera: Saturniidae) larvae feed on the leaves of *Acacia* and two other host species in tropical rain and open forest of the Ethiopian faunal region. The mature larva is approximately 8 cm long and known as *engu* (plural, *ovungu*). After removing the viscera, the larvae are either cooked in water, roasted, or sun-dried. Salt is added for further flavoring.

Usta terpsichore (Massen and Weymer) (Lepidoptera: Saturniidae) larvae are common in Angola and widely distributed in the Ethiopian region. They feed on several species of plants and are known locally as *olumbalala* (plural, *olombalala*). The fully grown larva is about 8 cm long and is prepared for eating in a fashion similar to *Imbrasia ertli*.

Rhynchophorus phoenicis (F.) (Coleoptera: Curculionidae) is a weevil that is an important palm pest in Africa, mainly affecting the oil palm (*Elaeis guineensis* Jacquin). The local name of the *apod* larvae, which are about 3 cm long, is *maghogho*. After first incising the body, the larva is fried whole in oil.

The high fat content of *Macrotermes subhyalinus* and *Rhynchophorus phoenicis* is reflected in their high energy values, 613 and 561 kcal/100 g, respectively (Table 1). *Usta terpsichore* is a rich source of iron, copper, zinc, thiamine, and riboflavin; 100 g of cooked insect provides more than 100% of the daily requirement of each of these minerals and vitamins. It is also relatively high in calcium compared with many insects, and in phosphorus. *Macrotermes subhyalinus* is high in magnesium and copper, and *Rhynchophorus phoenicis* is high in zinc, thiamine, and riboflavin; 100 g of insect in each case provides more than the daily requirement.

Zaire. In Zaire, Malaisse & Parent (1980) conducted nutritional analyses on 23 of the 35 species of caterpillar found to be used as food in the Kipushi Territory north of Lubumbashi. The caterpillars are roasted on heated sheet metal, cooked in boiling water, or fried in oil. Salt or possibly red peppers are sometimes added. When part of a harvest is to be preserved, the caterpillars are either smoked or boiled in salt water, drained, and dried.

For analysis of nutritional value, caterpillars were prepared in a manner identical to that which precedes their culinary preparation, then dehydrated. Crude protein content averaged 64%, ranging from 46 to 80%; kcal/100 g of dry weight averaged 457, ranging from 397 to 504. Most species proved a good source of phosphorus. They are also an excellent source of iron: On average, for 21 species, 100 g provides 335% of the daily requirement. One species of unidentified Limacodidae was, for an insect, unusually high in calcium, containing 1.6 g/100 g of insect. The samples analyzed included 17 species of Saturniidae, one of Limacodidae, and five of Notodontidae.

South Africa. In South Africa, the food insects of the Pedi are usually served as a relish with their cereal meal porridges and are what provides the porridge with some flavor. In preparing the relishes, the insects are used fresh and whole except for the caterpillar *Gonimbrasia belina* and grasshoppers, some of which are cured when supplies are plentiful. The only ingredients added during preparation are salt and water. The insects are stewed dry, then roasted crisp (except for *Bombycomorpha pallida* Distant and *Cirina forda* (Westwood), which are not roasted). The protein content and calories in these relish servings, as found by Quin (1959), are shown in Table 2. Quin noted 13 species, and other investigators have reported at least a dozen additional species used as food in various parts of South Africa.

Protein Quality of Insects Fed to Rats

Finke et al. (1987b) used rat-feeding trials to evaluate the protein quality of Mormon cricket meal, *Anabrus simplex* Haldeman (Or-

Table 1. Proximate, mineral, and vitamin analyses of insects used as food in Angola (percentages of daily requirements/100 g of insect as consumed) (Oliveira et al. 1976)[a]

Nutrient	Reference man (FAO 1973)	*Macrotermes subhyalinus*[b]	*Imbrasia ertli*[c]	*Usta terpsichore*[c]	*Rhynchophorus phoenicis*[d]
Energy	2850 kcal	21.5%	13.2%	13.0%	19.7%
Protein[e]	37 g	38.4	26.3	76.3	18.1
Calcium	1 g	4.0	5.0	35.5	18.6
Phosphorus	1 g	43.8	54.6	69.5	31.4
Magnesium	400 mg	104.2	57.8	13.5	7.5
Iron	18 mg	41.7	10.6	197.2	72.8
Copper	2 mg	680.0	70.0	120.0	70.0
Zinc	15 mg	—	—	153.3	158.0
Thiamine	1.5 mg	8.7	—	244.7	201.3
Riboflavin	1.7 mg	67.4	—	112.2	131.7
Niacin	20 mg	47.7	—	26.0	38.9

[a]From Ecology of Food and Nutrition 5: 96, 1976, Gordon and Breach Science Publishers Ltd., Great Britain.
[b]Termite (Isoptera).
[c]Saturnid (silkmoth) caterpillar (Lepidoptera).
[d]Palm weevil (Coleoptera).
[e]Protein percentages based on biological values, not crude protein.

thoptera: Tettigoniidae) (MCM) alone, when mixed with a complementary protein source, and when supplemented with methionine. Corn gluten meal (CGM) was selected as the complementary protein source because of its high methionine content. A four-parameter logistic model (Finke et al. 1987a) was used to describe the dose–response curves, and protein quality was evaluated by comparing the nitrogen intake required to achieve identical levels of performance. When used for maximum weight gain the order of ranking was MCM plus methionine, MCM–CGM, MCM, and CGM. The ranking of the protein sources when used for weight maintenance was MCM, MCM plus methionine, MCM–CGM, and CGM. The results show Mormon cricket meal to be a good-quality protein source with methionine being the first-limiting amino acid when used for growth rather than maintenance.

Finke et al. (In press) compared MCM, house cricket meal, *Acheta domesticus* (L.) (Orthoptera: Gryllidae) (HCM), and eastern tent caterpillar meal, *Malacosoma americanum* (F.) (Lepidoptera: Lasiocampidae) (TCM) to lactalbumin and isolated soy protein fed to weanling rats. The four-parameter logistic model (Finke et al. 1987a) was used to describe the dose–response curves, and protein quality was determined by comparing the curves at various performance levels. When compared with lactalbumin, the three insect protein sources and soy protein exhibited an inferior ability to promote maintenance or maximum growth. MCM was equal to and HCM was slightly superior to soy protein, however, at all levels of intake. The ability of TCM protein to promote growth was poor, but toxicity rather than protein quality may have been responsible.

From amino acid analyses cricket protein appears low in methionine and cysteine for rats, and by inference for humans and swine. Supplemented with methionine, however, these two cricket species have an almost ideal amino acid pattern. In comparing these results with those of Phelps et al. (1975) in Zimbabwe, it appears that cricket proteins are superior to termite protein in rat diets. As the termites were dried at 60°C and lightly fried to simulate their use as food in Africa, it is possible, however, that the high temperature may have altered the quality of the termite protein by decreasing lysine availability.

Protein Quality of Insects Fed to Poultry

Amino acid analyses indicate that insect proteins, compared with soy protein, are low in methionine-cysteine, arginine, and tryptophan if used in chick rations. Feeding trials have shown, however, that the quality of insect proteins is better than indicated by amino acid analysis. Several investigators have conducted studies on fly pupae or larvae as a high-protein source for poultry, generally with the aim of using the fly larvae to recycle animal wastes. The crude protein content of fly larvae and pupae ranges from about 53 to 63% on a dry weight basis compared with 44–48% in soybean meal.

Biochemical analyses backed by chick feeding trials have been conducted on the house fly, *Musca domestica* L., pupae produced in poultry manure (Teotia & Miller 1973, 1974); in CSMA (Chemical Specialties Manufacturers Association) fly medium (Calvert et al.

Table 2. Protein and energy content of insect relishes (per serving) used by the Pedi of South Africa (adapted from Quin 1959)[a]

Taxon	Stage consumed	Vernacular name	Weight of serving, g	Protein, g/serving	Kcal/ serving
Coleoptera					
Buprestidae					
Sternocera orissa Buquet	Adult	*lebitsi-kgoma*	57	16.9	96
Curculionidae					
Polycleis equestris Boheman	Adult	*kgakgaripane*	57	22.3	104
Polycleis plumbeus Guerin	Adult	*kgakgaripane*	—	—	—
Hymenoptera					
Formicidae					
Carebara vidua Smith	Flying sexual	*dintlhwa makhura* (female) *dintlhwa bogwale* (male)	28	2.1	68
Lepidoptera					
Lasiocampidae					
Bombycomorpha pallida Distant	Larva	*ngwana mamahlwehlwana*	114	17.2	159
Gonometa postica Walker	Pupa	*mmakonokono*	42	8.0	102
Saturniidae					
Cirina forda (Westwood)	Larva	*noto*	114	21.4	178
Gonimbrasia belina Westwood	Fresh larva	*notoleetsana*	114	13.5	93
	Cured larva		85	8.6	242
Gynanisa maia (Klug)	Larva	*legakgale*	57	11.7	92
Sphingidae					
Herse convolvuli (L.)	Larva	*naatla*	114	8.2	74
Orthoptera					
Acrididae					
Cyrtacanthacris septemfasciata (Serville)	Flier	*maphata-kalala*	—	—	—
Locustana pardalina (Walker)	Flier	*segongwane*	85	18.5	271
	Hind legs		8	4.4	20
Pyrgomorphidae					
Zonocerus elegans (Thunberg)	Hopper	*kodi*	42	12.4	58

[a]Adapted from Foods and Feeding Habits of the Pedi, p. 235, 1959. Witwatersrand University Press, Johannesburg.

1969); in municipal organic waste (Ocio et al. 1979); on larvae of *Musca domestica* and the blow fly, *Protophormia terraenovae* (Robineau-Desvoidy) (Calliphoridae) (Abdel-Gawaad & Brune 1979); and on larvae of the soldier fly, *Hermetia illucens* (L.) (Stratiomyidae) (Hale 1973). Similar tests have been conducted on pupae of the face fly, *Musca autumnalis* DeGeer, produced in cattle manure (Koo et al. 1980). In a series of feeding trials, Teotia & Miller (1974) adjusted the levels of corn, milo, and either soybean meal or house fly pupae so that protein levels were nearly equal. At seven weeks of age there were no significant differences in either final body weights or feed/gain ratios. In addition, an informal taste panel could not detect any differences between birds fed the control and experimental diets. Generally similar results were obtained by other investigators who incorporated fly pupae or larvae into chick diets.

During recycling, the muscid larvae convert poultry manure to a loose, crumbly texture. It is a nearly odorless substance that when dried is suitable for use as a feedstuff or soil conditioner (Miller et al. 1974). As summarized by El Boushy et al. (1985) from studies of others, moisture is reduced by 50–85%, and organic matter is reduced by 80% during digestion of manure by larvae. An attempt to develop a mass-production method based on larval recycling of poultry manure by *Musca domestica* was unsuccessful, however, mainly because of low yield and problems with moisture control, aeration, and regulation of larval density in the semi-liquid medium (Morgan & Eby 1975). Low yield of pupae may be an insurmountable problem for Diptera-based systems. Maximum yields of pupae plus larvae were estimated to be 3.2% of the fresh manure (Calvert 1977) and approximately 4% on a dry matter basis (El Boushy et al. 1985).

In parts of Asia pupae of the silkworm, *Bombyx mori* (L.) (Lepidoptera: Bombycidae), are available as a by-product of the silk industry and have been used both as human food and as a high-protein supplement for poultry. In 1971, Ichhponani & Malek reported the annual production of de-oiled silkworm pupae meal (pupal residue after oil extraction) at 20,000 metric tons in India alone. A crude protein content of 63% has been reported for silkworm pupae (74-76% for de-oiled pupae) fed to poultry (Bora & Sharma 1965, Chopra et al. 1970, Wijayasinghe & Rajaguru 1977). Landry et al. (1986) report a crude protein content of 49-58% (dry weight basis) for larvae of six North American lepidopteran species representing the families Saturniidae, Sphingidae, and Noctuidae. In chick feeding trials, weight gains and feed/gain ratios of chicks fed corn–larvae diets to three weeks of age did not differ significantly from chicks fed a conventional corn–soybean control diet.

In studies on the Mormon cricket (DeFoliart et al. 1982), proximate analysis revealed a crude protein content of 58% (dry weight basis), and amino acid analysis indicated that methionine, arginine, and tryptophan, in that order, would be limiting amino acids. In feeding trials, however, practical corn-and-cricket-based diets produced significantly better growth of broiler chicks to three weeks of age than was produced by a conventional corn–soybean-based diet supplemented with methionine.

Supplementing the corn–cricket diet with purified amino acids did not significantly increase the weight of chicks feeding on that diet over those on the unsupplemented corn–cricket diet. Finke et al. (1985), using Mormon crickets in purified diets, found that arginine and methionine are colimiting. In an eight-week chick feeding trial, however, in which Mormon crickets were incorporated into practical diets replacing soybean meal as the major protein source, there were no significant differences in weight gain or feed/gain ratios in the corn–Mormon cricket diet and the corn–soybean meal diet. All diets were formulated to meet or exceed National Research Council (1977) recommendations. In taste tests, no off-flavor was detected in the meat of broilers that had been fed Mormon crickets.

Using both semi-purified and practical diets in chick feeding trials (to three weeks of age) involving *Acheta domesticus* crickets, Nakagaki et al. (1987) found no significant differences in the final weight of chicks fed the practical experimental (corn–cricket) and reference (corn–soybean) diets. In the trials using practical diets, feed/gain ratios improved significantly, however, when diets were supplemented with both methionine and arginine but not with either alone. Feed/gain ratios in trials with the purified diets indicated that tryptophan is also limiting.

Minerals were analyzed in some of the above studies on fly pupae, silkworm pupae, and *Acheta domesticus*, but the only study on bioavailability of insect minerals to poultry appears to be that of Dashefsky et al. (1976) who found pupal phosphorus of *Musca autumnalis* highly available (92–100%) to chickens when used as a feed supplement.

Food Insects Research and Development Project

The Food Insects Research and Development Project (FIRDP) was organized at the University of Wisconsin in Madison in 1986. It is as yet little more than a set of objectives aimed at stimulating a wider awareness among food and agricultural scientists, government agencies, and the public that insects are a food resource that warrants serious investigation. The deeply rooted traditions of food insect use among many, if not most, ethnic cultures of non-European origin provide an existing base upon which to build—from the bottom up, as opposed to the usual direction of innovation from the top down.

Insects offer a number of attributes, such as high food conversion efficiency compared with conventional meat animals, use of a wide array of organic substances not efficiently used in conventional agriculture, and producibility without the need for additional arable land, irrigation, fertilizers, herbicides, pesticides, or expensive equipment, that make their use highly compatible with the principles of low-input sustainable agriculture. Further, because many important food insects are also important pest insects, it may be possible in some cases to incorporate food insect harvest as part of pest management programs, thus helping to reduce the need for insecticides for crop protection.

The project's resources include a food insects laboratory located in the Department of Entomology and approximately 25 faculty and research staff members in various university departments who are kept informed as to project objectives and developments and are available as advisers in their areas of expertise. They are also potential collaborators when and as funding opportunities arise. This informal liaison is maintained with researchers in the Department of Entomology, Nutritional Sciences, Food Science, Food Microbiology and Toxicology, Animal Sciences, Poultry Science, and Agricultural Engineering, among others, and with the university's Office of International Agricultural Programs. Creation of FIRDP as a framework to foster easy interdisciplinary communication among University of Wisconsin scientists was seen as a step in establishing a broader North American voice of advocacy.

Approaches for Enhancing the Nutritional Contribution of Edible Insects

Development of a stronger global voice of advocacy by establishing better communication and mutual support among scientists and others interested in the human use of insects as food and animal feed.

Wider advocacy by informed persons will be essential to gaining wider government recognition of the nutritional importance of insect foods and their contribution to rural economies. Researchers interested in this subject have had little opportunity for the kinds of contact and intellectual cross-fertilization that are taken for granted in more widely recognized disciplines. *The Food Insects Newsletter*, begun in 1988 and internationally distributed, should help facilitate such information exchange.

A current project in support of advocacy is the development of up-to-date inventories on the use of insects as food or animal feed in each of the 40 or more countries where such use is important. This is being accomplished by literature search and by soliciting unpublished information on current use from locally knowledgeable persons, including entomologists who work in developing nations and returned Peace Corps volunteers. The bibliography upon which the inventories are based currently stands at nearly 700 titles. The addition of literature updating the taxonomy or containing relevant biological information will increase this total to more than 2,000 titles.

Advocacy of stronger support for scientists and others from developing nations who are interested in maximizing the nutritional contribution of their indigenous food insect resources.

In attempting to accurately estimate the role and potential role of food insects as part of a national nutritional base, a great deal of new and resynthesized information will be needed. One of the urgent initial needs in most countries is for stronger taxonomic input. Accurate taxonomic identification is the essential starting point in gathering enough biological information to reveal desired lines of research and clues to simple species-specific innovations for improving harvest efficiency. Of utmost importance is information about the seasonal occurrence of each species in relation to the availability of other affordable foods offering similar specific nutrient value.

Food insect harvest methods are, for the most part, as primitive as they were generations ago. Some species will continue to be obtainable only by labor-intensive collecting; the supply of others could be significantly increased through simple innovations in small-scale harvest or culture. Still others will prove subject to more sophisticated methods of large-scale harvest from nature or have characteristics that make them excellent candidates for development of controlled mass-production, thus extending their period of seasonal availability. Whatever the approach, if there is to be any, lasting change in the status quo, the main thrust must come from local scientists and institutions.

Development of economical mass-harvest methods and strategies for potential food and feed insects that are attracted to light or to chemical traps.

Numerous species of insects in all of the major orders, including many that are of food importance, are highly attracted to light. The tettigoniid grasshopper, *Ruspolia nitidula*, is one example. Winged termites are another. Huge catches of miscellaneous insects, from gnats to large beetles and moths, are not uncommon in tropical regions, and such catches could, in some areas, prove to be excellent sources of high-protein feed for pond fish or poultry. Light traps or, where there is no electricity, lantern traps represent simple technology of potentially great use in the harvest of food and feed insects.

A current cooperative project in Nepal is aimed at harvesting the large cricket, *Brachytrupes portentosus* (Lichtenstein) (Orthoptera: Gryllidae), a crop pest that is attracted to light traps by the "bagfull" per light trap night (F. Neupane, Institute of Agriculture and Animal Science, Rampur, personal communication, 1986). The catches also include four smaller cricket species and a large scarabaeid beetle. The goal is to use the crickets and probably also the beetles as a high-protein replacement for the expensive fish meal now imported for poultry production. Crickets and tettigoniids, as detailed earlier, are among a variety of insect species that have been shown equivalent or superior to soybean meal as a high-protein source for chick growth (DeFoliart et al. 1982, Finke et al. 1985, Nakagaki et al. 1987).

This Nepal project, in addition to its immediate objective, has broader implications. *Brachytrupes portentosus* is widely sold as human food in Burma (Ghosh 1924), Southeast Asia (Nguyen-Cong-Tien 1928), and Indonesia (Bodenheimer 1951, 236). A related cricket, *Brachytrupes membranaceus* Drury, also a crop pest, is considered a particular delicacy in Uganda (Owen 1973) and in other parts of eastern Africa as far south as Zimbabwe (Gelfand 1971, Chavunduka 1975). What is learned about harvesting these crickets in Nepal could help facilitate their availability in much wider areas of Asia and Africa.

Some insects are attracted in large numbers to food or pheromone baits and lures. A well-known example is the Japanese beetle, *Popillia japonica* Newman (Coleoptera: Scarabaeidae), a congeneric species of which, *Popillia femoralis* Klug, is an important food insect in Cameroon. Japanese beetle traps can hold 4,000–5,000 beetles, and when beetles are numerous such as they were during the summer of 1987, the traps fill to overflowing in less than 24 hours (M. Klein, USDA, Wooster, Ohio, personal communication, 1987). Commercial Japanese beetle baits in this country contain both floral and sex lures. They are expensive, costing $2 to $3 for enough bait to operate a trap for about six weeks. According to Klein, both the sex lure and the floral (or feeding) lure in these baits show cross-activity for other *Popillia* species in Korea and Okinawa. When purchased in bulk, either the sex or the floral lure could be made available at only about 10 cents for enough homemade bait to operate a trap for six weeks. The traps are simple and can be made from inexpensive materials, thus representing easily transferable technology.

Development of controlled mass-production of food insects indigenous to developing countries.

It is likely that many of the insects that are now candidates for improved harvest will become candidates for controlled year-round production as more is learned about their biology that is relevant to sustained culture. Saturniid caterpillars, for which there is great demand in central and southern Africa, appear to be particularly promising candidates for controlled mass-production using simple methods of rearing. A project in Mexico under the direction of J. R. E. de Conconi is aimed at developing a mass-rearing method for the "white agave worm," the caterpillar of *Aegiale hesperiaris* Kirby (Lepidoptera: Megathymidae). The larva is considered a delicacy throughout Mexico and is served in the finest restaurants. It was formerly an item of export but is now relatively scarce because of over-collection. Problems in rearing involve failure to induce adequate mating and oviposition in captivity.

Another current project is related to the introduction of silkworm culture into southwestern Colombia several years ago as a diversification for small coffee farms (National Federation of Colombian Coffee Producers 1984). It is also spreading as a silk products cottage industry under the initiative of a local women's cooperative (P. Conway, Wisconsin Farmers Foundation, Inc.; The

As Brachytrupes *is a crop pest, this parasitic wasp is considered beneficial; for* Brachytrupes *as food or animal feed, the wasp becomes a pesst insect, reducing the potential harvest.*

Colombia Exchange, Milwaukee, Wis., personal communication, 1987). In Colombia, as in much of the developing world, the lack of inexpensive, high-protein feed sources is a major problem confronting poultry, swine, and pond fish producers, and the pupal by-product from this cottage industry could represent a major new resource for the farmers of the region, either for local use or for export. Pupal dry weight averaged 0.33 g in a sample sent from Colombia. At the expected production rate of 1.2 million to 1.44 million silkworm cocoons per hectare per year, the average yield of pupal by-product (about 63% protein) would be nearly half a metric ton (0.40–0.48) per hectare of mulberry bushes. In addition, the silkworm frass and other residues can be used as fertilizer in the mulberry plots or possibly, as is done in China, for pond fish food (Hyde 1984).

Development of insect recycling systems for converting organic wastes and under-used substances into high-protein feed supplements for poultry, swine, and fish production.

Practically every substance of organic origin, including cellulose, is fed upon by one or more species of insect, so it is only a matter of time before successful recycling systems will be developed. In addition to efforts to use fly larvae in recycling animal manures as mentioned earlier, G. Lardé (1987) is attempting to recycle coffee pulp waste in El Salvador using larvae of *Hermetia illucens* (L.) (Diptera: Stratiomyidae), *Ornidia obesa* (F.) (Diptera: Syrphidae), and *Musca domestica*. The cricket, *Acheta domesticus*, an omnivore that takes its food and water ad lib, appears an excellent candidate for recycling under-used agricultural organic matter. In screening tests (B. J. Nakagaki, University of Wisconsin, unpublished data) with various ratios of dried poultry (battery) manure and ground corn, crickets showed good growth on a manure/corn ratio of 4:1, supplemented with white grease to help raise the energy level of the diet. Assuming no cost for the poultry manure and $80 per ton for corn, the cost of this diet is only about 5 cents per kg of live crickets produced or 15 cents per kg of dry cricket meal containing 62% crude protein.

Even less expensive cricket diets might be possible if banana, pineapple, or other agricultural wastes widely available in the developing world can be substituted for corn as the energy source. Also, as a substitute for poultry manure, high-protein (20% or more) leaf and vine meals from certain agriculturally under-used tropical and arid-adapted plants (National Academy of Sciences 1979) might prove suitable as nitrogen sources for crickets. Exploratory research in this direction in some cases yielded high rates of survival but in all cases slow growth. Before further progress can be made in using various organic wastes that may be available within a region, a study is needed to determine cricket dietary requirements more precisely.

Research in Ohio by Schurr (1972, 1976; K. Schurr, personal communication, 1987) indicates that it should be economically feasible to harvest the biomass from terminal sewage lagoons as feed for animals. The high nutritional quality of the biomass comes mostly from aquatic insects at the top of the food chain in properly loaded terminal lagoons.

Development of mass-harvest strategies for migratory locusts, grasshoppers, the Mormon cricket, and other major pest species that form destructive aggregations that move en masse in nature.

Locusts, grasshoppers, or both are included in the diet of almost every country for which any published record exists. A quite modest attempt to combine food harvest with grasshopper control, without sophisticated technological input, was described in the Nov. 13, 1983, edition (p. 15) of *The National Review*, a newspaper published in Bangkok, Thailand. In a campaign launched by local officials in the Province of Prachinburi because attempts at control had been unsuccessful, villagers collected more than 10 tons of the pest grasshoppers. The article stated, "Fried and crispy grasshoppers are, according to many people, delicious snacks and many food shops in Prachinburi and other provinces [serve] them for their customers. For beer and whiskey drinkers, fried grasshoppers are marvelous. Grasshoppers have now become one of the exporting items for Prachinburi which has a long list of orders from traders who buy them at six baht a kilo. . . . Grasshoppers have become a favorite dish for many people who said the cooking method is also simple—merely taking out their wings, heads and tails and cleaning them before throwing them into the frying pan."

With more sophisticated organization, planning, and in some cases, technology, similar dual-benefit strategies could be considered for such targets as the desert locust, *Schistocerca gregaria*, and other migratory locusts that occur in Africa, Asia, and South America (see Walsh 1986 for a recent summary of locust control operations in Africa). A single swarm of *Schistocerca* in Africa can number up to 10 billion individuals (Gunn 1960); at one third of a million to the metric ton, a swarm of this size weighs 30,000 tons. The fact that these insects move en masse, first as "hopper bands" and later as flying swarms, suggests possibilities for developing dual-benefit strategies that would include locust harvest for food, feed, or fertilizer as well as for crop protection.

The Mormon cricket is a potential U.S. candidate for opportunistic mass-harvest of wild populations. It is a large (approximately 1 g dry weight) wingless insect that occurs throughout the western United States and travels in large bands. It has been a target of USDA pest control operations since before the turn of the century.

Although now reduced in numbers in most areas, it might be possible to manage it as a valuable poultry and meat animal feed resource, with the added benefit of reducing the need for insecticides on western rangelands. At cricket densities of 10–20/m^2, a 1-km^2 band totals 11–22 metric tons of high-protein (58%) powder (DeFoliart et al. 1982). As noted earlier, it is an excellent protein source for broiler chickens. The wholesale value of harvested crickets in a band of the above size, based on 1981 prices for corn and soybean meal, would have ranged up to $6,600 (DeFoliart et al. 1982).

Education of the American public about the palatability and nutritional quality of insects and their importance as food in much of the developing world.

Insects are certainly not needed now as a source of nutrition in the United States. Insects, along with many other plant and animal foods of the primitive gatherer, became unnecessary as agriculture became more stable and increasingly capable of ensuring a plentiful and well-balanced diet in the western world. The need for reshaping the American attitude is dictated by the fact that it exerts a negative influence on the respectability of insects as food in regions where this resource can contribute significantly to reducing malnutrition. Americans need to become aware of the fact that insects are an important source of nutrition in many populations in the Third World, and, with scientific input, might make a significantly greater contribution toward helping to solve problems of human malnutrition.

A change in the attitude of Americans toward insects *as* food might be followed by a change in attitude toward insects *in* food. Gorham (1979) has rightly pointed out that insect parts that find their way into foods are of two kinds, and one kind is much more objectionable than the other. Gorham divided them into "production insects," such as aphids and other herbivores associated with the growing crop, and "processing insects," such as ants, cockroaches, flies, and stored-product insects. The latter component may be involved as disseminators of microbial pathogens or as dermal or ingestant allergens. But while it is the processing insects that may present a health hazard, it is the harmless herbivores that are the target of increased insecticide use designed to produce unblemished fruits and vegetables. Pimental et al. (1977) have shown the cost to our environment, energy supplies, food purity, and pocketbooks of this emphasis on cosmetic appearance. If we must choose between more production insects and more insecticides in our food, there is no comparison in the nutritional value of the two: The insects are much to be preferred.

Individuals in public institutions can play an important educational role. The Live Insect Zoo at the Cincinnati Public Zoo, for example, has included exhibits on insects as food. On three recent occasions samples were served: crickets; larvae of the greater wax moth, *Galleria mellonella* (L.); and most recently, young cicadas during the much-publicized 1987 emergence of these insects. The exhibits of the Live Insect Zoo are seen by more than one million visitors annually. The exhibits and the samples have been well received (J. S. Carter, Cincinnati Public Zoo, personal communication, 1987).

Relative to FIRDP's educational objectives, four members of the University of Wisconsin's Department of Agricultural Journalism are routinely kept informed of project developments, thus helping to ensure the timely release of newsworthy information. Other educational efforts to date include a one-credit course, Use of Insects as Food and Animal Feed, initially offered at the university during the spring 1988 semester—possibly the first time a course has been offered on this subject.

Development, as small-farm enterprises, of controlled mass-production methods for certain insects as snack items on the U.S. market.

Only a small proportion of Americans indulge in the culinary delights offered by snails, yet escargot sales amount to more than $300 million each year in the United States (*News Tribune and Herald*, Duluth, Minn., Feb. 8, 1987). Given the proper publicity, similar markets might be created for certain edible insects, thus opening the door to a whole new class of low-input specialty crops for small farms dedicated to the principles of sustainable agriculture.

From the standpoint of palatability, at least three insect species that are routinely produced in the U.S. would be highly suitable for marketing as "fancy foods." These are honey bee brood (larvae and pupae of *Apis mellifera* L.), *Acheta domesticus* nymphs, and *Galleria mellonella* larvae. All three are among the insects on which Taylor & Carter (1976) based most of the gourmet recipes in their *Original Guide to Insect Cookery*. As opposed to the rationale for enhanced food insect use in the rural Third World, because of high labor costs insect snacks and hors d'oeuvres in the U.S. would probably be priced as luxury foods and advertised for the upscale diner.

Honey Bee Brood. The pupal fraction of honey bee brood is rich in vitamins A and D and of excellent flavor (Hocking & Matsumura 1960). When brood was prepared by either shallow frying in butter or deep-fat frying in vegetable cooking fat and tested by a Canadian panel (Hocking & Matsumura 1960, 114), "Most reactions were favourable and some were eulogistic; initial prejudice proved easier to overcome than we had expected. When the tasters were asked to compare the material to some more familiar food, those most commonly mentioned were walnuts, pork crackling, sunflower seeds, and rice crispies."

In a later, larger taste test, deep-fat fried, butter fried, and baked preparations were highly rated while smoked, pickled, and brandied were much less preferred. The authors noted that the pupae go very well indeed with crackers and cocktails. In a Saturday Evening Post article (10 Mar., 1956) entitled "My Adventures in Eating," which amounted to a four-star review of the Akahane, a Tokyo restaurant, Joseph Alsop stated that he very much enjoyed the appetizer of fried bees, the flavor being "halfway between pork crackling and wild honey."

Honey bees are associated in the public mind with such pleasing activities as flower visiting, pollination, and honey production, and they probably have the best public image worldwide of any insect species. Because of this, honey bees could be a valuable asset in changing U.S. attitudes toward insects as food. Canned "young bees" costing more than $1.00 an ounce (28 g) were formerly imported from Japan, but brood has not been harvested on a large scale as a food product in this country.

We are attempting to demonstrate the biological feasibility of drone brood harvest and that, given publicity to create a greater market demand, American beekeepers could more than double their income per colony per year by going into dual drone brood and honey production. No more environmentally harmonious food production system can be imagined. Unfortunately, introduction of the Varroa mite into the United States has made the future of this project somewhat uncertain.

Acheta Nymphs. Taylor & Carter (1976) describe 24 recipes that use crickets: tempura cricket with vegetables, cricket seaweed salad, Bombay curry, Punjab broth, cricket-on-the-hearth bread, confetti salad, creole pilaf, hot cricket–avocado delight, chocolate chirpies, jumping melon salad, pizza hopper, cricket pot pie, crickets and mushrooms, chirping stuffed avocados, cricket Louis, jumping jubilee (prepared over flaming brandy), cricket India, cricket patties Claremont, John the Baptist bread, eggs en cocotte, Indonesian hoppers, cricket crisps, cricket rumaki, and stuffed cherry tomatoes. "Fishin' crickets" (*Acheta domesticus*) are produced and sold by a number of wholesalers in the United States for about $14 per pound (454 g). This is the approximate live weight of 1,000 8th-instar cricket nymphs, the stage that would be desired for marketing as a novelty food. We are attempting to develop a low-input, mass-production system that would allow a self-employed individual, with little or no additional labor and an initial equipment investment of less than $10,000, to profitably produce at least five metric tons of nymphs each year at a per-pound wholesale price appreciably lower than $14. The product would be suitable and easily cost competitive as a snack food and for inclusion in dishes such as those described by Taylor and Carter.

***Galleria* Larvae.** The larvae of the greater wax moth are also expensive to produce but are of gourmet food interest because of their extraordinary palatability. Taylor & Carter (1976, 135) state that "They are our favorite insect. They are thin-skinned, tender, and succulent. . . . When dropped into hot vegetable oil, the larvae immediately swell, elongate, and then burst. . . . Anyone who enjoys the flavor of potato chips, corn puffs, or the like would delight in the taste of fried wax moth larvae." With gourmet outlets and clubs and trendier restaurants flourishing (Anonymous 1980; Hamlin 1985), wax moths could be produced commercially as an expensive item for these markets. Given a choice, New York diners looking for adventure and willing to pay $22 for half a roasted free-range chicken accompanied by a large pile of shoestring potatoes might well prefer a smaller pile of fried *Galleria* at the same price.

Conduct extensive studies on the food quality and safety of selected insects.

In-depth studies are needed on the composition and dietary quality of minerals, vitamins, lipids, and fiber in selected food insects. There have been numerous biochemical analyses, but few studies on bioavailability and other aspects of metabolic functioning. Lipid studies, for example, should include not only determination of total fat content (% dry weight), but the content of cholesterol, triglyceride, and phospholipids; fatty acid profiles; and determination of these parameters in relation to different feeding regimens. In some situations, studies may be needed on the hazards posed by certain insects as ingestant or other allergens, as sequesterers of plant toxins, or as carriers of infectious helminths, *Salmonella*, or other microbiological agents. Where desirable, food chemists and engineers should be able to develop processing procedures that extend storage life or improve nutritional quality, shape, texture, or flavor, thereby increasing attractiveness to a broader range of consumers.

Insects as food for long-term space flight.

Among possible foods for long-term space travel, the National Aeronautics and Space Administration has considered insects to the extent that it contracted for a report on their general use and nutritional value as food (Dufour 1981). A major requirement of all life support systems in space is that they be compact and light weight. An overriding problem, according to University of Wisconsin space farming researcher, T. W. Tibbitts (personal communication, 1987), is how to reduce the quantity of waste materials to a minimum because they cannot be merely jettisoned in space. Anything that cannot be recycled must be returned to earth. This is where insects with a recycling capability become of interest. Kok (1983) proposed a closed system for space based on a small beetle, *Stegobium paniceum* (L.), although there is as yet no information on the nutritional quality of this insect. Possibly, however, the glamour of using insects as food in space may be helpful in some quarters in promoting more research on their use as food here on Earth. ■

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