Insects as a Source of Protein[1,2]

By G. R. DeFoliart[3]

C. F. Hodge (1911) calculated that a pair of house flies beginning operations in April could produce enough flies, if all survived, to cover the earth 47 feet deep by August. This, of course, is an ecological absurdity but it does convey some idea of the tremendous reproductive potential of some insects. If one can reverse for a moment the usual focus on insects as enemies of man, Hodge's layer of flies represents an impressive pile of animal protein.

Any public suggestion at this time that insects be used directly as food for humans in this country or in any other industrial culture would be met with repugnance. As pointed out by Ruddle (1973) many people regard entomophagy as either a curiosity or a relict of barbarism. The main immediate potential of insects therefore appears to lie in their recycling of waste materials into protein-rich feeds for other animals that are more acceptable as human food—such as poultry, fish, and livestock.

Pre-industrial cultures make wide use of insects as food, and although the insects form a small part of the bulk of the diet, they are important in compensating for the general deficiency in animal proteins, fats, and calories that occurs among marginal societies in the tropics. Much of the available information has been obtained as a rather cursory part of anthropological studies and the literature is widely scattered, the only comprehensive summary being that by Bodenheimer (1951). In one of the more recent studies, Ruddle (1973) observed that the Yukpa Indians of eastern Colombia utilize at least 25 species of insects representing 22 genera and 7 orders, and these are utilized not only during emergency periods but as a complementary food source at regular seasons during the year.

Quality and Quantity of Insect Protein

Table 1 shows the results of analyses of house fly pupae by 2 research groups, Calvert et al. (1969) and Teotia and Miller (1974). Both groups were interested in determining whether biodegradation of poultry manure by the larvae would help reduce the pollution problem posed by disposal of the manure, and, secondly, whether the resulting pupae would contain sufficient nutritive value to be substituted for soybean meal in the ration of growing chicks. The pupae were found to be high in protein—above 60% based on total nitrogen—and they contained a substantial amount of fat. Teotia and Miller found the metabolizable energy value of pupae to be higher than that of soybean meal, slightly lower than that of fish meal, and 4–5 times higher than that of the digested manure. Analyses of amino acids also indicated that the protein is of good quality, comparable to bone or fish meal and superior to soybean oil meal. Calvert et al. found 17 amino acids, Teotia and Miller 16, including a good supply of all of the limiting amino acids. In an analysis of pupal fat, Calvert et al. found a fatty acid pattern resembling that of some fish oils, while Teotia and Miller determined mineral content and found the pupae a good source of minerals, including phosphorus and calcium.

A number of feeding trials have been conducted by the above investigators in which dried fly pupae were substituted for all or part of the protein source in chick rations. In a trial in which pupae were substituted for the soybean oil meal in the diet of chicks from 1 day to 4 weeks of age, there was no significant difference in weight gain, food consumption, or food conversion between chicks fed pupae and chicks fed a fully balanced ration (Teotia and Miller 1974). When chicks were fed an experimental diet through the 7th week of age in which pupae replaced all other protein including fish meal and meat and bone meal, again there was no significant difference in gain, food consumption, or conversion, although the chicks fed pupae gained slightly less and consumed less feed than the chicks on the control diet (Teotia and Miller 1973a). No trace minerals or B vitamins were added to the above rations containing pupae. Calvert et al. (1969) obtained results similar to those in the above tests in feeding trials with chicks up to 2 weeks of age. Teotia and Miller (1973a) reported finding no adverse effect on carcass quality or taste of birds fed the pupal diet.

Termites are among the insects that have been used most extensively as human food. They are not only high in protein (Table 1) but are rich in fat and, therefore, have a very high calorie value, 561 cal/100 g of dried fried termites according to Tihon (1946) and 508 cal/100 g according to Auffret and Tanguy (1947–48). Data of the latter authors revealed the protein content of the termites to be as high as that of dried salt-fish and much higher than that of beef from the same region and with a calorific value much higher than either fish or beef. Tihon's data were obtained on termites as sold in the market at Kinshasa, Zaire; they are slightly fried, aromatic and oily in appearance, and eaten as sold by the handful or converted into a colorless oil for frying. A 100-g portion of these fried termites would go a long way toward meeting the daily requirement of 65 g of protein recommended by USDA and would supply a nice ratio of protein to fat calories. One can even visualize that the chitin which constitutes 5 to 10% of the dry weight of insects would provide sufficient "roughage" to help maintain the intestinal tone. If one wanted to go "insect" all the way, there is no more energizing, easily digestible, carbohydrate source than honey, 100 g of which provides 300 cal.

There have been a number of chemical analyses of whole locusts (Table 1) with the crude protein content ranging from 50.6 to 75.3% (dry weight) based on total N. Calculating on the basis of protein N only, Korigawa (1934) found 46.6% protein in *Oxya* species. This high protein content, based on protein N only, was confirmed for 2 other locust species by Lapp and Rohmer (1937), who found 46.1% in *Nomadacris septemfasciata* and 56.7% in the males and 42.3% in the females of *Schistocerca gregaria*.

Hemsted (1947) reported that locust meal, when fed to pigs in an amount estimated to provide the ration with a protein content of 20%, imparted a fishy taint to the meat. This conclusion was based on data from only

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Table 1.—Whole body analyses of various insect species (dry weight basis).

Order, genus or species	Proximate composition (%)[a]			Reference
	Protein[b]	Fat	Ash	
House fly pupae				
Musca domestica	63.1	15.5	5.3	Calvert et al. 1969
Musca domestica	61.4	9.3	11.9	Teotia & Miller 1974
Termites				
Isoptera	36.0	44.4	6.4	Tihon 1946
Isoptera	45.6	36.2	5.0	Auffret and Tanguy 1947–48
Adult locusts				
Melanoplus	75.3	7.2	5.6	McHargue 1917
Oxya[c]	67.8	4.5	3.8	Korigawa 1934
Oxya	74.7	5.7	6.5	Ichikawa 1936
Schistocera gregaria	61.8	17.0		Das 1945
Schistocerca paranensis	51.1	18.4	4.2	Basso Stajano and Escalante Rossi 1947
Nomadacris septemfasciata	63.5	14.1	8.7	Hemsted 1947
Sphenarium	50.6		18.9	Massieu et al. 1959

[a] Data for some adult locusts are as cited by Uvarov (1966).
[b] N × 6.25.
[c] Intermediate percentage within range given.

2 pigs, but the tasters were quite unanimous in their assessment and it may be that locusts and some other insects can be fed only in limited amounts without adverse effect on flavor.

The above data, as well as data on other insect groups that could be cited, indicate that many species contain ca. 35–50% digestible protein on a dry weight basis. In addition they are a good source of minerals, especially phosphorus, and iodine numbers in the neighborhood of 100 (Lapp and Rohmer 1937, and others cited by Bodenheimer 1951) indicate that the fats and oils of many insects, locusts included, bear a resemblance to vegetable oils in their degree of unsaturation.

Recycling and Mass Production

Teotia and Miller (1973b) and Miller et al. (1974) found that poultry manure, after digestion by fly larvae, was reduced to about half its raw weight. It was granular in texture, readily dried, and had a much less offensive odor. A variety of factors influenced the yield of pupae and the condition of the digested manure. At low larval densities, the manure was not well broken down. At high densities larval mortality was high and surviving larvae produced small pupae and sub-fertile adults. When moisture levels of the manure were below 60% or above 80% larval development was poor. Changes in temperature and humidity within the digestion chamber in some combinations had a significant effect on the total weight of pupae produced. The maximum yield of pupae, 76 g dry weight per 4 kg of fresh manure, was obtained at a larval density resulting from an inoculation rate of 0.75 g of fly eggs per kg of manure in a chamber maintained at 27°C and 41% RH. Under these environmental conditions, ca. 8 days were required for development to the pupal stage. Under caged birds, where environmental temperatures were lower and larval development consequently slower, 11 to 12 days were required for development to the pupal stage.

Morgan et al. (1970) devised simple equipment whereby the raw excreta of hens could be processed by house fly larvae to produce a semi-dry crumbly product that with additional drying and pelleting could be converted into a soil conditioner. They estimated that, from the excreta of 100,000 hens, they could harvest 500 to 1,000 pounds of pupae daily.

Sewage lagoons may represent another system whereby animal wastes can be recycled through insects to produce harvestable protein. In Ohio, Schurr (1972) found that a large number of insects occupy the top of the food chain in secondary lagoons and this biomass (freeze-dried) yielded 18.7% protein compared to 9.6% for a commercial alfalfa meal. Arthropods found in significant numbers in the biomass included a variety of aquatic beetles, bugs, midges, mites, and dragonfly nymphs. Schurr concluded that, at its peak in August, the biomass is of sufficient yield to be of commercial value, and since it can be dried and chopped by the same machinery used in producing alfalfa meal it would not be necessary to develop a special technology for handling it.

Although only 2 examples have been cited above, the possibilities for recycling of waste materials by insects would appear to be endless. There are a million known species of insects and it is probably safe to say that there is no substrate of plant or animal origin, from cellulose to feathers, that is not utilizable as food by one species or another. As illustrated above with the house fly, however, the first problem is how to wed mass production technology to the recycling of waste materials. It will require imaginative research by entomologists, thoroughly familiar with the biology of specific insects and aware of the existing quantities and distribution of wastes in a given region, to determine the true feasibility of specific systems.

In one respect, insect mass production for protein should be less complex than mass production for biological control. One of the main problems that has arisen in producing sterile males or insect parasites and predators for biological control programs has been the necessity of maintaining through many generations of culturing under artificial conditions insects that are vigorous and competitive when placed back in nature with wild populations. In rearing for protein there should be less necessity to produce insects that remain biologically unchanged.

Some insects may not lend themselves readily to recycling of wastes and mass production, yet, nevertheless, may represent a considerable protein potential if economically feasible methods of harvesting wild populations can be devised. There have been some notable accumulations of locusts, for example. Plagues of these insects have been recorded since ancient times, often in numbers that darken the sky or leave the earth barren. In 1881, 1.6 billion egg pods were destroyed on the island of Cyprus (Essig 1942). It can be calculated that these eggs represented the potential for ca. 80 million pounds of locust protein, which would equal the protein need for 1½ million people for a year. Metcalf and Flint (1939) noted that 274 tons of grasshoppers were collected in one county in Utah in the early 1900s when a 60¢/bushel bounty was offered. There are one or more major migratory locust species on every continent, not to mention thousands of other species of locusts, grasshoppers, and crickets. In some areas, the location of locust breeding grounds and movement patterns prior to and during migration have been well studied. It should be possible to devise methods for harvesting part of this wild locust crop.

The potential value of locusts as fertilizer should also not be overlooked. According to Powell (1975), a ton of Wisconsin dairy manure contains about 10 lb of available nitrogen, 4 lb phosphate (P_2O_5), and 10 lb potash (K_2O). In an analysis of dried locusts, *Schistocerca gregaria*, as fertilizer, Das (1945) found the following composition (percent): organic nitrogen 9.90, phosphate 1.20, potash 0.84, and lime 0.59. According to the sample analyzed by Das, therefore, a ton of locusts contains about 20× more nitrogen, 6× more phosphate, and 1.7× more potash than a ton of dairy manure. Bodenheimer (1951) cites that, in Argentina in 1936, 3,000 tons of locust flour containing 9.7% nitrogen were available for export as fertilizer.

Hocking and Matsumura (1960) reported that more than 130 tons of bee brood, mainly pupae, go to waste each year in the prairie provinces of Canada. The uncertainty of winter survival of honeybee colonies under the severe winter climate of the region has led to the practice of eliminating the colonies in the fall and restocking in the spring. At the time of killing, colonies contain ½ to 5 lb of mature capped brood. In analyzing the brood, Hocking and Matsumura found it to contain 18% protein and to be rich in vitamins A and D.

Insect protein literally abounds all around us. It has been established that it is of high quality. The need now is for those who are familiar with the biology of specific insect species to become acquainted with the kinds and quantities of wastes available and to do some exploratory research to determine the true economic feasibility of harvesting this protein and of utilizing insects in recycling wastes for the production of protein.

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