Insect Pests of Tropical Food Legumes

Edited by

S. R. Singh

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Reginald H. Painter
1901–68

This book is dedicated to Dr. Reginald H. Painter, world authority and pioneer in research on host-plant resistance, under whom I had the distinct privilege of doing my doctoral research.

Contents

feed on the leaflets and seldom reduce yields, although outbreaks of locusts result in complete defoliation and failure of most species of plants including pigeon pea. One grasshopper that causes unusual damage to pigeon pea is *C. erubescens*, which girdles branches of the plant, causing them to wither and die. No control measures are normally required, for the densities of these insects seldom reach economic thresholds.

GRYLLIDAE

The cricket, *Gryllus bimaculatus* Deg., is known to cause substantial damage to pigeon pea roots and seedlings in Kenya.

Thysanoptera

THRIPIDAE

Several genera and species of thrips have been recorded from pigeon pea. In India the commonest species appears to be *Megalurothrips usitatus*, which feeds in the flowers. In East Africa, other species of *Megalurothrips* are common on pigeon pea and are regarded as being of some importance.

Heavy infestations of thrips can lead to bud and flower drop. Rawat *et al.* (1969b) found a reduction of 36 per cent in pod formation in unprotected pigeon pea in India, and *Frankliniella insularis* Schmutz infestation caused 47 per cent reduction in pod set of pigeon pea in Trinidad (Pollard and Elie, 1981). In India, Yadav *et al.* (1974) noted two species of thrips, *Frankliniella sulphurea* Schmutz and *Taeniothrips nigricornis* Schmutz, visiting flowers of pigeon pea, when the buds began to unfold and deserted them only after the initiation of pod development. Significant differences were noticed in the development of pods in relation to different levels of thrips populations. A moderate population of thrips (23–150 per 100 flowers) was found beneficial to fertilization and pod setting. The black adults (1 mm) and nymphs of *M. usitatus* are easily seen with the naked eye, particularly when they are on yellow flower petals. A generation can be completed within 4 weeks. Studies at ICRISAT showed that the mean incubation was 5.6 days, the mean nymphal period, 10.7 days and the adult longevity, 14.1 days (Pawar and Srivastava, 1985). Thrips in India seldom build up enough on pigeon pea to cause substantial damage. In most cases, insecticides used to control major pests (e.g., endosulfan for *Helicoverpa* control or dimethoate for podfly control) will incidentally reduce the thrips populations.

We gratefully acknowledge assistance from colleagues at ICRISAT in the preparation of this chapter.

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Edited by S. R. Singh

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Pests of Groundnut in the Semi-Arid Tropics

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Arachis hypogaea L. (groundnut or peanut), which originated in the eastern slopes of the Andes, among the headwaters of the Amazon, is now mainly grown in Asia, especially in India and China. Other key zones include Southern and West Africa, although production in the latter, especially in Nigeria, has fallen considerably as a result of climatic and political changes. North Carolina, Georgia, and other southern states in the U.S. are the leading producers in the developed world. Groundnuts are also grown in Australia, mainly in Northeast Queensland, where the industry is comparatively small but scientifically important because the crop is grown in a dry environment comparable to much of the semi-arid tropics. Thus, much of the information generated by the sophisticated (well-funded) scientific and extension services in Australia is applicable to the farms of the developing world.

Insect pests of groundnuts were first extensively reviewed by Feakin (1967, revised 1973); later Smith and Barfield (1982) listed 356 taxa then known to be associated with the crop and discussed the control of groundnut pests largely from the point of view of the developed world. More recently, Wightman and Amin (1988) briefly discussed pests of groundnuts grown in the semi-arid tropics, and Amin (1988) reviewed the Indian situation. The pattern of pests on Western-style farms was discussed by Wightman (1989). These texts, together with internal documents from ICRISAT, have provided much of the background for this chapter.

In this chapter, we have supplemented and updated these works rather than replaced them. A major source of information has been a 5-month survey of groundnut fields carried out by one of us (J.A.W.) in Africa and India, the results of which are being finalized for publication.

Groundnuts (*Arachis* spp.), which are a valuable source of dietary protein (ca 35 per cent), vitamins, and minerals and contain 45–50 per cent high-quality oil, are unusual legumes in that the seeds grow underground. Fertilization activates an intercalary meristem in the base of the ovary. This results in the production of a stalk-like structure, the gynophore or peg, that grows downward and into the soil, carrying the presumptive germinal tissue in the tip. The ovules grow and turn into pods holding usually two, but sometimes three or four, seeds. The duration of a crop can be as short as 90 days, as in the case of some Spanish bunch cultivars grown in India, or can extend to about 150 days (e.g., Valencia and runner types popular in parts of Southern Africa where the summer rains last 4 months or so). Groundnut can be grown in the arid and semi-arid parts of the tropics because it tolerates high temperatures in its canopy and extended periods of low moisture in the soil.

The crop is vulnerable to four cohorts of insects:

- non-viruliferous foliage feeders;
- viruliferous foliage feeders (virus vectors);
- invertebrates living in the soil; and
- those that feed on the harvested and stored pods and kernels.

Of these, the virus vectors and soil insects are the most insidious – the former, because a small number of an otherwise harmless population can cause considerable yield losses, and the latter, because they are seldom detected before they have caused considerable damage. Soil-inhabiting insects can attack the pods, the roots or both, and the crop as a whole when it is drying in the sun after harvest. Pod feeders, even when they do not reduce yields to any extent, increase the risk of aflatoxin contamination caused by the invasion of *Aspergillus flavus* (McDonald, 1966; McDonald and Harkness, 1968). Root invaders can kill the plants or markedly reduce yields, particularly on drought-prone farms with light soils (as in central Zimbabwe and Senegal) where the plants need extensive systems of fine roots to survive.

As farmers commonly sell part of their crop soon after harvest, they avoid the problems involved in maintaining the quality and economic value of the product during storage. These problems are then faced by market traders, oil millers and exporters. One of the main causes of deterioration of stored groundnuts is insect infestation. Attack by postharvest insect pests results in a reduction both in the overall quantity of kernels and in the quality of the oil. Insect infestation also generates heat and moisture within silos or stacks of groundnuts, thereby increasing the risk of fungal attack and the attractiveness of the product to other insects.

More than 100 species of insect are capable of infesting stored groundnuts (Redlinger and Davis, 1982). A majority of these are only occasional pests or can survive on groundnut kernels only after more destructive species have altered the environment, e.g., by increasing the moisture in the kernels. A number of species are important pests of shelled groundnuts, particularly when many of the kernels are broken during decortication (Duerden and Cutler, 1957). These species are found also in stocks of in-shell groundnuts, feeding on kernels that are exposed as a result of mechanical damage to pods during harvesting, drying or transport. As few species are able to penetrate intact pods, storage in this form reduces the number of species likely to cause significant losses.

The importance of postharvest insect pests and the degree to which their control by insecticide application is warranted largely depend on how the groundnuts in stock will ultimately be used. In some tropical regions, groundnuts being stored prior to local processing for oil extraction may be protected sufficiently by a combination of initial drying, in-shell storage and good storage management. However, groundnuts intended for seed supply or for export are often shelled soon after harvest so that imperfect or damaged kernels can be discarded (Rouzière, 1986). If prolonged storage is necessary after shelling, then more rigorous control procedures are almost certainly required.

To reduce the susceptibility of groundnuts to insect and fungal attack during storage, producers commonly leave them to dry in windrows or loose stacks until moisture content is below 7 per cent (Blatchford and Hall, 1963).

As new stocks can be cross-infested from crop residues, stores should be swept clean and material from the previous harvest removed and burned before they are refilled. If the store or container is known to have held stocks infested by pests such as *Elasmolomus sordidus*, then it is advisable to apply an organophosphorous insecticide, preferably as a wettable powder, to the interior surfaces of the store after it has been cleared (Table 5.1). In areas where groundnuts are stored in gunny, the sacks should be checked for live insects, including pupal cocoons, before they are refilled. To ensure against survival of the pests, one can roll the sacks together and place them in a sealed oil drum with a single phosphine tablet for 5–10 days.

Since infestation of clean groundnut stocks will usually begin in the surface layers of a stack or bulk, the application of an insecticide spray or dust provides some measure of protection, particularly against such pests as *E. sordidus*, which will come in contact with the insecticide throughout its life cycle. Sacks of pods can be sprayed with any of the insecticides recommended for residual application to store walls (Table 5.1). Spraying each layer while a stack is being constructed is more effective than applying a single treatment once the stack is completed but involves greater expenditures both of insecticides and of labour.

Table 5.1. Chemical control measures for protection of stored groundnuts[a]

Control operations	Insecticide common name and formulation	Application rate of whole product with specified a.i. concentration
Space treatment of empty stores	Dichlorvos: resin strips	1 strip/30 m^3
	fog or aerosol	12 mL (5 g a.i./L)/m^3
Application of insecticidal spray to interior surfaces of stores or to sacks of pods	Malathion (wp)	500 g 25% a.i. in 5 L water/100 m^2
	Fenitrothion (ec)	200 mL 50% a.i. in 5 L water/100 m^2
	Chlorpyriphos-methyl (ec)	200 mL 50% a.i. in 5 L water/100 m^2
	Pirimiphos-methyl (ec)	100 mL 50% a.i. in 5 L water/100 m^2
	Iodofenphos (wp)	300 g 50% a.i. in 5 L water/100 m^2
	Bromophos (wp)	400 g 50% a.i. in 5 L water/100 m^2
	Permethrin (ec)	40 mL 50% a.i. in 5 L water/100 m^2
	Deltamethrin (wp)	50 g 50% a.i. in 5 L water/100 m^2
Direct application of spray to surface layer of pods in bulk storage	Malathion (wp)	250 g 50% a.i. in 5 L water/100 m^2
	Fenitrothion (ec)	100 mL 50% a.i. in 5 L water/100 m^2
	Chlorpyriphos-methyl (ec)	100 mL 50% a.i. in 5 L water/100 m^2
	Iodofenphos (wp)	150 mL 50% a.i. in 5 L water/100 m^2
	Bromophos (wp)	220 mL 50% a.i. in 5 L water/100 m^2
Admixture of insecticidal dust with pods	Malathion	250 g 4% a.i./t
	Fenitrothion	400 g 4% a.i./t
	Pirimiphos-methyl	400 g 4% a.i./t
	Bromophos	500 g 4% a.i./t
Fumigation of bagged or bulk stocks of pods or kernels under gastight sheeting	Methyl bromide (gas)	60-70 g/t for 48 h (increase dosage by 50% for control of *Trogoderma*)
	Phosphine (solid aluminium phosphide)	3-5 g/t for 7 days (3-5 tablets or 15-25 pellets)
Fumigation of small quantities of pods or kernels e.g. in polythene sacks or oil drums	Phosphine (solid aluminium phosphide)	0.4-0.6 g/100 kg for 7 days (2-3) pellets)

[a] a.i. = active ingredient; ec = emulsifiable concentrate; wp = wettable powder.

In parts of West Africa, where heaps of pods are stored in the open air, insecticides can be applied as a spray or dust to the surface of these heaps. However, as trading and movement of groundnut stocks take place, the surface layer of pods will be disrupted and the efficacy of surface treatments reduced.

The ideal is to add phosphine (1 g/m^3, equivalent to 5 tablets or 25 pellets/t) to the groundnuts as the store is filled (FAO, 1985). Phosphine can also be used to treat small quantities of groundnuts, e.g., seed supplies placed in airtight containers. One pellet (0.6 g) placed on top of groundnuts in polythene-lined sacks should give satisfactory control of insect infestation (Proctor and Ashman, 1972). Oil drums, sealed with aluminium tape or strips of polyurethane foam, can be used for the same purpose.

Research on appropriate methods of managing the pests of groundnuts in the developing world is carried out by several agencies besides the national research programmes of the many countries that grow groundnut. ICRISAT, which is near Hyderabad in peninsular India, is invested with a global responsibility for promoting groundnut production. It maintains a collection of the world's groundnut and wild species and has the capacity to carry out an extensive crossing programme each season. Through these facilities, it supports national programmes and international research organizations by supplying them germ plasm, breeding lines, or populations.

Its Legumes Entomology Unit is concentrating on the development of integrated pest management (IPM) for the small farmers of the semi-arid tropics, in part, by carrying out basic research that is beyond the scope of some national programmes. The international collaborators include scientists in the Peanut Collaborative Research Support Program (PCRSP) of the United States Agency for International Development (AID) who are currently active in Burkina Faso, Philippines, and Thailand (Campbell, 1986) and who are also able to supply entomologically important germ plasm.

The U.K.-based Overseas Development and Natural Resources Institute (ODNRI) arranges for entomologists to work with ICRISAT scientists on problems such as termite control and the mechanisms of host-plant resistance.

Cooperation with the Australian Centre for International Agricultural Research and with the Food and Agriculture Organization of the United Nations (FAO) has led to IPM training workshops in Asia. In other words, a range of research on groundnut pests is in progress around the world, and we have been able to draw on it — though many of the results are as yet unpublished — in the preparation of this chapter.

Orthoptera

Grasshoppers are often conspicuous in groundnut fields because they are large and can fly when disturbed. They can sometimes be seen feeding on the young, unfolded leaves and are, thus, responsible for the symmetric holes found on opened leaflets. Feeding caterpillars, in contrast, tend to attack the leaves later, leaving behind randomly distributed holes.

There are no reports of yield losses caused by grasshoppers, although fields of the crop have probably been destroyed by plague locusts (*Locusta migratoria*, *Scistocerca gregaria*, and *Cyrtacanthacris septemfasciata*, etc.) along with any other crops that are in the path of a swarm. Examples of non-damaging grasshoppers are *Zonocerus elegans* and *Pyrgomorpha granulata*, which are both common in Africa.

In groundnut fields in Southern Africa, plants missing from around holes in the ground inhabited by crickets and mole crickets indicate that seedlings have been attacked. However, once established, groundnut plants seem to be safe from these insects, even the large bush crickets (75 mm long) such as *Brachytrupes membranaceus* that are common some years in countries like Botswana.

Researchers can, with patience, find stick insects in groundnut crops, and mantids (many species) were sufficiently abundant on groundnut in parts of Malawi to have deserved a rating of 'important predators'.

Dermaptera

EARWIGS

Earwigs damage groundnuts in India where *Euborella stali* is the major earwig pest and in Israel where *Annisolabis* sp. bores holes in pods (Cherian and Basheer, 1940; Melamed-Madjar *et al.*, 1970; Palaniswamy, 1977). Cherian and Basheer in 1940 indicated that *E. stali* and *A. annulipes* are synonymous, the former having precedence.

Earwigs lay eggs in clusters in the soil where, in southern India, they incubate for 7–11 days. Under laboratory conditions, the females lay 20–140 eggs (n = 5). There are five nymphal instars. The adults can live for 2–3 months (Cherian and Basheer, 1940). On the ICRISAT farm, we find that they are commonest on Vertisols.

Their pod-boring results in either mouldy seeds, premature germination or the rejection of consignments at the wholesale market. The extent and intensity of damage are not known because wire-worms, false wire-worms, ants, termites and millepedes can cause similar damage. As the culprits usually have disappeared by harvest time, when the damage is discovered, there is scope for confusion. However, Amin (1988) found that earwigs can damage up to 65 per cent of the pods of a crop.

Dry formulations of insecticides such as aldicarb, carbofuran, phorate, chlordane and DDT (Melamed-Madjar *et al.*, 1970; Padmanabhan *et al.*, 1973; Palaniswamy, 1977) have been recommended for control but none is particularly effective. This information was presumably oriented toward farmers who have 'earwig hotspots' because none of the authors indicated how to predict an attack.

Isoptera

TERMITES

Termites are often misnamed 'white ants'. The reason presumably is that their soil mounds or termitaria are confused with ant hills, the denizens of which have no taxonomic relationship with termites but share the characteristics of a complex social or caste system and a largely subterranean existence. Termites are as much a part of the tropics and sub-tropics as drought and mango trees. They also have as much influence on the landscape in that they remove dead plant material from the soil surface, using it as cement in termitaria that can be seen all over Africa, Australia, and Asia.

Their importance as pests and as soil movers is recognized in a number of reviews: Verma and Kashyap, 1980 (emphasis on India); Lee and Wood, 1971; Harris, 1961, 1969. There is also an extensive bibliography of the termite literature (Ernst and Araújo, 1986). Ruelle (1985) gives a concise account of the termites of Southern Africa.

There are nine families of Isoptera, two of which are relevant to our understanding of the groundnut fauna. Termitidae is the most important. It contains 80 per cent of the species of this order, including economically important genera such as *Microtermes*, *Odontotermes*, *Macrotermes* and *Trinervitermes*, together with the soldierless termites that were consistently found 10–20 cm below the soil surface under groundnut plants in the moister parts of Southern Africa (J.A.W.). This last group eats organic matter in the soil and probably has no economic importance. The Hodotermitidae (harvester termites) includes *Hodotermes mossambicus*, which attacks groundnut plants in many parts of Africa.

Termites are pests of groundnut crops mainly in Africa, although they also create problems for farmers in India. A special survey of groundnut insects, especially those living in the soil (Table 5.2), indicates *Microtermes* and *Odontotermes* are the genera most likely to cause yield losses, although others are implicated. Termites do not figure highly in the relevant literature from Southeast and East Asia, presumably because the termite's way of life is not compatible with rice farming (groundnut is often grown in rice fallow in Asia). Termites do not seem to be part of the groundnut fauna in Australia or in South America, either.

Biology

With few exceptions, termite colonies consist of members of four castes: primary reproductives, supplementary reproductives, soldiers, and workers. The reproductives produce eggs and are larger than the other castes. The 'queen' can be 5 cm long, her abdomen being crammed with ovarioles that produce millions of eggs over many years. The flying termites that are a common sight at dusk after the first showers of the rainy season are new reproductives seeking mates. After finding a suitable site, they mate and initiate a new colony. The supplementary reproductives take over whenever a king or queen dies.

Soldiers and workers are sterile and have no wings or flight muscles. The soldiers have large, heavily sclerotized heads. They protect the colony from predators, usually with powerful mandibles, which in the case of *Macrotermes* spp. are strong enough to draw blood from a person's hand. The nasute soldiers, e.g., those of *Trinervitermes* spp., eject a sticky substance from the pointed front of their pear-shaped head when they are disturbed.

Table 5.2. The distribution of termites associated with the groundnut crop[a]

Species	Location	Reference
ASIA		
Coptotermes formosanus	China	Verma and Kashyap, 1980
Odontotermes sp.	Thailand	J.A.W.
Odontotermes obesus	South Asia	Roonwal, 1979
O. brunneus	India	Reddy and Sammaiah, 1988
Trinervitermes biformis	India	Feakin, 1973
	Sri Lanka	Roonwal, 1979
Microtermes thoracalis	India	Smith and Barfield, 1982
M. obesi	South Asia	Roonwal, 1979
EAST AFRICA		
Eremotermes nanus	Sudan	Feakin, 1973
Macrotermes bellicosus	Sudan	Feakin, 1973
M. subhyalinus	Sudan	Verma and Kashyap, 1980
Odontotermes nilensis	Sudan	Feakin, 1973
O. anceps	Kenya	Smith and Barfield, 1982
Microtermes thoracalis	Sudan	Feakin, 1973
M. lepidus	Sudan	Hebblethwaite and Logan, 1985
SOUTHERN AND SOUTH AFRICA		
Microtermes sp.	Zambia	J.A.W.
	Malawi	J.A.W.
	Zimbabwe	J.A.W.
	Botswana	J.A.W.
Microcerotermes sp.	Malawi	J.A.W.
Odontotermes sp.	Tanzania	Feakin, 1973
	Malawi	J.A.W.
	Zambia	J.A.W.
O. badius	South Africa	Feakin, 1973
O. latericius	South Africa	Feakin, 1973
O. lacustris	Malawi	J.A.W.
O. bomaenis	Zambia	J.A.W.
O. amanicus	Malawi	J.A.W.
O. kibarensis	Zimbabwe	J.A.W.
O. transvaalensis	Malawi	J.A.W.
	Zimbabwe	J.A.W.
	Botswana	J.A.W.

continued

Table 5.2 continued

Species	Location	Reference
O. rectanguloides	Zimbabwe	J.A.W.
O. latericus	Zambia	J.A.W.
O. montanus	Malawi	J.A.W.
Ancistrotermes latinotus	Zaire (Congo)	Feakin, 1973
	Malawi	J.A.W.
	Zimbabwe	J.A.W.
	Zambia	J.A.W.
Allodontotermes sp.	Malawi	J.A.W.
A. morogorensis	Tanzania	Smith and Barfield, 1982
A. tenax	Zimbabwe	J.A.W.
	Zambia	J.A.W.
Nasutitermes sp.	Malawi	Smith and Barfield, 1982
Pseudoacanthotermes sp.	Malawi	J.A.W.
P. militaris	Malawi	J.A.W.
	Zambia	J.A.W.
Trinervitermes sp.	Malawi	J.A.W.
Hodotermes mossambicus	Malawi	J.A.W.
Macrotermes sp.	Malawi	J.A.W.
M. falciger	Malawi	J.A.W.
M. ?natalensis	Malawi	J.A.W.
	Zambia	J.A.W.
WEST AFRICA		
Amitermes evuncifer	Nigeria	Feakin, 1973
Microcerotermes sp.	The Gambia	Feakin, 1973
Hodotermes mossambicus	Senegal	Smith and Barfield, 1982
Odontotermes vulgaris	Senegal	Appert, 1966
Ancistrotermes crucifer	The Gambia	Feakin, 1973
O. smeathmani	Nigeria	Johnson *et al.*, 1981
Microtermes sp.	Nigeria	Feakin, 1973
	The Gambia	Feakin, 1973
	Niger	Lamb, 1979
M. lepidus	Nigeria	Johnson and Gumel, 1981
M. subhyalinus	Nigeria	Perry, 1967
M. parvulus	Senegal	Appert, 1966
Trinervitermes geminatus	Senegal	Feakin, 1973
T. obenerianus	Senegal	Verma and Kashyap, 1980
SOUTH AMERICA		
Syntermes sp.	Brazil	Smith and Barfield, 1968

* This table adds to the lists of previous reviews; 'J.A.W.' signifies data from the unpublished survey records of J. A. Wightman.

There are often two sizes of soldiers. Even though sterile, some have rudimentary reproductive organs and are recognizable as males or females. When collecting termites for identification, one should seek soldiers rather than workers because workers of different species are not clearly distinguishable. They are pale, sterile individuals of both sexes; they vary in size and aggregate to perform all the duties not carried out by the soldiers and reproductives — building and maintaining nests, finding and hauling food, and, most importantly in the case of the Macrotermitinae (Termitidae), tending fungal gardens.

Termites primarily feed on organic matter, but some, and these are the pest species, feed in or on live plants. The workers digest their food completely, including lignin, with the assistance of the symbiotic protozoa that are in their gut. They supply the other castes, either with a watery secretion from the mouth, which the reproductives receive, or anally (soldiers). There are many variations on this theme.

Many of the termites that are found in groundnut fields construct gardens of fungi of the genus *Termitomyces*. The fungus is cultured on the fresh faeces of the workers and forms part of the diet of the colony.

Like most soil insects, termites are influenced by the soil moisture. This was shown on a macro scale by Johnson *et al.* (1981), who derived a relationship between annual rainfall (x) and the percentage of groundnut stands with taproots invaded by *Microtermes* spp. (y) whereby:

$$y = (24493/x) - 20.6$$

Their data showed that, in those areas of Nigeria where the annual rainfall is more than 800 mm, less than 10 per cent of stands are attacked. On a smaller scale, Wheatley *et al.* (1989) showed that the number of termites (*M. obesi*) attacking wooden pegs was strongly influenced by soil moisture. Most of the attacked pegs were in soil with moisture of 10–13 per cent where the field capacity of this Alfisol was 18.3 per cent and the wilting point 12.0 per cent.

Generally soil insects are regarded as beneficial to agricultural systems because of their role in the comminution of organic matter. However, termites use the organic matter efficiently, moving it through several members of a colony before plastering it into the wall of their nest. Thus the nutrients that were once potentially available for recycling are locked up until the nest collapses.

If termites have a beneficial role, it is aeration of the soil as they tunnel and build galleries underground. In times of flood, these tunnels presumably permit the rapid percolation of water.

Damage and Economic Importance

On a world basis, termites vie with white grubs as the 'worst field pest' of groundnut because of the damage they do and the difficulties in stopping them from doing it. Termites can:

- kill plants by boring into the root, sometimes via the lesion made by a white grub, but usually of their own volition, e.g., *Microtermes* spp. in many parts of the world, but especially in dry conditions, particularly at the end of the growing season. *Ancistrotermes* sp. and *Nasutitermes* sp. in Malawi appear to behave in the same way as *Microtermes* (J. A. Wightman, personal observation), as does *Amitermes evuncifer* in Nigeria (Sands, 1962);

- cover plants in a thin layer of soil (sheeting) to protect the workers from solar radiation and perhaps predators while they remove the stems and leaves from within the sheeting, e.g., *Odontotermes* spp.;

- 'fell' the stems and lower branches of the plant by chewing through just a few millimetres of the stem where it abuts the crown (*Macrotermes* spp. mainly but sometimes *H. mossambicus*). The effect is similar to that of beavers chopping down pine trees to construct a dam. The termites form sub-colonies at the base of the plant, complete with exits guarded by soldiers and with several ventilation chimneys. They proceed systematically along the row, sometimes cutting all of the stems on a plant but more often about half of them. They are usually most active along the sides of a field. The damage they cause can go unnoticed because the dead stems are removed by other species of termites within a few days and the branches of the depleted plants, when there are some, spread out and hide the damage;

- remove the soft corky tissue from between the fibrous 'veins' of the pods (*Microtermes* spp. in Africa and, seemingly, *Odontotermes* spp. in India). This process of scarification does not have much effect on yield and does not apparently influence the value of the product on the local market but it does permit infection by fungus, including *A. flavus*. This fungus produces a powerful carcinogen (aflatoxin) as a metabolic by-product (McDonald and Harkness, 1968);

- bore the pods and remove the kernels (again, mainly *Microtermes* spp., which also cut through the pegs) (Johnson *et al.*, 1981); and

- deplete the crop as it is drying in the field (*Odontotermes* spp.), Burrell *et al.* (1965) reporting up to 30 per cent damage of pods.

The later the harvest the greater is the level of termite damage and the level of aflatoxin contamination. For example, in experiments carried out in northern Nigeria, there were no toxic samples in groundnuts harvested in a crop 162 days old, but after 176 days, kernels from broken gleanings had medium to very high levels of aflatoxin. Termite damage, which was 4–38 per cent (average 18 per cent) in all picked pods, averaged 60 per cent in gleanings (McDonald and Harkness, 1968). Drying procedures were tested but did not improve the results except in the wet season. Placing pods on a mat to dry so that they could be moved under cover at night and when it rained did help (Burrell *et al.*, 1965; McDonald and Harkness, 1966).

Separating the influence of the activities of individual species on crop yields is difficult. The most extensive research in this field was by Johnson *et al.* (1981) and Johnson and Gumel (1981) in Nigeria between 1977 and 1979. Damage to the foliage (under soil sheeting) by *Odontotermes* sp. did not result in more than 5 per cent yield loss. Most of the crop loss was attributed to *M. lepidus*, which attacked the pods (boring and scarifying) and killed plants outright by invading the taproots. Its worst attacks during the 3 years were in the sudan savanna where it caused 8–41 per cent losses in yield. This zone was a commercial groundnut-growing area.

McDonald and Harkness (1966) were perhaps the first to link termite damage with aflatoxin incidence in northern Nigeria. Gleanings, which are the section of the crop most likely to be eaten by the farm family, had up to 100 per cent incidence.

The incidence — and the importance of scarification as the cause — of infection with *A. flavus* was also the subject of a special study by Johnson and Gumel (1981). They found that root damage by *M. lepidus* was related to the incidence of scarified pods. Again, in the sudan savanna of Nigeria, in unhealthy stands, where taproot penetration had taken place, 44–88 per cent of the pods were scarified. This percentage compares with 8–32 per cent scarification in healthy stands. Despite the high level of scarification in the farmers' fields, the incidence was only 5 per cent in samples from the local markets.

The implication is that scarified pods were retained by the farming families either for eating or for seed. As 85–91 per cent of the scarified pods were infected by fungus but only 5 per cent by *Aspergillus* spp., the extent of the risk of aflatoxin-induced cancer to which the families were exposed is hard to determine. However, it was clearly present.

In an earlier survey in Nigeria by Broadbent *et al.* (1968), 400 kernels were examined from each of 73 markets. The kernels from 31 were less than 1 per cent mouldy, from 14 were 1–2 per cent mouldy and the remainder were 2–5 per cent mouldy. *Aspergillus flavus* was found 16 times, with other species being considerably more abundant.

In view of the importance of fungi in the life of termites, it is not surprising that they are contaminated with fungi. However, experimentation has indicated that they are not directly responsible for introducing *Aspergillus* spp. into groundnut pods (Johnson and Gumel, 1981).

In Botswana, although the groundnut crop is small compared with that of Nigeria in its heyday, the problems are similar. At Sebele Research Station, Gabarone, 5–40 per cent of the plants were killed by termites (*Microtermes* sp.) depending on the location within the research area. In one experiment, plants from seeds that had not received any insecticidal treatment had 64 per cent sound pods. Of the remainder, about 15 per cent were perforated by termites, 11 per cent scarified, and 10 per cent totally destroyed. Seed treatment with an insecticide (carbaryl) did not improve matters. This means that only 50 per cent of the potential crop was worth harvesting. A. Mayeux considered the situation to be worse in other parts of Botswana (extracted from an ICRISAT internal report entitled 'Effects of soil insects on groundnut yields in Zambia and Botswana', J. A. Wightman, Jan. 1988).

Also, one of us (J.A.W.) encountered a crop that had been totally destroyed by *Microtermes* sp. in the south of Malawi, in an area experiencing intense late-season drought. All fields sampled in this vicinity had up to 10 per cent plant mortality caused by termites. *Macrotermes* sp. activity caused 12 per cent reduction of pods on plants (number of plants examined was 1200 of 80 000) growing on a study plot at Chitedze Agricultural Research Station in Malawi (ICRISAT internal report 'An evaluation of five insecticides for the control of foliage and soil insects in a groundnut crop in Malawi and some effects of soil insects on yield parameters', J. A. Wightman and A. S. Wightman, Jan. 1988).

Similarly, in India, reports reviewed by Verma and Kashyap (1980) indicated 5–50 per cent mortality in the Nimar tract of Madhya Pradesh, accompanied by 8–23 per cent pod damage and, in western Rajastan, 10–45 per cent damage by termites was recorded.

Sudhakar and Veeresh (1985) showed that the avoidable loss caused by termites to a groundnut crop, with and without insecticide application, was 51.2 per cent (year 1) and 50.2 per cent (year 2). Their study site was near Bangalore in Karnataka. At ICRISAT centre, Logan (1988) reported that 48.5 per cent of the untreated plants in an insecticide field trial carried out in rainfed conditions had been attacked by termites and that 5.5 per cent of the pods from these plants were scarified. The influence of termites on yield cannot, in this experiment, be separated from the damage caused by other soil insects, but the control of termites contributed to the 80 per cent improvement in yield in the more successful insecticide treatments.

Control

Insecticides: The routine application of cyclodiene insecticides to the soil of a groundnut field at 1–2 kg a.i./ha before sowing is the best way to prevent yield losses caused by termites. Dust, prill or granular formulations are the most effective. This method is not recommended, however, because these insecticides find their way into the kernel oil at contamination levels that are not acceptable under the FAO/WHO (World Health Organization) *Codex Alimentarius*.

There is no doubt that many other insecticides will kill termites if they come in contact with them. However, the conventional formulations of other insecticides do not persist long enough in tropical soils to protect the crop to the end of the growing season. It has already been shown that termites are mainly an end-of-season problem. The few termites present in a field early in the season may be controlled by an organophosphate or carbamate insecticide, but as soon as conditions are suitable later, the termites will invade the crop. Side dressings of such insecticides may be beneficial but can only be effective if rain falls at the right time and in the correct quantity to allow the insecticide to penetrate the soil without getting washed away.

It is suspected that the termite workers are able to separate their main galleries from insecticide-contaminated soil by lining them with soil sheeting deposited through their anuses. This may explain the comparative advantage of termites over the ants that occupy the same tract of insecticide-treated soil.

There is room for experimentation on this topic, as data collected in Malawi indicated that *Macrotermes* proliferated rapidly after the application of chlorpyriphos, perhaps because their ant predators had been killed (Wightman and Wightman, 1988, unpublished).

The need to protect insecticides from degradation in the soil has been answered in part by the development of a formulation consisting of plastic pellets that release the active ingredient for a predetermined period. Several of these slow- or controlled-release formulations controlled termites effectively when tested on the ICRISAT farm and near Bangalore in India.

Chlorpyriphos was particularly promising at the rate applied (5 kg a.i./ha), but we would not recommend furthering its use by farmers in semi-arid tropics because of the price and the residue in the kernels (Logan, 1988). In a field trial in Malawi this material protected the haulms of the harvested crop from nearly 20 per cent weight loss caused by the activities of *Odontotermes* spp. Farmers throughout Southern Africa were united in their conviction that termites can cause up to 50 per cent losses in pod weight at this stage.

Host-plant resistance: Amin *et al.* (1985) described the screening of 530 accessions for resistance to scarification by *Odontotermes* sp. As termites usually have an aggregated distribution within a field, the researchers attempted to increase and sustain the population by releasing adults collected from light traps, providing sawdust for them to eat during the dry season and cultivating shallowly during the afternoons (when termite workers seek cool soil strata).

Scoring damage on a 1–9 scale and noting the percentage of scarified pods, they found, over a period of three seasons, that NCAc 2243 tan, 2243 dark purple, 2240 dark purple, 2240 tan, 2242 and 2142, were highly resistant (these accessions were the result of irradiation of groundnut in experiments at North Carolina State University), as were NCAc 10033, 343, 17888, 2230, 1705, FESR 386 and the cultivar M 13. The implications of these data are being determined in field trials in Botswana, Burkina Faso, Malawi, and Niger.

Johnson *et al.* (1981) observed a certain amount of resistance in 'well established local varieties' grown in Nigeria, compared with improved lines. They also noted that the other key legumes in the area, bambara groundnut and cowpea, were not attacked by termites. They thought the findings reflected the indigenous nature of these two crops and the exotic status of groundnut in Africa. This observation may be valuable in future, as genetic engineering techniques develop.

Natural enemies: Termites in the soil are the natural prey of ants, perhaps because they occupy the same or similar niches. In any case, ants dominate the invertebrate predators' guild in many groundnut fields and reduce the levels of termite attack. This is illustrated by the results of an insecticide field trial in Malawi (Wightman and Wightman, 1988, unpublished) where the number of *Macrotermes* for every 10 m of row ranged from 11.5 (controlled-release phorate, 2 kg a.i./ha) to 79.0 (isofenphos granules, 2.5 kg a.i./ha) in the insecticide treatments, compared with 1.0 in the untreated control (SE = ± 12.6). These data were collected 13 weeks after sowing. They illustrate a detrimental effect of insecticides.

There are a number of vertebrates that prey on termites (anteaters, armadillos, echidna, and numbats), but their influence on groundnut production is not known. Birds are the main predators of the reproductives that swarm during the day and the night fliers are taken by bats. The wingless, nest-seeking prereproductives are a valuable food source for small rodents and insectivores.

Cultural: The relationship between late-season drought and termite attack suggests that crops harvested before drought are less vulnerable than those harvested later. This implies that farmers should sow a variety with a short growing season. This approach is also sound from the perspective of disease avoidance and the general agronomy of the crop.

Many farmers do not clear their fields of crop residues after harvest, but they could reduce the amount of food available to sustain termites through the dry season by incorporating residues into the soil, composting them off the field or, as a last resort, burning them. Mechanical cultivation, repeated each season might, in time, reduces the general population of termites.

Table 5.3. Termite damage to groundnut pods as influenced by mulches, ICRISAT centre, January-March 1989 (split pod design; data are means of 20 replicates)

	Percentage of pods with scarification[a]	Degree of damage[b]
Neem cake mulch	2 (0.02)	0.04
Ipomaea, mulch of chopped branches, leaves	7 (0.07)	0.14
Celosia mulch	17 (0.17)	0.38
Sunn hemp litter	59 (0.66)	1.69
Bare ground (control)	36 (0.37)	0.88
F value	**132.6**	
Pods on top of mulch	20 (0.21)	0.50
Pods mixed with mulch	28 (0.31)	0.75
F value	**22.1**	

[a] Figures in parentheses are arc-sine-transformed values of radians.

[b] Damage scored on a 0–4 scale where 0 = no scarification; 2 = 26–50 per cent; and 4 76–100 per cent of the surface of each pod scarified.

Experiments in Colombia have shown that sunn hemp (*Crotalaria juncea*) sown as an intercrop reduces the amount of damage caused by a burrowing bug, *Cyrtomenus bergi*, to cassava (Vargas, 1988); however intercropping groundnut with sunn hemp at ICRISAT centre did not reduce scarification or pod boring by *Odontotermes* sp.

An experiment carried out at ICRISAT showed that mulches had a profound influence on the level of damage caused to dry pods by termites (Table 5.3) (Gold *et al.*, 1989). Four mulches were compared: neem cake, sunn hemp litter, the weed *Celosia argentia*, and the chopped foliage and branches of another weed, *Ipomaea fistulosa*. The control treatment was bare ground. The *I. fistulosa* was included because of the observation that the leaves of this plant are not eaten by goats nor by any other mammal and, in our experience, by only one species of insect. Groundnut pods either were laid on the surface of the mulch or were admixed.

The data showed clearly that the pods were protected from termites (*M. obesi* and *Odontotermes* spp.) by the neem cake and by the chopped *I. fistulosa*. The *C. argentia* deterred termites slightly but not significantly, whereas the sunn hemp litter apparently attracted termites. The pods on the top of the mulch were less damaged than those that had been mixed with the mulch. The implication of these results is that a base of either neem cake or *I. fistulosa* can be used to protect piles of groundnut plants from termites when they are drying in the field. A further possibility is that the mulch would protect plants growing in the field, provided there is sufficient rain to carry the potentially insecticidal leachate into the soil. This is currently being tested.

Nigerian farmers' methods: Farmers are, of course, aware that termites reduce their groundnut yields and that there may be ways of preventing them from coming into the fields. In fact, Malaka (1972) surveyed farmers in part of Nigeria and asked them how, other than by the purchase and use of insecticides, they controlled termites. The responses were listed under 23 headings, including the hiring of drummers to drive them away and burying dead goats or fish viscera in the fields. Some other approaches were:

- sprinkling alum solution, kerosene, DDT sold for bedbug control, the liquid left after boiling locust bean seed, or the contents of expired cell
atteries around the crops;
ouring disinfectant or an infusion of *Sanseveria libericum* into nests;
utting soldier ants into nests;
emoving the 'royal couple' from nests;
urying cassava meal (fufu); and
lanting termite grass (*Vetiveria nigrotana*) around ornamentals and
igitaria sp., *Cymbopogon shoenanthus* and *Pennisetum purpureum* around
arms.

Homoptera

APHIDIDAE

Aphis craccivora (syn. *A. laburnae*, *A. leguminosae*), the groundnut or cowpea aphid, is the aphid usually reported to be a pest of groundnut. The adults are black and shiny with brown legs. The cauda is prominent, and the cornicles are long, thin and black. It reproduces asexually throughout the year in the tropics. The nymphs are a dusty brown.

Biology

Hosts are mainly legumes, including a wide range of cultivated species, but the insect is not restricted to this family nor does it accept all legumes as a host. Srikanth and Lakkundi (1988) found that, in experimental conditions in Bangalore, south India, the aphid moved freely to field bean, blackgram, and cowpea, moved less often to green gram and groundnut, and avoided soybean and green pea entirely. In comparing the reproductive performance of *A. craccivora* on these hosts, they found that cowpea promoted higher growth and reproductive rates than did groundnut. They did not examine the possibility that rearing the parent colony on cowpea influenced the result.

A similar experiment was reported by Hamid *et al.* (1977) who also found that *A. craccivora* would not reproduce on soybean, reproduced poorly on green pea and horse gram but was well adapted to vetch and *Medicago hispida*. They found no reproducing colonies on soybean in an extensive survey of Pakistan. These authors ascribe importance to their observation that the species was attended by ants *Pheidole* sp. and *Momorium indicum* at 90 per cent of the sites visited.

These results and observations are in contrast with those of Highland and Roberts (1984) who compared the feeding preferences and reproductive rates of three species of aphid including *A. craccivora* (collected from the field in Virginia, USA), on four species of host plant. In a 'settling preference' test, soybean was preferred to groundnut, but cowpea and groundnut scored equally. Reproductive performance on groundnut was the same as on soybean, cowpea being superior in this test.

In other words, American and South Asian aphids of the same species differ in their response to host plants — a finding that indicates existence of biotypes in this species (Simon *et al.*, 1982).

A common pattern in the tropics is for *A. craccivora* to spend the dry or winter season on wild hosts such as *Medicago* spp., *Melilotus* spp., and *Trifolium* spp., as well as on volunteer growth of legume crops, including groundnut (Hamid *et al.*, 1977, writing about Pakistan). Evans (1954) lists more than 20 species of possible off-season hosts from Southern and East Africa, some of which may harbour virus.

Aphis craccivora disperses soon after the rains start. Farrell (1976a), working in Malawi, found that the main migratory flights are 5–6 weeks after the emergence of the earliest groundnut crop. In Hyderabad, India, the first colonies are found on groundnut 3–4 weeks after crop emergence in mid- to late July, 4–6 weeks after the start of the rainy season.

Damage and Economic Importance

This species has been found in most parts of the world between about 40°S and 40°N. It causes damage primarily as a vector of viruses, but it can injure plants by its feeding activity alone. It concentrates on the upper stems, in the flowers, and on the pegs. Plants that are heavily attacked early in the crop season become twisted, stunted and become covered in honeydew, which results in a sooty mould. Plants that are thus damaged are likely to be covered by their more robust neighbours. Feeding damage has been cited as the cause of yield loss in India (e.g., Bakhetia and Sidhu, 1976a) and West Africa (e.g., Mayeux, 1984). Such claims from India have not been accompanied by supporting data, but Mayeux (1984) stated that plants up to 7 weeks old can suffer as much as a 48 per cent loss in yield potential. After this time, the aphids disappear.

The ability of this and other species of aphid to transmit virus diseases is, however, the key to the damage it causes. The groundnut rosette virus (GRV) has been a major preoccupation among groundnut farmers and scientists in sub-Sahelian Africa since the mid 1920s, although the disease was diagnosed by Zimmerman as being caused by a virus as early as 1907. Storey and Bottomley (1928), working in South Africa, established that the vector was *Aphis leguminosae* (= *craccivora*) and was probably not a jassid. Their experiments were based on the collection of insects from infested plants in the field and on glasshouse tests. The techniques they adopted are still a model for contemporary virologists. The signs and characteristics of the virus complex have been described by Storey and Bottomley (1928). GRV is, in fact, a composite virus (Hull and Adams, 1968; Dubern, 1980), but this does not apparently influence considerations of the vector.

Aphids can transmit a virus in a persistent or non-persistent manner. For instance, with the persistent virus, GRV, a minimum of 4.5 h is required for acquisition and 3 min for inoculation. The latent period is 22.5 h or more. The insects retain the ability to inoculate plants with the virus, but no transovariolar transmission has been detected (Dubern, 1980, on a strain of GRV in Côte d'Ivoire). In contrast, *A. craccivora*, *A. solanella*, *Myzus persicae* and *Liaphis erysimi* retain the peanut stunt virus for only 30 min (*A. gossypii*, *A. solanum* and *Rhopalosiphum maidis* do not transmit this virus) (El Sadiq and Ahmed, 1986). *Aphis craccivora* does not transmit all groundnut viruses, according to Sreenivasulu *et al.* (1981). In a study of peanut green mosaic virus, *A. gossypii* and *M. persicae* transmitted the southern Indian strain non-persistently, but *A. craccivora* would not, despite repeated attempts.

A recently named affliction of groundnut in Southern Africa, groundnut streak necrosis disease (GSND), is transmitted, apparently in a non-persistent manner, by *A. gossypii* — transferring the sunflower yellow blotch virus from *Tridax procumbens* — which is a common weed in the Rift Valley. Also of relatively recent concern is the peanut stripe virus, which is now widespread in parts of Southeast Asia and was reportedly brought into the USA in seeds from the People's Republic of China. *Aphis craccivora* is known to be one vector, being able to transmit the disease after feeding on an infected plant for 1 min (Demski *et al.*, 1984a,b). Another potyvirus, peanut mottle, is also spread by *A. craccivora*, after 30–60 s feeding on an infected plant. *Myzus persicae* is a more effective vector (Paguio and Kuhn, 1976).

Control

Insecticides: Aphids are susceptible to most insecticides — a conclusion from David *et al.* (1965), Sundara Babu (1969), Bakhetia and Sidhu (1976b), and Thakkar *et al.* (1981) who wrote about *A. craccivora* in India and from Davies (1975) who reported for East Africa. However, their susceptibility does not mean that they are simple to control by chemical methods. They reproduce faster than their natural enemies, which tend to be susceptible to the same insecticides. The result is flare-ups by the aphids and the need for repeated applications at frequent intervals, unless selective aphicides such as menazon and pirimicarb are applied (Evans, 1954; Davies, 1975; Cameron *et al.*, 1983).

Davies (1975) found that a series of four foliar sprays of menazon reduced GRV incidence in rainfed conditions in Tanzania. However, the experiments were presumably carried out with estate or commercial production in mind because this procedure would probably not fit into the production pattern of the small-scale grower.

Host-plant resistance: Evans (1954) detected resistance to *A. craccivora* in several lines of the Mwitunde group of cultivars from the northwest of Tanzania in a series of field trials designed to seek resistance to GRV. Although the disease appeared in the crop initially, the secondary infestation, i.e., spread by aphids moving out from infestation loci initiated by immigrant alates, was restricted. This was reflected in the superior yields of the aphid-resistant genotypes.

In a screenhouse test in the Punjab, India, Brar and Sandhu (1975) found that spreading and semi-spreading plant forms promoted the rate of aphid population growth when compared with bunch types. Several genotypes appeared to have some resistance — AH 7983, AH 6279 and Faizpur.

Brar (1981), reporting a field experiment, also in the Punjab, India, found little difference among 43 genotypes, as far as their ability to support aphid population growth was concerned, but did demonstrate that the spreading varieties carried more aphids than semi-spreading and bunch forms. He apparently did not try to relate this to the relative number of growing points in the different plant-growth types.

Screenhouse tests at ICRISAT centre indicated that *Arachis chacoense*, *A. villosa*, *A. correntina* and *A. glabrata* exhibited high levels of resistance to *A. craccivora*. Progenies of interspecific hybrids of *A. hypogaea* with *A. chacoense* and *A. villosa* also showed high levels of resistance (Amin, 1985).

However, of the many genotypes tested, EC 36892 (ICG 5240) has been the most consistently resistant in southern India and in Malawi; it is, thus, the most promising source of resistance for breeding (Tables 5.4–5.6) (Padgham *et al.*, 1989).

Table 5.4. ***Aphis craccivora*** **from eight randomized plots at ICRISAT centre 20 days after emergence, rainy season, 1987**

	Mean	Minimum	Maximum	Log mean	Rank
NCAc 343	436.3	160	1058	2.64	4
EC 36892 (ICG 5240)	167.1	33	440	2.22	1
NCAc 2240	1376.7	956	2262	3.14	8
M 13	781.5	272	1230	2.89	7
ICGS 11	503.0	208	860	2.70	5
ICGS 44	376.5	126	466	2.58	3
JL 24	235.0	72	838	2.37	2
ZMB 2087	619.8	256	1034	2.79	6
SE ±	101.1			0.28	
CV	54			14	

The aphids in Asia appear to respond to the antibiosis differently from those in Africa (Table 5.7) — an indication of *A. craccivora* biotypes. Also, the data provide evidence of 'natural selection' by farmers, with Chalimbana, a cultivar popular in Malawi, performing well in Africa.

Host-plant resistance to a vector such as aphids has been demonstrated as protection against GRV infection (Table 5.7). The GRV level in EC 36892 remained low even under an abnormally heavy infestation by viruliferous aphids in a screening nursery up to about 40 days after emergence, by which time the virus has a reduced effect on crop yield.

Table 5.5. ***Aphis craccivora*** **at 11 days and 6 days after five apterous adults were placed on 20 potted plants 5 days after emergence in a glasshouse in Malawi**

	Aphids (no./plant)					
	At 11 days			At 6 days		
	Mean	± SE	Rank	Mean	± SE	Rank
EC 36892 (ICG 5240)	104.4	14.0	1	68.7	38.4	1
ICGM 620 (ICG 5725)	123.8	13.4	2	74.1	11.9	2
ICGM 493 (RG 1)	133.9	13.6	3	76.5	6.0	3
Chalimbana (ICGM 489)	165.1	16.2	4	88.1	8.1	4
RMP 40	177.3	16.0	5	90.4	12.1	5
RMP 93	193.7	17.7	6	102.6	16.4	6
NCAc 343 (ICGM 660)	200.7	20.8	7	-	-	-
Mani Pintar (ICGM 490)	217.1	19.0	8	116.1	11.7	8
RMP 19	242.1	23.4	9	-	-	-
ICGM 576 (RMP 12)	244.9	21.4	10	-	-	-
NCAc 17090 (ICGM 543)	266.3	15.4	11	-	-	-
ICGM 578 (RMP 91)	286.8	19.3	12	-	-	-
NCAc 2214 (ICGM 539)	293.0	24.5	13	116.3	12.8	9
ICGM 577 (RMP 89)	353.1	22.0	14	112.6	14.3	7

Table 5.6. Comparison of ***Aphis craccivora*** **numbers on five genotypes where the aphids were from Malawi and ICRISAT centre**

Genotype	Malawi			ICRISAT centre		
	Mean	RA[a]		Mean	RA[a]	
		1	2		1	2
EC 36892 (ICG 5240)	104	100	88	13	100	53
NCAc 343 (ICG 2271)	201	114	100	125	188	100
Chalimbana (ICGM 489)	167	110	97	253	215	115
Mani Pintar (ICGM 490)	217	116	101	213	209	111
NCAc 17090 (ICG 1697)	266	120	105	63	162	105

[a] RA = relative abundance with 1 = EC 36892, 2 = NCAc 343 as standards.

Table 5.7. Incidence of groundnut rosette virus (GRV) in 10 rows of a susceptible genotype (Malimba) with infected plants every 1.5 m, interspersed with 10 paired rows of an aphid-resistant genotype, EC 36892 (ICG 5240), and single rows of eight GRV-susceptible genotypes (lumped data) at Chitedze Agricultural Research Station, Malawi, 1987 (courtesy of Dr K. R. Bock)

	Initial number of plants (12 June)	Virus incidence (%)			
		29 Jan	13 Feb[a]	12 Mar	13 Apr[b]
Malimba	487	49.9	69.6	81.3	99.3
EC 36892	248	8.1	13.7	31.8	43.9
Susceptibles[c]	262	30.9	69.5	82.1	97.8

[a] Plants infected after this time would lose little yield as a result of GRV.
[b] Adjusted for within-season plant mortality, this was the pre-harvest count.
[c] AH 138, Matimule Encarnado, AH 229, AH 134, AH 202, AH 188, AH 15714, and Morrumbene Castanho.

Natural enemies: There is no systematic study of the effectiveness of the natural enemies of *A. craccivora* as natural control agents. Farrell (1976b), writing of Malawian conditions in the mid 1960s, presented the most complete investigation. He concluded that the natural enemies reduce population densities only after the aphid population starts to decline toward the end of the season, as a result of the deterioration of the host. Coccinellid and syrphid larvae were the most numerous predators. *Aphidius colemani* (Braconidae) and *Psyllaephagus pulvinatus* (Encyrtidae) were found among the aphids after the population began to decline. Entomophagous fungi also appeared late in the season.

Booker (1963) also listed the coccinellid and syrphid larvae he found eating *A. craccivora*. Farrell's report is not in complete accord with J.A.W.'s observations in the farmers' fields around the research station where Farrell carried out his experiments, albeit some 20 years earlier.

Aphis craccivora does not tolerate high densities (Farrell, 1976b), but few plots with more than 50 aphids/plant were found in the heterogenous environment of the farmers' fields. On the other hand, coccinellids, syrphids and other potential predators were present on the plants in relatively high densities, i.e., one coccinellid or syrphid larva per aphid colony of about 20 individuals at the time of expected population build-up.

Table 5.8. *Arachis hypogaea* genotypes with some degree of resistance (*) to jassids *Empoasca fabae* (Ef), *E. kerri* (Ek), *Jacobiasca formosana* (Jf), thrips *Frankliniella schultzei* (Fz) and *F. fusca* (Ff), and termite *(Odontotermes* sp.) (t) scarification

Genotype identity		Pest species						References[a]
		Ef	Ek	Jf	Fz	Ff	t	
AH 7729	ICG 1602							7
Benihandach		*						7
EC 36892	ICG 5240		*					7
EC 99219	ICG 589, 3569		*					7
FESR 386							*	1
GNLM[b]	ICG 2741		*		*			1,5,6
K 4								5,6
M 6-76	ICG 7446		*					7
M 13	ICG 156		*				*	1,5
M 57-72	ICG 7490		*					7
M 137-74			*					7
M 896-76 (1)								7
M 399-72	ICG 7490							7
NC 6	ICG 6429	*	*			*		2,4,7
NCAc 343	ICG 2271	*	*		*	*	*	1,2,3,4,5,6
NCAc 406	ICG 266	*	*					1,9
NCAc 489		*	*					1,9
NCAc 785		*	*					1,9
NCAc 1006			*					7
NCAc 1337	ICG 398		*					1
NCAc 1694			*					7
NCAc 1705	ICG 6764	*	*		*		*	1,5,6,9
NCAc 1741		*	*			*		6,9
NCAc 1787			*					7
NCAc 1807	ICG 7490		*					7
NCAc 2139	ICG 6826		*					7
NCAc 2142	ICG 2036	*						
NCAc 2144	ICG 2307	*						,6
NCAc 2154	ICG 5037							,6
NCAc 2214	ICG 5040	*						,6,9
NCAc 2230	ICG 5041	*						,5,6,9
NCAc 2232	ICG 5042	*						,5,6,9
NCAc 2240	ICG 5043	*						,5,6,9
NCAc 2242	ICG 5044							1,5,6
NCAc 2243	ICG 5045	*	*		*		*	1,5,6,9

Table 5.8 continued

Genotype identity		Pest species						References[a]
		Ef	Ek	Jf	Fz	Ff	t	
NCAc 2460	ICG 7803	*						1,9
NCAc 2462	ICG 2320							1
NCAc 2666	ICG 1660	*						1,9
NCAc 2700	ICG 411	*						1,9
NCAc 2772	ICG 2350	*						9
NCAc 10033								1
NCAc 10207	ICG 8314	*						3,4
NCAc 10211	ICG 5727	*						3,4
NCAc 10247	ICG 5681	*						3,4
NCAc 10272	ICG 5682	*						3,4
NCAc 10277	ICG 5683	*						3,4
NCAc 15729	ICG 5691	*						3,4
NCAc 15730		*						3,4
NCAc 15736		*						3,4
NCAc 15739	ICG 5731	*						3,4
NCAc 15744		*						3,4
NCAc 15745	ICG 8241	*						3,4
NCAc 16940	ICG 8099							5,6
NCAc 17888	ICG 6317	*						1,9
PI23442								7
RC44	ICG 8896							6
RMP 40								1
Thai numbers								
	207							8
	278							8
	309							8
	324							8
	329							8
	331							8
	807							8
	875							8
	950							8
	986							8
	1149							8
	1150							8
	1155							8
VRR 257	ICG 7113							5

[a] References are: 1 Amin *et al.*, 1985; 2 Campbell, 1986; 3 Campbell *et al.*, 1976; 4 Campbell *et al.*, 1977; 5 ICRISAT, 1982; 6 ICRISAT, 1983; 7 ICRISAT, 1984; 8 Sathorn Sirisingh and Manochai Keerati-Kasikorn, 1986; and 9 Prof. J. C. Wynne, personal communication, germplasm data base, North Carolina State University.

[b] GNLM = Gujarat Narrow Leaf Mutant.

A possible line of research is to plant perennial 'off-season' hosts of the aphid in unused land around the farms to sustain aphids and their natural enemies during the dry season in the vicinity where farmers need them after the crops are sown. However, one would have to be careful to make sure that such plants did not act as the reservoirs of the components of the GRV complex or of other crop virus diseases.

Commonly, in India and African groundnut fields, rain displaces aphids from groundnut plants (J.A.W., personal observation). Although many regain their feeding sites, some may become prey to predators living on the soil surface, such as carabids, spiders and ants. Also, periods of persistent rainfall increase the RH around the plants, thereby promoting the development of entomophilous fungi. Thus, a density-independent factor (rain) could be important in the natural control of aphids.

Cultural: There are two ways in which farmers can escape infestations by GRV-carrying aphids — close spacing and early sowing. These have been demonstrated in Nigeria by A'Brook (1964) and Booker (1963), in Malawi by Farrell (1976a,b), and in Uganda by Davies (1976). They were also referred to by Mayeux (1984) writing of West African conditions. Farrell (1976b) showed that the aphids reproduced less rapidly on closely spaced plants, suggesting a form of pseudoresistance induced by the physiologic state of the host.

Close planting should be possible at all stages of the season. However, early sowing may not always be possible because of other activities that compete for farmers' time, such as the sowing and weeding of the staple or of more important cash crops. J.A.W. found that the majority of the farmers that he surveyed in central Malawi and other parts of Southern Africa sowed within about a week of the start of the rainy season. This may account for the low incidence of GRV in this area. Farmers used wide spacing — in part to fit with the row spacing adopted for maize and tobacco but also to make their seed supply go further.

Farrell (1976c) found that intercropping groundnut with field beans *Phaseolus vulgaris* could reduce the rate of the spread of the virus through a crop. He noticed that the aphids became impaled on the recurved trichomes that are on the underside of the bean leaflets. He attributed the comparative slowness of secondary spread of virus to this resistance factor in the beans. However, he considered that an early sown, closely spaced, monocrop reduced the losses caused by GRV more effectively than intercropping with beans.

Several writers have pointed to the need for removing off-season volunteer growth from the vicinity of groundnut fields as a means of reducing the level of *A. craccivora* and GRV in susceptible areas (e.g., Evans 1954; Misari *et al.*, 1980). The areas that apparently need most attention are river banks, the sides of drainage and irrigation canals and land irrigated for off-season crops. This seems reasonable, as it is likely that at least one of the components of the virus complex could overwinter in volunteers, although this has yet to be confirmed.

TETTIGOMETRIDAE

Weaving (1980), the origin of much of the following information on *Hilda patruelis*, commented that published literature on the family Tettigometridae is limited, and her observation is still true. As far as pests of groundnut are concerned, two species in this family deserve mention.

One is well known to groundnut growers in much of Africa — *H. patruelis*. This insect is sometimes called the groundnut planthopper, but the title is not particularly appropriate because it is mainly subterranean when living on the groundnut crop. This makes it more of a 'digger' than a 'hopper'. Rose (1962) and Taylor (1981) have provided further information about the species, and all three of these authors drew on observations made in Zimbabwe.

The other species, *Hypochthonella caeca* has no common name, is virtually unknown, and can be dealt with quickly. The only record of extensive damage caused by this insect was by Rose (1962), attributing to it the destruction of 70 per cent of a groundnut crop in Zimbabwe. However, as soil insects are not always considered when maladies of groundnut are diagnosed, its damage elsewhere may have gone unheralded. One of us (J.A.W.) found *H. caeca* under groundnut plants in central Zambia, in low numbers. It is white and about 3 mm long. The plants it lives on turn yellow and are stunted. It is attended by doryline ants. Rose stated that it causes similar damage to tobacco. As these two crops are common in rotations in Southern Africa, there is at least the potential for the build-up in population densities of this insect.

Biology

The eggs are silvery blue–mauve and are laid in rafts of 10–40 on the pods, pegs or upper roots of the plant, although sometimes they number more than 100/raft, as more than one insect may lay in the same place. The eggs are the most easily found stage. The period from oviposition to final moult is 37 days at 23°C and 74 per cent RH, the egg stage lasting 10 days at 20° and 12 days at 23°. In Tanzania, the life cycle lasts 6 weeks, according to Jepson (1948). The adults are mottled olive green, brown and cream and attain 3–4 mm in length. The nymphal stadia are similarly coloured. All stages have been well illustrated by Weaving (1980).

Hilda is oligophagous, some 42 host species having been listed in Zimbabwe. Roots of common and persistent weeds such as *Conyza sumatrensis*, *Bidens pilosa*, and *Tagetes minuta* become infested and allow the populations to survive through the dry season. The fleshy taproots of *C. sumatrensis* are particularly popular. The life cycle can be completed above ground on trees and ornamentals such as *Cassia*, *Hybiscus*, and *Protea*. The insect has been found on the root systems of, besides groundnut, soybean, sunflower, maize, sunn hemp and potato (Taylor, 1981).

Ant attendants palpate the nymphs with their antennae and receive honeydew from the anus. They build a network of galleries around the base of the plants. These probably allow hilda to move around in the soil among the roots, as neither the adults nor the nymphs have fossorial adaptations. The galleries are destroyed by heavy or persistent rainfall, despite efforts by the ants to repair them. This explains to some extent the 'local knowledge' in Southern Africa that associates hilda epidemics with dry seasons. Weaving's analysis of official records indicated that hilda outbreaks were most frequent in years when the rainfall was below average.

Damage and Economic Importance

Signs of damage by *H. patruelis* are often easy to see, although, because of its cryptic colouring and motility, the insect is not always easy to find. It lives on the roots of groundnut plants, just below the crown, and moves from one plant to another, usually along a row.

Infestation can be detected by the rapid wilting and death of plants around the periphery of fields and by the presence of small black ants, e.g., *Pheidole megacephala*, that tend hilda.

Weaving's (1980) literature review and J.A.W.'s survey indicate that hilda is found south of a line extending from Sudan in the east to Nigeria in the west. The presence of crops such as groundnut, sunflower, and cashew as well as of certain common weeds may be the factors determining its distribution.

Hilda is believed to inject toxin into host plants when it feeds (ICRISAT, 1985). The vascular tissues of the roots turn brown soon after attack, the leaves turn yellow, and the stems droop until they become prostrate.

Outbreaks of hilda are highly sporadic. J.A.W. found specimens throughout Southern Africa but found only one field (out of about 100) where it was a pest. This was in Malawi, and the plant mortality was so high that the farmer had abandoned the crop. Hilda had spread to other farms by the time of the survey and probably caused considerable damage in the 6–8 weeks remaining before harvest.

Extension officers in Malawi found that some farmers would not grow groundnut for up to 5 years after seasons in which hilda was epidemic. Farmers over large tracts of Tanzania that appeared to be suitable for groundnut production did not grow this crop because of the 'black ants'. It is possible that the ants attending hilda were blamed for crop failures. The region in question had many cashew trees, which are a favoured alternative host for hilda in the off season.

Control

Insecticides: Taylor (1981) was not positive about the feasibility of controlling hilda with insecticides. She stated that monocrotophos, the only insecticide registered in Zimbabwe for hilda control at that time, was erratic in controlling infestations. Estate farmers in Zimbabwe apply carbofuran granules before sowing as prophylaxis (J.A.W., unpublished) and spray insecticides on weeds edging fields. However, these activities are beyond the means of the smallholders, about whom we are most concerned.

In 1985, an unattributed article in *Kenya Farmer* recommended that aldrin or dieldrin be worked into the soil before sowing or that diazinon, fenthion or fenitrothion be sprayed onto the bases of plants. The advice is questionable, as insecticide application would be effective only if farmers could forecast outbreaks and the cyclodienes might leave residues in the kernels.

Host-plant resistance: We know of no report of host-plant resistance to this species, but hot spots in Tanzania would be a good choice if screening for resistance becomes necessary.

Natural enemies: Hilda eggs are parasitized by *Psyllechthrus oophagus* (Hymenoptera: Encyrtidae). During 15 months of testing, Weaving (1980) found that 56 per cent of all eggs were parasitized and that only 14 per cent of the egg batches contained no parasites.

Parasitism was lowest in July–August and in December–January. The former period coincided with a low rate of oviposition by hilda and the latter, with high rainfall. Observations by Mchowa and Mitumbili (1987) in Malawi concur with the low rate of parasitism in the early part of the growing season when farmers need some natural control of this pest. Research on the host–parasite system might be of benefit. The only known predator of hilda is a coccinellid, *Hyperaspis*, that was seen feeding on eggs laid on the stem of *Hybiscus*.

Cultural: No systematic research on the cultural control of this 'difficult' species has been carried out. The ability of the insect to live through the dry season on weeds points to the possibility that farm hygiene would reduce the risk of an infestation. Delaying groundnut planting until the rains are established may also help. In fact, the heavy attack J.A.W. encountered in Malawi was in a field sown in early November with some early showers. The farmer took a risk in the hope of getting high preseason prices for his crop. Several other farmers in central Malawi had done the same but had suffered small losses to hilda. The rest of the farmers sowed with the main rains in early December, and none had detectable infestations. It could be that the early sown crops became infested because the farmers provided a preferred host when other plants had not started growing or that planting coincided favourably with the phenological characteristics of the parasite. Much is left to learn about this species.

CICADELLIDAE OR JASSIDAE

Smith and Barfield (1982) listed 15 entries, including five genera, under the family Cicadellidae or Jassidae. *Empoasca* spp. predominated the list, and we can add *E. pruthi* from India (Amin, 1983) and *E. signata* collected (by J.A.W.) from near Harare, Zimbabwe, but apparently common on groundnut throughout Southern Africa where there are reportedly about 350 species of *Empoasca* (J.G. Theron in Scholtz and Holm, 1985).

Austroasca viridigrisea may be a groundnut pest in Australia but was not included in the list. The literature takes note of jassids because of the insects' widespread and often abundant appearance, although the information about their pest status is conflicting.

Biology

DeLong (1971) gave an account of the biology and ecology of leafhoppers in general. They are slender, small (3–5 mm), and yellow or green. The adults fly readily when disturbed. In fact, observers can estimate their density after a little experience, by noting how many are flushed out by a walk through the crop.

The nymphs are usually found on the underside of a leaf. The egg is embedded in the tissue of the host, usually in the leaf. Incubation does not extend beyond a week in the tropics. There are five nymphal instars in the species found on groundnut. They resemble the adult except for the absence of fully developed wings. The nymphal period is also relatively rapid, lasting 7–14 days, according to the season.

The females are, in general, relatively fecund, laying up to 300 eggs, the actual number depending upon the food quality of the host and the seasonal and climatic conditions, as well the survivorship of the female. Thus, the life cycle can be completed in 2–4 weeks in tropical conditions.

Wheatley *et al.* (1989) found that when groundnut plants were grown along a drought-gradient, jassids were most abundant where the hosts were least stressed. They were also found where leaf (canopy) temperatures were lowest, i.e., about 30°C as opposed to temperatures exceeding 45°C. This experiment was carried out in peninsular India after the rainy season.

Damage and Economic Importance

Empoasca spp. and their close relatives appear wherever groundnut crops are grown. *Austroasca* spp. are found in Queensland, Australia. *Cicadulina* spp. are found in Africa, and *Orosius* spp. and *Erythroneura tripunctula* have been recorded from Asia.

The damage caused by *Empoasca* spp. and closely related genera is easy to diagnose. The first sign is a whitening of the veins on the underside of the leaflet. Chlorosis then sets in, usually at the tip of the leaf, and moves down the blade, followed by necrosis, again starting at the tip. The crop can take on a scorched appearance as a result of the necrosis. This is called hopper burn and is probably produced by a salivary toxin. The toxin appears to be lacking in *Austroasca viridigrisea*, the (Australian) vegetable jassid, which stipples the leaves. The related lucerne jassid (*A. alfalfae*), which is also found in Australia, produces the conventional feeding signs (Turner, 1980).

The economic impact of jassids in groundnut crops is not easy to determine. From the practical point of view it is difficult to get a groundnut field with only jassids present so that experimental plots can be treated with insecticides to eliminate these insects alone. Reports, therefore, often lump data for the removal of both jassids and thrips. For example, Sivasubramaniam and Palaniswamy (1986) applied monocrotophos every 15 days to half their study plots. Jassids and thrips were the only insects present, and, in 1983, this gave a pod yield increase of 48.5 per cent (1.75 t/ha compared with 0.9 t/ha). In the protected plots, an average 2.3 jassids were found for every three leaflets and in the unprotected plots, 2.19, whereas thrips numbered, respectively, 2.11 and 2.98. The authors do not state whether the mean insect densities were for the whole season or were just one observation. In 1984, a repeat of the experiment showed a 19.6 per cent increase (1.27 t/ha to 1.58 t/ha) in pod yields from the protected plots (jassids, per three leaflets, numbered 2.06 in unprotected plots compared with 0.46 in protected plots, and thrips were 3.51 compared with 1.92). The data from the 1984 study are similar to those of Saboo and Puri (1978) who attributed a 40 per cent loss in pod yield to jassids and thrips.

These results are difficult to understand when one considers that complete defoliation by caterpillars to all but the young plants causes no more than about 10 per cent loss in yields of TMV 2, a cultivar that is susceptible to many pests but that is widely grown in peninsular India. Furthermore, ICRISAT data point to no more than a 10 per cent pod loss attributable to jassids (*E. kerri*) even at much higher densities. Similarly, Campbell (1986) indicated that, in an experiment carried out by Kollmer, 60 per cent of leaves had to be scorched before yield loss could be detected. Even when all leaves were scorched, the loss in yield was only about 15 per cent. These findings are also in line with those of Turner and Briar (1979) in Australia and Ellis (1984) in Canada. The possibility of a 'host-genotype-environment-pest biotype' interaction should not be excluded.

Control

Chemical: Experience at ICRISAT has been that any insecticide applied at rates lethal to aphids or small caterpillars also kills jassids.

Host-plant resistance: Smith *et al.* (1985) have described methods of evaluating the reaction of groundnut genotypes to jassids (*E. fabae*). They concluded that the proportion of jassid-damaged leaflets was the best indication of the loss in photosynthetic area as well as the host's reaction.

Many groundnut genotypes are resistant to jassids (Table 5.8), and some have been used in breeding programmes (ICRISAT, 1985, 1986, 1987, 1988). W. V. Campbell and J. C. Wynne working in North Carolina (North Carolina State University, personal communication to J.A.W.) found resistance to leafhoppers in hybrids, primarily C12 × C37, that resulted from their crosses of NC Bunch and PI 121067. NCAc 343, also known by the ICRISAT identity number of ICG 2271, is one. It has a wide spectrum of resistance to a number of pests, although its agronomic characters were considered to be sub-optimal when it was registered (Campbell *et al.*, 1971). NCAc 343 is a parent of NC 6, a large-seeded Virginia-type, that was bred for sustained high yield in the presence of pests, including *E. fabae*.

Wynne and Campbell also found resistance to jassids in mutants selected after the irradiation of NC 4. Examples include NCAc 1705, 2142, 2144, 2230, 2232, 2240, 2243, and 2462, which in some cases have resistance to other pests as well (Table 5.9; Campbell *et al.*, 1971, 1975, 1976; Prof. J. C. Wynne, 1989, personal communication).

Likewise, many *Arachis* spp. have resistance to jassids (Campbell and Wynne, 1980; ICRISAT, 1986, 1987). This 'wild' resistance will probably not be exploited, as genes for resistance are readily available in cultivated species and the pest is of doubtful importance. Even though jassids may not cause economic damage in groundnut, their presence may induce farmers to apply insecticides.

Resistance has been transferred from one continent to another by Campbell and colleagues in the USA and in Southeast Asia, and jassid resistance is now included in several genotypes with multiple pest resistance (Campbell *et al.*, 1986; Sathorn Sirisingh and Manochai Keerati-Kasikorn, 1986).

Much of the information available points to the surface structures of the leaves as being of prime importance in the mechanism of resistance. In particular, the trichome length, density, straightness and location are implicated as well as the thickness of the epidermis (Campbell *et al.*, 1976; Dwivedi *et al.*, 1986).

The genetic studies of Holley *et al.* (1985) and Dwivedi *et al.* (1986) indicated that the genes responsible for resistance to jassids have a high level of combining ability. In fact, one character, 'long trichomes on the leaf margins' was used by Dwivedi and co-workers to select for jassid resistance in the absence of the insects. Their work pointed to NCAc 2230 as the best parent to impart jassid resistance, despite the low yield potential of the cultivar.

However, Holley *et al.* (1985) concluded that the most resistant parents did not always produce the most resistant progeny and vice versa. They also pointed out that the direction of the cross can influence the results so one must investigate, or at least be aware of, maternal and reciprocal effects.

Natural enemies: DeLong (1971) indicated that, although jassids are parasitized by members of 12 insect families, parasitism probably has little influence on their population density. He indicated that pipunculids and dryinids (Hymenoptera) are prominent jassid parasites.

As with many small plant-eating insects, jassids living on groundnut are probably eaten by many general predators, such as lycosid spiders. However, DeLong commented that chrysopids and coccinellids have been seen to ignore jassids in favour of other prey.

Cultural: At ICRISAT, peak populations of jassids occur in the second month after sowing (September and late-December–early January). The pattern is characteristic of phytophagous insects on an annual crop where natural enemies eventually provide control, but the pattern may reflect immigration followed by emigration caused by a change in the quality of the host plant. If older plants are unfavourable as hosts to immigrating adult jassids, then early sowing may help avoid an attack.

In a general review, Andow (1983) found that 32 populations of nine jassid species increased in intercropped life systems with non-hosts, whereas two populations representing two species decreased. He found that 12 populations (five species) increased in cropping systems with multiple hosts, and none decreased. ICRISAT data showed that densities of *E. kerri* in groundnut intercropped with sunflower, sunn hemp and pearl millet were lower than in groundnut grown as a sole crop. We do not know the reason for this.

OTHER HOMOPTERAN FAMILIES

Smith and Barfield (1982) indicated that pseudococcids (mealybugs) and coccids (scale insects) have been taken from groundnut plants from all around the world, but we know little about their applied ecology on this crop. One of us (J.A.W.) found mealybugs on the stems and roots of plants in Southern Africa, including what may be the first record of *Phenacoccus solani* from Malawi. This species has previously been found in South Africa and Zimbabwe, but the individuals found in Malawi differed slightly in an important character. During the survey, the plants with mealybugs feeding on them seemed smaller than the average. However, it was too early in the season for effects on pod yield to be manifest and too brief an observation to rule out the possibility that the insects were seeking a biochemical milieu of plants stunted by less obvious factors.

Johnson and Gumel (1981) found that superficial pod damage was caused by the mealybug *Dysmicoccus* sp. in Nigeria. Also, J.A.W. observed membracids, *Oxyrachis* sp., feeding on the roots of dying plants near Gabarone, in Botswana.

Heteroptera

Most of the Heteroptera attacking groundnut plants belong to the families Coreidae and Pentatomidae. They include species conspicuous by virtue of their size, such as *Leptoglossus australis* and *Anoplocnemis curvipes*, or abundance, such as *Nezara viridula* and *Piezodorus* spp. They come under the general heading of 'tip wilters' because their feeding causes the growing points to bend. The significance of this damage is not known but is likely to be small.

Elasmolomus sordidus — synonym *Aphanus sordidus* (Fabricius) — is widespread in tropical Africa and India (Conway, 1976) and has been reported from Brazil (Slater, 1972). It attacks a number of oilseed crops and feeds on groundnuts while they are drying in the field and when in store. The adult is dark brown, approximately 10 mm long and 2 mm wide. In the field, females lay cylindrical eggs in the soil or on drying groundnut haulms, but in stores eggs are laid loosely among the groundnuts or in sacking.

The first-instar nymphs have a bright red abdomen, but later instars become progressively darker. The length of the life cycle and optimum conditions for development have not been established. All stages are highly mobile, but adults and the larger nymphs tend to be restricted to the surface layers of stacks or sacks because they are too large to penetrate into a bulk or sack of pods. All stages feed on kernels, by piercing the pod with their rostrum. Mould grows where the testa has been punctured, and intensive feeding eventually causes the kernels to shrivel. The free fatty acid increases in the oil, producing a rancid flavour (Gillier, 1970). When large populations build up in stores, the pods become covered in dark spots of faecal material.

Thysanoptera

Thrips seem to feed on groundnut plants throughout the geographical range of the crop. Smith and Barfield (1982) listed 18 species belonging to 7 genera but, strangely, left out *Megalurothrips*, which is commonly found in large numbers in the flowers of groundnut plants and many other legumes. None of the best represented genera — *Caliothrips*, *Frankliniella*, *Scirtothrips* and *Taeniothrips* — are restricted to any one continent. The identification of thrips is a task for experts, although Amin and Palmer (1985), Ananthakrishnan (1969), Dyadechko (1964) and Lewis (1973) are helpful in this respect.

Scirtothrips dorsalis forms the bulk of the thrips fauna in groundnut fields (and in the air above them — according to ICRISAT suction trap data) in South and Southeast Asia. This species may be the vector of the yellow spot virus. Its feeding damage is conspicuous: brown lesions and severe distortion. It lives in the folded leaflets. *Scirtothrips aurantii* was found by J.A.W. on groundnut it Malawi but is normally thought of as a pest of citrus. *Frankliniella schultzei* is mainly a flower dweller and has been implicated as a vector of the tomato spotted wilt virus with *Frankliniella occidentalis* and *Frankliniella fusca*. *Thrips palmi* is probably the main vector of the tomato spotted wilt virus, with Thrips tabaci, both of which live mainly in the folded leaflets. *Caliothrips* species cause mottling on the leaf surface, but there is no information available about their economic importance. *Megalurothrips usitatus* is often (usually?) found in the flowers of legumes all over Asia, and J.A.W. found this species in flowers in Southern Africa.

Damage and economic importance

Wightman (1990), on reviewing the groundnut pests in Western agriculture, found that reports about the economic importance of damage caused by thrips (especially *F. fusca*) were strongly polarized. One set of data indicated that the economic burden of thrips on groundnut farmers in the state of Georgia was the huge cost of insecticides applied to kill them. However, since that time,'a definitive study in North Carolina has shown that a yield loss will occur when there is more than 40% leaf damage in a crop up to 6 weeks after sowing (Turnjit and Campbell, personal communication, 1989) — i.e., when damage is severe among the young plants. This is pertinent information because the distortions caused by thrips to the foliage of young plants look serious, especially when temperatures are low so that the crop cannot outgrow the damage. This occurs in groundnut sown in winter under irrigation in India when it is suspected that the yield losses are small, especially when compared with the damage caused by thrips when they introduce a virus into a crop.

When tomato spotted wilt virus is introduced into groundnut, it causes bud necrosis disease. In the West this is mainly thought of as a crippling disease of tomatoes and ornamentals, but it also causes widespread death and stunting of groundnut in the USA, Australia and Asia. Even if the plant achieves maturity, the seeds are usually shrivelled and discoloured.

The role of thrips as vectors has been discussed by Reddy and Wightman (1988), and new research at ICRISAT, in conjunction with the British Museum of Natural History (unpublished), has shown that *T. palmi* is probably a major vector of the tomato spotted wilt virus in India.

Control

ICRISAT focuses on control measures to stem the spread of the tomato spotted leaf virus by regulation of the density of the vectors.

Chemical: Many insecticides will kill thrips, but relatively high doses are required to eliminate these tiny insects (Reddy and Wightman, 1988). In fact, following insecticide use, population explosions have been reported (Reddy and Wightman, 1988).

Natural enemies: Phytophagous thrips are preyed upon by a number of general predators, such as mirid and anthocorid bugs, as well as by predatory thrips. There are no data about the natural control agents, but the relative ease with which phytophagous species reproduce after insecticide application indicates that natural enemies regulate their densities.

Host-plant resistance: Despite great efforts by ICRISAT's virologists, little resistance to the tomato spotted wilt virus has been found in *A. hypogaea*. This does not mean that the breeders have been inactive in this area because many lines with resistance to thrips have been located and the appropriate genes incorporated into agronomically acceptable genetic backgrounds (Table 5.8). Many of the genotypes and hybrids with resistance to jassids are also resistant to thrips. Robut 33-1 (Kadiri 3) is a popular cultivar in southern India and Tanzania. It is a source for resistance to thrips and a parent to high-yielding lines such as ICGS 11 and ICGS 44.

Cultural: One method of reducing the risk of an outbreak of tomato spotted wilt virus is to phase the sowing of the crop in such a way that the seedling (i.e., the stage that is the most vulnerable to the virus) will not be exposed to an invasion of thrips. This implies the need for knowledge of flight periodicity of the species. Research at ICRISAT has shown that the prevalence of the virus increases as the planting date is delayed — both in the rainy and in the postrainy season. Furthermore, a densely sown crop is likely to have lower losses attributable to the virus than a widely spaced crop (Wightman and Amin, 1988).

Physical barriers across the prevailing wind also influence thrips' density. This can mean an intercrop that is not a host, such as sorghum, maize and millet or a row of trees.

Weeds harbour both the vectors and the virus; however, weed clearing operations in Australia succeeded in reducing the prevalence of the virus only to a limited extent (Saint-Smith *et al.*, 1972). Whether coordinated, selective weed destruction would have had the desired effect of reducing 'off-season' reservoirs is not clear.

Hymenoptera

Smith and Barfield (1982) listed Formicidae as the only hymenopteran family attacking groundnuts. Of the eight genera listed, only one, *Dorylus*, includes species causing extensive damage. *Dorylus orientalis* is found in peninsular and northeast India, Bangladesh, south China, Nepal (Terai), Sri Lanka, Burma, Thailand and the northern tip of the Malaysian peninsula. Another species of *Dorylus*, or perhaps the same one, was found for the first time by J.A.W. throughout Southern Africa underneath groundnut plants and damaging the pods.

The workers in this genus are almost totally subterranean and eyeless. They are light brown, 5–11 mm long (major workers) or 2.5–3 mm long (minor workers). They are polyphagous and cause damage to many root and tuber crops as well as to seedlings and to beehives, attacking the brood and stealing honey and pollen. The workers are said to eat other insects and earthworms. They make a 2-mm-wide hole in the distal end of groundnut pods and remove the contents. They leave little trace of their passage, whereas termites leave soil and most pod-boring beetle larvae leave frass.

The pods of plants growing in small plots at ICRISAT centre have been entirely destroyed by *D. orientalis*, and probably many other such instances have gone unrecorded in South Asia.

However, in Thailand the pest potential of this species has been realized and publicized by Manochai Keerati-Kasikorn and Preecha Singha (1986). These scientists found that attacks started 7 weeks after emergence, i.e., as soon as the pods started to form. Farmers in the area of north Thailand lost 15–48 per cent (mean, 32 per cent) of their crops as a result of this pest. Attempts to control it by using copra baits treated with insecticide were not successful.

J.A.W. has seen notches cut out of leaves by megachilid (leafcutter) bees, but this is probably of no economic importance.

Coleoptera

BRUCHIDAE

Caryedon serratus (Olivier), commonly referred to as groundnut borer, groundnut weevil, or groundnut bruchid, is found in many parts of the tropics, breeding on the seeds of common tree legumes such as *Cassia* spp., *Acacia* spp., *Bauhinia* spp., *Piliostigma* spp. and *Tamarindus indica*, as well as on harvested groundnuts (Davey, 1958). Synonyms are *Bruchus serratus* Olivier, *Bruchus gonagra* Fabricius, *Caryedon fuscus* (Goeze), and *Caryedon gonagra* (Fabricius).

In West Africa, *C. serratus* is recognized as a serious pest of groundnuts both in commercial storage (Pattinson and Thornton, 1965; Pointel *et al.*, 1979) and in farmers' seed stores (Conway, 1975). It also attacks groundnuts in commercial storage in India (Dick, 1987). Although it occurs in some parts of Central and South America (Johnston, 1986) and the Caribbean (USDA, 1976), it apparently does not infest stored groundnuts in these regions (Robert, 1985).

The adult is 4–7 mm long and reddish brown, with dark irregular markings on the elytra. It has prominent, compound eyes and can be easily distinguished from other storage pests by its broad hind femur, which bears a conspicuous comb of one large spine and 8–12 smaller ones.

Adult females attach their eggs singly to the pods. When the first instar larva hatches, it burrows directly through the pod wall and the seed coat to feed on the cotyledons. Larval development is completed within a single kernel. When mature, larvae may partially or completely emerge from the pod, leaving a characteristic round hole, approximately 3 mm in diameter. Larvae frequently migrate to the bottom of a stack or heap before pupating

(Conway, 1983; Dick, 1987). Damage caused by subsequent generations is commonly heaviest in this part of the stack.

The papery, ovoid cocoons are distinctive. Their discovery is often the first indication of infestation. Under optimal conditions (30–33°C and 70–90 per cent RH), the period from egg to adult emergence is approximately 40 days.

Infestation by *C. serratus* can begin in the field with the migration of adult beetles from wild hosts to newly harvested groundnuts. Alternatively, clean groundnut stocks can become infested when placed in stores containing infested residues from previous crops.

The relative importance of these two possible sources of infestation is unclear and would influence the efficacy of control procedures. In a country-wide survey in the Gambia, Conway (1975) found that 21 per cent of samples from windrows and 40 per cent from stacks drying in farmers' fields were already infested with *C. serratus.*

Although the mean level of infestation was low (0.1–2.0 per cent of pods in each sample), Conway concluded that field infestation was the main source of the bruchid populations found in groundnut stores. Other authors (Appert, 1954; Green, 1959) doubt the ability of *C. serratus* to migrate from wild hosts to the cultivated crop and consider crop residues to be the primary source of infestation.

In the Congo, Matakot *et al.* (1987) were unable to find a consistent relationship between the presence of *C. serratus* in storage and infestations in the field. They concluded that outbreaks of the pest originated chiefly from residual populations surviving in village stores. Their studies suggested that the size of bruchid populations is ultimately determined more by factors that influence the rate of population development than by the initial source of infestation.

Control

Chemical: In West Africa, lindane, malathion, bromophos, or iodofenphos dust are reportedly applied frequently to windrows to prevent infestation by *C. serratus* of groundnuts intended for seed supply or for the confectionary market (Conway, 1975; Deuse and Pointel, 1975; Gillier and Bockelee-Morvan, 1979).

In Senegal, bromophos dust (2 per cent a.i.), applied at a rate of 200 g/m^2 to the surface and base of large seccos, reportedly gives effective control of *C. serratus* (Pointel *et al.*, 1979). Small quantities of pods or kernels retained by farmers as seed can be protected by the admixture of insecticidal dust. However, insecticide should not be applied directly to groundnut kernels intended for consumption or oil expression.

Table 5.9. The survival of *Caryedon serratus* eggs and the subsequent F$_1$ generation on,the groundnut pods of some advanced breeders lines (ICGV) and cultivars

Genotype	Egg survival (%)	F$_1$ prepupae and pupae (no./100pods)
ICGV 87204	18.7	6.9
ICGV 87354	22.0	10.4
TMV 2	28.7	10.0
2133	29.7	10.9
ICGV 86014	31.2	12.8
J 11	32.4	10.2
NCAc 343	32.5	12.8
ICGS 44	33.9	10.4
ICG (FDRS) 43	34.5	11.5
Robut 33-1	34.9	15.2
ICGV 86042	35.5	14.8
ICG (FDRS) 10	36.4	13.4
ICGS 11	39.9	10.8
M 13	39.9	16.5
ICGV 86016	40.1	15.7
ICGS 1	40.1	9.7
ICGV 86127	40.9	13.0
ICGV 86124	41.0	11.7
ICGV 86015	41.6	16.4
ICG (FDRS) 4	41.8	11.0
NCAc 17090	43.4	12.2
ICGV 86056	43.6	10.0
JL 24	52.4	17.2
ICGV 86055	55.6	13.2
ICGS 5	59.8	9.2
SE ±	12.5	3.3

If groundnuts are already infested with *C. serratus* when they are stored, then bruchid larvae may be present throughout a heap or stack and may have caused considerable damage before they are detected. In this situation, the only effective treatment is fumigation with methyl bromide or phosphine gas. Methyl bromide has been used extensively in West Africa to protect groundnut stocks (Gillier and Bockelee-Morvan, 1979). The recommended dosage for the control of *C. serratus* infesting groundnut pods and kernels is 60–70 g/t for 48 h (FAO, 1985). The number of times any one consignment of groundnuts can be fumigated is limited because inorganic bromide is retained in the oil of groundnut kernels (Feakin, 1973). Western countries, in general, and the USA, in particular, have now become concerned about bromide residues in foodstuffs. Also, repeated applications may reduce the germination potential of groundnuts kept for seed, particularly if the seeds' moisture content is above that recommended for safe storage (Redlinger and Davis, 1982).

Phosphine has certain advantages over methyl bromide in that it requires no special equipment for application and leaves no residues. However, effective treatment takes longer than with methyl bromide (5–10 days) and could disrupt routine stock movements.

Natural enemies: The larvae of *C. serratus*, particularly when feeding inside intact pods, are well protected from predators and parasites. However, final instar larvae often migrate within a store before pupating and are then vulnerable to attack by predators, such as the reduviid bug *Amphibolus venator* (Klug) (Howe and Freeman, 1955; Dick, 1987).

Caryedon serratus pupae are preyed on by prostimatic mites of the genus *Pyemotes* (Bruce and LeCato, 1979). Matakot *et al.* (1987) reported that parasitism of *C. serratus* pupae by *P. tritici* contributed to regulation of *C. serratus* populations in groundnut stores in Congo. Similarly, in Gambian stores, heavy mortality of *C. serratus* pupae was caused by *P. ventricosis* (Conway, 1975).

Host-plant resistance: To date, there have been no large-scale breeding programmes aimed at reducing the inherent susceptibility of groundnuts to attack by *C. serratus*. The lack of attention probably reflects the relative cost-effectiveness of insecticide applications, the limited geographical area in which this pest has been considered to be of major importance and the failure of entomologists and breeders to come together in a suitable place.

Opportunities to reduce susceptibility to *C. serratus* derive from genotypic variability in characteristics that affect oviposition on pods, larval penetration of the pod wall, and development of larvae in the kernels. Significant variation among genotypes has been demonstrated for a number of these characteristics (Table 5.9) (Mittal, 1969; P. Dobie, Overseas Development and Natural Resources Institute, 1986, personal communication).

BUPRESTIDAE

The larvae of *Sphenoptera indica (perotetti)*, jewel beetle, penetrate groundnuts below the crown and burrow through the central core of the root, thereby killing or stunting the plant. By the time they pupate (in the root cortex they have hollowed out), there is little vascular or pithy tissue remaining.

Jewel beetles are a rainy season pest at the ICRISAT farm. In one season we attributed 14 per cent plant mortality to this insect in a rainfed field and 8 per cent in a field that was irrigated whenever water was needed. The full range and the extent of damage caused by this species are not known. First-instar larvae have been found in groundnut pods at ICRISAT but this is considered to be rare. Experiments at ICRISAT showed that this species was controlled by a presowing treatment of chlorpyrifos at 4–5 kg a.i./ha.

CURCULIONIDAE

The only species of weevil that really concerns groundnut growers is the white-fringed weevil or railroad weevil, *Graphognathus leucoloma*. It is common in North America and is apparently still extending its range in Australia. J. Rogers (personal communication) indicated that it is currently causing losses to groundnut farmers in central Queensland.

The adults eat the foliage but it is the root-eating habits of the larvae that cause stunting and plant death. The species is parthenogenetic, each female laying 1000–2000 eggs during her long adult period. The host range is wide, including potatoes and several common pasture and forage legumes – *Trifolium* spp. and *Medicago* spp. – but, according to Feakin (1973), groundnut is a favoured host. Feakin also indicated that the application of a persistent insecticide at the time of sowing in fields with recent infestation gives satisfactory control in high-input cultivations.

Another weevil species that may reduce yields, this time in northern India, is *Myllocerus undecimpustulatus maculosus*, the ash or grey cotton weevil. The adults appear in the rainy season. They cause an irregular scalloping around the edge of groundnut leaflets. Brar and Sandhu (1975) reported marked resistance to this species in all the spreading genotypes they tested. AH 288, AH 8045, C 112, C 148, C 162, Karod 4-11, M 13, M 145, S 230, T 28, 1-2, and 4-6 were the least attractive to the adult weevils. Research may reveal that the larvae cause considerably more damage to their hosts than is suspected (Wightman, 1987).

Both Rose (1962) and Broad (1966) pointed to problems caused by the larvae of weevils in Zimbabwe, mentioning *Systates exaptus* and *Mesoleurus dentipes* specifically. Groundnut crops are believed to induce local increases in population densities, which endanger the following maize crop. These species feed on the roots and pods of groundnut plants.

J.A.W. found *Systates* spp. in Zimbabwe and Malawi, and *Diaecoderus* sp. in Malawi. Jepson (1948) reported plants being skeletonized by *S. articollis* in Tanzania. He also reported the 'yellowing and failure of a young plantation' as being associated with an attack by *Diaecoderus* sp. The yellowing is a sign of nitrogen deficiency and is a result of an attack on the nodules by the larvae. For example, it occurs when *Sitona* spp. attack legumes, including groundnut (Smith and Barfield, 1982; Wightman, 1987).

DERMESTIDAE

The khapra beetle, *Trogoderma granarium* Everts, is more tolerant of hot, dry conditions than many other storage pests and is commonest in the semi-arid areas of Africa, West Asia and northern India. It has not been recorded from Southeast Asia, South America, or Australia (Banks, 1977).

In some areas, such as northern Nigeria, where *T. granarium* has been a major obstacle to exporting groundnut, intensive programmes of fumigation have succeeded in reducing its importance (Halliday, 1967). In other regions, such as Somalia, it is still regarded as the most serious pest of stored groundnuts (Fenili *et al.*, 1983).

Adults are oval, 2–3 mm long, and dark brown with black mottling. Their dorsal surface is covered with fine hairs. They live for about 2 weeks and do not feed or fly. The larvae are straw-coloured and, from the fourth instar onward, have characteristic, dense tufts of hair on each abdominal and thoracic tergite. The bionomics of this species developing on groundnuts have not been rigorously examined in the laboratory, and optimal conditions for its development are still a matter for debate. Its common occurrence in hot, dry areas is generally attributed to its inability to compete with faster-breeding species in humid environments (Smith, 1963).

Larvae of certain strains enter diapause when subjected to adverse conditions such as extremes of temperature or population density. When almost mature, the pre-diapause larvae often leave their food supply to enter crevices in the storage structure where they may remain for many months (Burges, 1962, 1963). In this state, metabolic activity is low, and the larvae are extremely resistant to insecticides. Complete disinfestation is, therefore, difficult. Because of this, *T. granarium* is considered a most important pest by countries that import groundnuts, and the presence of even a few individuals is likely to result in the rejection of an entire groundnut consignment.

Methyl bromide is effective against all the main beetle pests of shelled groundnuts, although the dosage must be increased by 50 per cent to be effective against *T. granarium* (FAO, 1985). *Trogoderma granarium* is, however, as susceptible as most other species to phosphine, which should be applied at the same rates as those used for pyralid moths (Table 5.2).

Mattesia trogodermae has potential for the control of *Trogoderma* spp. (Schwalbe *et al.*, 1974). A commercial product would have to contain spores of a number of different pathogen species because they are relatively specific.

ELATERIDAE AND TENEBRIONIDAE

Wire-worms and false wire-worms

Wire-worms and false wire-worms can be dealt with together because the convergence of their evolution that led to their morphological similarity extends to their predilection for groundnut pods. There are problems with their identification. The larvae are pencil-shaped and can be up to 4 cm long. They are creamy white to brown. Their life cycles tend to be longer than those of white grubs, but little is known about their biology except that they damage groundnut pods by boring through the shell and eating the seeds. Only the adult lives aboveground. Both types of insect have been found damaging groundnut pods and the newly sown seed at ICRISAT centre, but their identity and that of other species in Asia are not known.

The adults of false wire-worm species in the genus *Gonocephalum* (e.g., *G. simplex*) are called dusty brown beetles. They are found throughout sub-Saharan Africa, and J.A.W. found large numbers associated with groundnut crops in a black soil area in the south of Malawi in December and January.

The larvae can clearly damage many pods during their long development, even though their density rarely exceeds 10/100 plants (Wightman, 1989). When their density is added to that of other pod borers (millepedes, termites, ants and white grubs), this cohort must destroy many pods during a cropping season. Central Malawi was particularly hard hit by this group of insects, with one for every two plants in some places.

Rust-red Flour Beetle

Among Coleoptera, the key pest of stored groundnuts is *Tribolium castaneum* from the family Tenebrionidae. Commonly known as the rust-red flour beetle, it is found throughout the tropics. The adults are 3–4 mm long, chestnut brown and have a life span of several months. They are strong fliers and are often the first insects to colonize new stocks of groundnuts.

The females lay their eggs in cracks in the testa or in holes in the kernels created by the adult while feeding. Thus, the first-instar larvae, which cannot penetrate an intact seed coat, are able to feed directly on the cotyledon.

The larvae are cylindrical, with two prominent 'horns' on the last abdominal segment. They create tunnels in the cotyledons as they feed and pupate within the kernels. Both adults and larvae feed on the eggs and pupae of other storage pests and are also strongly cannibalistic. Development from egg to adult takes about 32 days at 30°C and 90 per cent RH, but the period is doubled when the RH drops to 70 per cent.

Feeding by the adults and larvae creates a fine dust that contains less oil than whole kernels and has a much higher free fatty acid content (Davey *et al.*, 1959). Thus, the feeding of *T. castaneum* reduces the quality, as well as the quantity, of the oil produced.

Measures to prevent infestation of stores by *C. serratus* are effective also against *T. castaneum*, and phosphine treatment is recommended over methyl bromide because it leaves no residue.

Natural control has promise, as populations of *T. castaneum* released into large plywood bins containing 200 L of groundnut pods have been effectively suppressed by *X. flavipes*, introduced 7 days later (Press *et al.*, 1975). After 14 weeks, the predator had reduced *T. castaneum* populations to less than 10 per cent of control populations and had reduced the number of damaged kernels by 66 per cent. Also, laboratory studies suggest that a pathogen *Nosema whitei* controls *Tribolium* sp.

As with the other pests of stored groundnuts, there have been few studies of host-plant resistance to the beetles that commonly attack decorticated stocks. Mbata (1986) examined the susceptibility of some newly released Nigerian varieties to infestation by *T. castaneum*. Significant differences existed between genotypes, both in the time of development and in the number of F_1 adults produced.

Whether the adults were fewer because of differences in the number of eggs laid or in the mortality of immatures was not reported. The larvae of *T. castaneum* developed more quickly and more reliably on broken kernels than on whole kernels, probably because of both the marked oviposition preference of *T. castaneum* females for broken rather than whole kernels and the inability of first-instar larvae to damage intact groundnut kernels (Mathur and Kausal, 1984). The significant differences observed in development period on the broken kernels must however reflect differences in the suitability of the cotyledons as sources of nutrition.

MELOIDAE

Blister, pollen or flower beetles are large (up to 3 cm long) and conspicuous; they feed on the flowers of legume crops in all of Africa and in much of Asia. The genera include *Mylabris*, *Coryna* and *Epicauta*. The younger larvae (triungulins) feed in or on the eggs of locusts and grasshoppers and are, therefore, considered to be beneficial. The flower-eating habit of the adults probably has little influence on the yield of groundnut because the crop produces an excess of flowers, and the flowers are self-pollinated early in the day. Their bright or metallic colours are conspicuous so that their importance may be overestimated.

SCARABAEIDAE

White grubs share with termites the reputation of being among the most widespread and most serious field pests of groundnut in the developing world. In general, termites are most serious when rainfall is limited or badly distributed, particularly at the end of the growing season, whereas white grubs are most damaging when rainfall is adequate, especially early in the season when the plants are young (J.A.W., personal observation). In this chapter, we are most concerned with melolonthids and rutellines. Members of other sub-families have life systems oriented more towards dung and other forms of dead organic matter (Veeresh, 1978).

Biology

There is general agreement about the life cycle of these insects in the tropics, e.g., Broad (1966) for Southern Africa and Brar and Sandhu (1980a) for India. There are three larval instars that can be easily distinguished by the size of the head capsules. This stage feeds on the roots of hosts. Oligophagy is probably commoner than polyphagy. Depth of feeding, and therefore the type of roots, is determined by soil moisture, soil temperature and the amount of feeding activity of other white grubs (Wightman, 1972).

When the larva has reached its maximum size, it burrows well below its normal feeding zone and forms an earthen cell. It pupates within this cell and awaits the start of the next rainy season before it ecloses. The adults emerge at dusk and, in sequences and combinations that are species-specific, mate, feed on ground-level vegetation, and fly up to several hundred metres to feed on trees of selected species. The adults are active in the month or so following the 'planting rains'.

The eggs are white, oblate spheroids. They are found in clusters, 15 cm or more below the soil surface. The insects are not particularly fecund, each female producing 20–80 eggs. The eggs hatch as the groundnut reaches the late seedling stage, and the larvae sometimes feed on organic matter in the soil before they commence feeding on the roots.

This general picture does not tell the full story. For example, in Africa, J.A.W. found relatively large specimens (i.e., third-instar larvae measuring 2–4 cm long) in groundnut fields quite soon after sowing. This implies that they had overwintered, as is the case with *Rhopaea magnicornis* in Australia for instance (Gough and Brown, 1988). J.A.W. also found eggs and newly hatched larvae well into the growing season. These findings suggest that gaining an understanding of the bionomics of this taxon in Southern Africa will be complicated by the diversity of the species and the variation within species.

Table 5.10. White grubs associated with the groundnut crop[a]

Species	Location	References
Adoretus cribrosus	Zimbabwe	Smith and Barfield, 1982
A. umbrosus	Africa	Smith and Barfield, 1982
Adoretus spp. (up to 4)	Malawi, Zambia, Zimbabwe	J.A.W. J.A.W.
Anomala antiqua	Burma	Smith and Barfield, 1982
A. atrovirens	Indonesia	Smith and Barfield, 1982
A. phebeja	Africa	Smith and Barfield, 1982
Anomala spp. (up to 11)	Botswana, India, Malawi, Zambia, Zimbabwe	J.A.W. J.A.W. J.A.W.
Eulepida mashona	Africa	J.A.W.
Heteroligus claudius	Nigeria	J.A.W.
Heteronyx brevicollis	Australia	J.A.W.
Lachnosterna caudata	Australia	J.A.W.
L. (Holotrichia) consanguinea	India	J.A.W.
L. fissa	India	J.A.W.
L. serrata	India	Vereesh (1978)
Lepidiota sp.	Australia	Gough and Brown, 1988
Maladera sp.	Thailand	Sathorn Sirisingh, personal communication
Oxycetonia versicolor	India	Smith and Barfield, 1982
Podalgus (Crator) cuniculus	Africa	Smith and Barfield, 1982
Popillia japonica	China	Smith and Barfield, 1982
Rhopaea magnicornis	Australia	Smith and Barfield, 1982
Schizonycha africana	Africa (NE)	Smith and Barfield, 1982
S. fusca	Malawi	J.A.W.
S. straminea	Malawi	J.A.W.
Schizonycha spp. (up to 8)	Malawi	J.A.W.
Schizonycha spp. (up to 3)	Zimbabwe	J.A.W.
Trissodon (Isodon) puncticollis	Australia	J.A.W.
Trochalus sp.	Malawi	J.A.W.
Xylotrupes gideon	Burma	Smith and Barfield, 1982
?Sericini (tribe) (indet. 8 species)	Malawi, Zimbabwe, Zambia	J.A.W. J.A.W.

[a] This table adds to the lists of previous reviewers; J.A.W. signifies data from the unpublished survey records of J. A. Wightman.

Damage and Economic Importance

White grubs are found wherever groundnut crops are grown in the developing world (and in Australia). It is clear that many species are yet to be described. J.A.W.'s survey in Southern Africa accounts for about half of the current records (Table 5.10) and indicates the dearth of taxonomic back-up. Most of the larvae he collected were undescribed species belonging to three genera. They were most frequently recovered from sandy soil or well-tilled ferruginous loam, especially where rainfall was average or better than average. For example, white grubs were abundant in the red loams of central Malawi but were less frequent in the silts of the Luangwa Valley and in the light red soil near Chipata in Zambia (Table 5.11). In Zimbabwe, white grubs were not common in fields that had just come out of fallow or that had been converted from bush earlier in the season.

Table 5.11. White grubs detected during a survey of groundnut farms in Southern Africa, 1986, rainy season[a]

Country	Location	Number of fields	White grubs (no./100 plants)
Malawi	Mitundu	6	18.4
	Likundu	4	50.7
	Chileka	7	39.7
	Nsalu	3	76.1
Zambia	Choma	3	2.4
	Mumbwa	5	14.6
	Chipata	5	13.3
	Luangwa Valley	5	3.0
	Kabwe	3	19.2
Zimbabwe[b]	Masvingo	5	11.1
	Chilimanzi	4	7.5
	Manyene	4	37.3
	Mawere	6	33.3
	Wedza	6	45.4
	Chinhoyi	4	91.8

[a] Data collected by J. A. and A. S. Wightman

[b] Data for Zimbabwe are arranged with the southernmost (and, therefore, the driest) location first.

Similarly, in Australia, J. Rogers, working from central Queensland, was able to recognize 18 species living under local groundnut crops, although he has not yet determined their identity (personal communication). The point is that both Dr. Rogers and J.A.W. actually set out to look for these insects in the soil in groundnut fields so one can expect further such surveys will reveal many more species.

At present, Africa is the continent where white grubs are a widespread problem. This is in line with Veeresh's (1978) statement that only two species are important (sometimes very important locally) in India: *Lachnosterna (= Holotrichia) consanguinea* mainly in the light alluvial soils of northern India and *L. serrata* throughout the sub-continent.

There are also several records from Southeast and East Asia (Table 5.10). *Maladera* sp. is the most abundant white grub in north Thailand and another unidentified species has recently been found in northeast Thailand (Sathorn, personal communication).

White grubs sever fine roots, often close to the taproot of the groundnut, the result being elimination of a relatively large amount of water-absorbing area even when only a small amount of tissue is eaten. As the attacks come mainly during the late seedling stage, they can stunt or even kill the plant, particularly if soil moisture is limited. Often, examinations of older plants that have been attacked reveal distinct lesions on the taproots, which become entry points for *Microtermes* spp. and *Odontotermes* spp., as well as for fungal infections. White grubs also destroy pods at all stages of development.

There are many generalizations in the literature about the degree of damage caused by white grubs to groundnut crops, but few give specific data or attempt to relate insect number to damage. The most precise report came from Australia, where Gough and Brown's (1988) data showed one white grub (*Lepidiota* sp.)/3 m of row (about 15 plants) caused a loss of pods equal to 44 kg/ha.

Bakhetia (1983) showed, in experiments carried out at two sites in the Punjab in northern India during 2 years, that the avoidable loss caused to groundnut crops by *H. consanguinea* was from 29 per cent to 42 per cent. Bakhetia and Brar (1983) increased the yield of groundnut crops from 0.68 t/ha to more than 1.2 t/ha by using insecticides that ostensibly controlled white grubs, again in the Punjab. Similarly, in tests from Varanasi, in northern India, the best insecticide treatment (phorate 10G at 2.5 kg a.i./ha) reduced a population of 52 larvae/m^2 to 12/m^2 with a resultant improvement in yield of 300 kg/ha over a control plot yield of 775 kg/ha. Initially populations were about 4 larvae/plant (Janardan Singh and Paras Nath, 1985). In Tirupati, in southern India, a plot protected with phorate, at 1.5 kg a.i./ha yielded 1.72 t/ha compared with a mean control plot yield of 1.17 t/ha (Siva Rao *et al.*, 1984).

Table 5.12. Insecticides that have been recommended for the control of white grubs in groundnut crops

Location *species*	Insecticide	Rate[a] (kg a.i./ha)	Reference
India			
Holotrichia consanguinea	Phorate 10G	1-3	Bakhetia, 1982a
		1	Brar and Sandhu, 1980a,b
		2.5	Ram and Yadava, 1982; Vishwa Nath and Srivastava, 1981;
		1.5	Siva Rao *et al.*, 1984
		SC[a]	Ram and Yadava, 1982
	Carbofuran 3G	1-3	Bakhetia, 1982a
		1	Brar and Sandhu, 1980a,b,; Bakhetia *et al.*, 1982
		1.5	Siva Rao *et al.*, 1984
		SC	Bakhetia, 1982b; Ram and Yadava, 1982
	Isofenphos 5G	1-3	Bakhetia, 1982a
		1	Brar and Sandhu, 1980
		SC	Bakhetia, 1982b
	Quinalphos 5G	1	Bakhetia, 1982b
	Quinalphos 25EC	1	Bakhetia, 1982b
	Dazomet 10G	2.5	Vishwa Nath and Srivastava, 1981
	Heptachlor (10% dust)	2.5	Vishwa Nath and Srivastava, 1981
	Fensulfothion 5G	1	Bakhetia *et al.*, 1982
	Chlorpyriphos	SC	Bakhetia, 1982b
	Phoxim	SC	Bakhetia, 1982b
	Fenitrothion	SC	Bakhetia, 1982b
Africa			
Eulepida mashona	Dieldrin dust 2%		Broad, 1966; Rose, 1962
	Aldrin, endosulphan, and heptachlor (no details)		Rose, 1962
Australia			
Heteronyx spp.	Carbofuran	3	Rogers, personal communication

[a] SC = seed coating.

These data show that white grubs can have a marked influence on the yield of groundnut crops. However, they do not exclude the possibility that other insects were also exerting an influence on crop yield and that their influence had gone undetected. In fact, in a series of five experiments carried out in Malawi, dieldrin was applied to experimental plots, with resultant yields up to 60 per cent higher than control plots. Although white grub was implicated in some cases, clearly other soil organisms (especially termites) were also involved (Wightman, 1989).

Control

Chemical: A number of insecticides have been listed for the control of white grubs (Table 5.12). Carbamate and organophosphate, although they break down rapidly in tropical soils, should kill larvae before losing their potency. As the insects have only one generation per year (compared with continual invasion and reinvasion characteristic of termites), control can be effective by materials that remain active for a comparatively short period.

Host-plant resistance: No resistance to these insects has been confirmed.

Natural enemies: Brar and Sandhu (1980b) listed the natural control agents of white grubs in India. Microbial agents include the fungi *Aspergillus parasiticis, Beauveria bassiana,* and *Metarrhizium anisopliae*; the bacteria *Bacillus cereus, B. thuringiensis, Diplococcus* sp., *Clostridium* sp., and *Micrococcus* sp. Two scolid parasites, *Scolia aureipennis* and *Campsomeris callaris,* have also been reported. Predators include carabid larvae, toads, many bird species and mammals such as mongooses and pigs.

Cultural: There is scope for community action for reducing the general population of white grubs in a farming area when the beetles are above-ground in the evening to mate and feed. Brar and Sandhu (1980b) cited cases where literally millions of beetles have been destroyed. They also maintained that repeated ploughing, flooding and puddling reduce white grub densities.

SILVANIDAE

The merchant grain beetle — *Oryzaephilus mercator* (Fauvel) — and its sibling species *O. surinamensis* are found throughout the tropics. The two are difficult to distinguish morphologically, but *O. surinamensis* is generally associated with cereal products rather than oilseeds (Howe, 1956).

Oryzaephilus mercator is ecologically and behaviourally similar to *T. castaneum*, although it is generally regarded as a less serious pest. The adults are 2.5–3.5 mm long with a distinctively ridged prothorax, bearing six large teeth on either side. The larvae are cylindrical and cream-coloured. They can be distinguished from *T. castaneum* larvae by the absence of 'horns' on the last abdominal segment. First-instar larvae cannot penetrate intact testae and must feed on exposed kernels of groundnut. Under optimal conditions (30–33°C and 70 per cent RH), the life cycle is completed in 28–35 days.

Infestation by these beetles is unlikely to begin in the field. Thus, the measures recommended for prevention of infestation of clean stocks by *C. serratus* and *E. sordidus* are appropriate, perhaps as a routine. Methyl bromide and phosphine are effective.

Both *Tribolium* and *Oryzaephilus* spp. are preyed on by *X. flavipes*. In small silos filled with groundnut pods, *X. flavipes* adults, released on the surface of the bulk, suppressed populations of *T. castaneum* and *O. mercator* introduced into the groundnuts at different depths from the surface (Press *et al.*, 1979). Dispersed populations of *O. surinamensis* and *T. castaneum* were successfully controlled by *X. flavipes* when the predator was released into a warehouse in which small quantities of culture media had been used to simulate debris from previous harvests (LeCato *et al.*, 1977).

In contrast to the relatively numerous studies that indicate the potential for control of moth pests by bacteria and viruses, there is little indication that stored-product Coleoptera can be similarly suppressed by these pathogens (Hodges, 1984). However, several protozoa are known to be pathogens of the beetle pests of groundnut. The results of laboratory trials have shown that *Nosema oryzaephili* has considerable potential for the control of *Oryzaephilus* spp. (Burges *et al.*, 1971).

OTHER COLEOPTERAN SPECIES

Other coleopteran species that occasionally infest stored groundnuts but rarely cause significant losses include *Tenebroides mauritanicus* (L.), *Lasioderma serricorne* (F.), *Latheticus oryzae* Waterhouse, *Cryptolestes* spp., *Alphitobius* spp., and *Carpophilus* spp. These minor pests are usually found in association with one or more of the major pests and appear to be successfully controlled by the same chemicals.

Lepidoptera

Defoliators, especially Lepidoptera, can cause such foliar damage that farmers apply insecticides because of concern about the appearance of the crop. We at ICRISAT believe that such injudicious use of insecticides has intensified pest problems. In 1980, Amin and Mohammad described the proliferation of insects, including Lepidoptera, that are rated as groundnut pests in India. The number of species, the intensity of attack and their geographical range have all increased.

In trying to work out how or why this happened, we have been led to consider changes in land management, particularly the introduction of irrigation schemes that have made possible the highly profitable cultivation of groundnut during the dry season. For instance, canals have been dug in northwestern India; the digging of wells and the purchase of pumps have been subsidized; and subsidized or free electricity has been made available to run the pumps in rural areas.

The agriculture, which was primarily dryland, has changed in some communities to continuous or relay-cropping of groundnut. One result is a build-up of lepidopteran insects, especially where cash surpluses have permitted the purchase of insecticides. A prime example is *Spodoptera litura*, which, 20 years ago, would not feed freely on groundnut but which has since become a major pest in key areas. Many successive generations have had access to groundnut crops so one presumes that local populations of the species have become adapted to this particular host. The start of the same process has recently been detected in our surveys of groundnut crops in coastal Andhra Pradesh, with *Helicoverpa (= Heliothis) armigera* being a potential new pest.

This is the background in which groundnut entomologists at ICRISAT centre have had to select the direction in which to orient their research, in the context of the needs of Asian groundnut growers (there are different problems in Africa). The main emphasis of the research is on two lepidopteran species — *S. litura* and *Aproaerema modicella*. It is not possible to give a full account of the results of the ICRISAT research because much is currently in progress.

ARCTIIDAE

Other lepidopteran species that damage groundnut include *Amsacta albistriga* (red hairy caterpillar) in southern India, *A. moorei* (hairy caterpillar) in northern and central India, and *Diacrisia obliqua* (Bihar hairy caterpillar) in northern India, Burma, China, and Bangladesh. Recently, Amin (1988) gave a full account of the hairy caterpillars. This group of Arctiidae are among the most feared insect pests, at least in India, because they can appear apparently from nowhere, just as crops are becoming established at the start of the rainy season. The moths eclose from the underground pupal cases within days of the first planting rains. Each female is capable of laying nearly 1000 eggs, usually in clusters. The 'hairy' larvae are cryptic, at least initially, so that farmers may not be aware that they have infested the field until it's too late to protect the crop. Fortuitously they usually have only one generation a year, and it lasts about 1 month in the tropical zone and a little longer in the north. This means farmers may be able to sow a second crop.

Amin indicated that egg parasites could be effective control agents. However, the sporadic and localized nature of the insects' appearance makes it difficult to carry out research on their control or to screen for host-plant resistance. If the diapause could be broken, screening with reared individuals would be possible and — if farmers expressed interest in obtaining cultivars with resistance — desirable.

GELECHIIDAE

The groundnut leafminer, *Aproaerema modicella*, is a serious pest of groundnut and soybean in South and Southeast Asia. It has been reported from India, Sri Lanka, Bangladesh, Burma, Thailand, Laos, Kampuchea, Vietnam, China, the Philippines, Indonesia and Malaysia (references in Mohammad, 1981; Islam *et al.*, 1983; Crowe, 1985).

In India, it has been called the most important pest of groundnuts (Amin, 1983). The literature on this pest was reviewed by Mohammad (1981), and we have relied heavily on that work for this text. By correspondence with the British Museum of Natural History, London, he made clear the synonymy of this species. *Anacampsis nerteria, Aproaerema nertaria, Stomopteryx nertaria, S. subsecivella,* and *Biloba subsecivella* are alternative names that have appeared in the literature this century, even quite recently.

Biology

Female moths deposit the small (ca 0.6 mm in diameter), white, oval eggs on the undersides of leaflets, often near the midrib but also on the petioles and stem. In experimental conditions they lay between 87 and 186 eggs, although one female laid as many as 473 (Cherian and Basheer, 1942; Gujrati *et al.*, 1973). Under field conditions typical of South Asia, eggs hatch in 3–4 days, but, at cooler temperatures, up to 8 days may be required (Kapadia *et al.*, 1982).

First-instar larvae are pale white or yellow with dark brown head capsules. The body may change to light green or brown in later instars. The feeding by early instars is discernible by the serpentine (sometimes blotch) mines. Later instars (third instar onwards) leave the mine. They then web together two halves of one leaflet or two or more leaflets to form a refuge from which they continue to consume epidermal and mesophyll tissue.

The number of larval instars is not clear: Kapadia *et al.* (1982) and Amin (1988) reported three, Gujrati *et al.* (1973) four, and Islam *et al.*

(1983) six. Research at ICRISAT, in which the head width of a cohort of larvae was checked daily, indicated that there are five instars with a Dyar's constant of 1.4 to 1.7.

The larval period lasts between 9 and 28 days in the field and is clearly dependent upon temperatures (Cherian and Basheer, 1942; Sandhu, 1978; Kapadia *et al.*, 1982). Pupation occurs within the webbed leaflets and lasts 3–10 days. This species appears sporadically, both within and between seasons.

Peak leafminer populations occur in Thailand in July and August (Campbell, 1983), although Mohammad (1981) reported that other researchers found heavy infestations during November and December, with only negligible numbers in March through July. The densest populations on groundnuts in Bangladesh are in March and April (Islam *et al.*, 1983). In India, peak leafminer populations occur at the end of the season following the rains — March–May (Amin and Mohammad, 1980). Leafminer populations can also build up in September and October, the end of the rainy season, especially in low-rainfall years (Amin, 1983). Seven generations on a single crop of soybean have been reported from China (Yang and Liu, 1966), although in India three or four generations are typical.

Conventional wisdom is that *A. modicella* is favoured by warm sunny days and that rainfall inhibits its proliferation. Wheatley *et al.* (1989) did not dispute the predilection for warm, sunny days but found no experimental evidence that rain slowed the build-up. They pointed to the possibility that chemical changes in the nutritional quality of the leaflets during drought stress favoured the development of the larvae.

All except one of the known host plants are legumes (Table 5.13). The exception is *Rhychosia minima* (Rubiaceae), a weed. Pigeon pea and alfalfa are two other crops, in addition to groundnut and soybean, that *A. modicella* attacks. Phisitkul (1985) attempted to rear groundnut leafminer on a variety of other plants — sunn hemp (*Crotalaria juncea*), winged bean (*Psophocarpus tetragonolobus*), yard-long bean (*Vigna sinensis* subsp. *sesquipedalis*), siratro (*Macroptilium atropureum*), hamata (*Crotalaria pallida*), and sword bean (*Canavalia gladiata*). The females oviposited on these plants at a much lower rate than on groundnut or soybean, and larvae were unable to complete their development. These findings indicated that the species has a limited host range among cultivated legumes: further research is needed to delimit the number of wild hosts.

Damage and Economic Importance

The groundnut leafminer larvae feed on leaves, thereby reducing the photosynthetic potential of the plant. At a certain population intensity, pod and haulm yields are reduced. As with other caterpillars, the older instars consume much more tissue than early ones. Islam *et al.* (1983) reported that a single larva will consume 175 cm^2 of leaf tissue, and, according to Jagtap *et al.* (1984), the groundnut leafminer and *A. craccivora*, together, were responsible for an average of 16 per cent loss in dry pod yield over 3 years, the loss being equivalent to 303 kg/ha. Reduction in the dry weight accumulation as a result of larval feeding also translates into reduced haulm yield. Significant increases have been observed when yields of insecticide-treated plants (plots) have been compared with those that received no insecticides (Sivasubramaniam and Palaniswamy, 1983; Rajput *et al.*, 1984, 1985). Using screen cages and artificial infestation, Tej Kumar and Devaraj Urs (1983) found that each additional per cent of infestation by the groundnut leafminer resulted in 1.2 per cent yield loss.

In Thailand, Sathorn Sirisingh and Manochai Keerati-Kasikorn (1986) provided complete insecticide protection from the groundnut leafminer and compared the results with those from other levels of protection. Yields of plants given a pre-sowing treatment of granules and five foliar sprays of monocrotophos were 1597 kg/ha compared with 747 kg/ha for unprotected controls. Among the controls, 660 leaflets/20 plants were damaged after 40 days. The plants that received just one application of monocrotophos 30 days after emergence gave 73 per cent of the yield of the full treatment.

Research at ICRISAT showed that the cultivar Robut 33-1 (Kadiri 3) can withstand considerable damage before exhibiting losses in yield (ICRISAT, 1986). This cultivar was grown under four insecticide regimens: dimethoate, at high and low rates; diflubenzuron; and dichlorvos were used (Table 5.14). The 'high' level of dimethoate far exceeded what was needed but represented what many farmers actually apply to their crops. The 'low' level of dimethoate was clearly adequate to protect the crop, and, in fact, as the heavy infestation of leafminer did not appear until pod filling, two sprays could have been dispensed with. There were low populations of *S. dorsalis* and *E. kerri* on the crop, but these were believed to have had little impact on yield. These data indicated that the economic threshold for this cultivar grown post rainy season for third generation only is between 30 and 70 larvae/plant. This is for plants that were close to harvest.

An exercise in simulation and dynamic programming by Dudley *et al.* (1989) indicated the degree of host-plant resistance given a range of parasitism levels. It also showed that if the pest attack became too severe, farmers would lose money if they harvested the crop.

Control

Most research on the groundnut leafminer has been directed at its control.

Table 5.13. Host plants of *Aproaerema modicella*, the groundnut leafminer

Host species	Reference
Arachis hypogaea	Maxwell-Lefroy and Howlett, 1909
Vigna radiata (= *Phaseolus aureus*)	Prasad *et al.*, 1971
Cajanus cajan	Bainbridge-Fletcher, 1914
Medicago sativa	Sandhu 1977, 1978
Psoralea corylifolia	Maxwell-Lefroy and Howlett, 1909
Inigofera hirsuta	Jai Rao and Thirumalachar, 1977
Vigna umbellata (= *Phaseolus calacaratus*)	Jai Rao and Thirumalachar, 1977
Glycine soja	Vanhall, 1922 (in Mohammad, 1981)
Trifolium alexandrium	Thontadarya *et al.*, 1979
Teramnus labiolis	Das and Misra, 1984
Lablab purpureus	Das and Misra, 1984
Rhychosia minima	Srinivasan and Siva Rao, 1984
Boreria hispida	Srinivasan and Siva Rao, 1984

The goal of integrated pest management is to reduce the reliance on chemical control and instead emphasize cultural control, host-plant resistance and biological or natural control.

Chemical: Insecticides of all classes have been screened for activity against the groundnut leafminer. These chemicals have generally been applied to foliage, either as a liquid spray or as a dust, but some systemic insecticides have also been evaluated. Isofenphos applied as a granular formulation before sowing at 2 kg/ha in the furrow provided season-long protection from the groundnut leafminer on the ICRISAT farm.

Table 5.14. The effect of four insecticide regimens on the maximum number of groundnut leafminer larvae and groundnut yield (data are means of five replicates, 1984-85 post rainy season, ICRISAT farm)

Treatment[a]	Larvae (max./ plant)	Larval parasitism (%)[b]	Haulm yield (kg/ha)	Pod yield (kg/ha)
Dimethoate (8 × 400 g a.i./ha)	1.9	0	1880	1780
Dimethoate (3 × 200 g a.i./ha)	31.4	33.9	1640	1700
Diflubenzuron (3 × 250 g a.i./ha)	74.9	42.5	1420	1430
Dichlorvos (3 × 300 g a.i./ha)	67.9	50.0	1510	1580
Control (no spray)	85.0	61.0	1270	1150

[a] All insecticides in 350 L water/ha.

[b] One week before the crop was harvested.

No one has reported resistance among groundnut leafminers to any insecticide, although it is equally true that no tests have been reported despite the use of carbaryl and gamma-BHC (lindane) for more than 20 years and parathion for 10 years (Rajput *et al.*, 1984; Ghule *et al.*, 1987). Nearly all synthetic chemicals have proved effective in reducing populations of the pest or in increasing yields compared with unsprayed plots.

Host-plant resistance: The only cultivar in which host-plant resistance has been detected is M 13. However, resistance, including tolerance, to groundnut leafminer has been detected in several germ-plasm lines (ICRISAT, 1986), including spreading, Spanish bunch, and Valencia types. Resistance in soybean has been much less promising. In two trials that evaluated nearly 40 varieties, no differences in densities of groundnut leafminers were found (Mundhe, 1980; Shetgar and Thombre, 1984). Sathorn Sirisingh and Manochai Keerati-Kasikorn (1986) found that genotypes Colorado, Congo Red, M-gango, Tatu, and TMV 1 had high levels of resistance. A further 49 lines had moderate resistance.

Natural enemies and entomopathogens: Natural control by diseases, predators and parasitoids seems to play a large role in suppressing leafminer populations. At least three disease agents infect the larvae in India: nematodes, viruses and fungi (Oblasami *et al.*, 1969; Kothai, 1974, in

Mohammad, 1981; Srinivasan and Siva Rao, 1986). The impact of these organisms on the population dynamics of groundnut leafminer has not been quantified, although they are often responsible for a high level of larval mortality.

The most important natural control agents are hymenopterous parasitoids, which have been studied in detail only in India. More than 30 parasitic Hymenoptera, including hyperparasites, have been reared from leafminer eggs, larvae and pupae. In southern India, nine parasitoid species are active during and after the rainy season, with parasitism highest from September to November and from February to March (Srinivasan and Siva Rao, 1986).

Eight parasitoid species have been recorded from northern India, six having been recovered in the rainy season (July–October) and four post rainy season (December–May). Two species were present in both seasons (Yadav *et al.*, 1987). Phisitkul (1985) reported two larval and two pupal parasitoids in northeast Thailand but at low levels. The parasitoids found on groundnut leafminer at ICRISAT centre included at least 10 species, some primary and some secondary. Preliminary results have indicated that early in the groundnut-growing season the parasitoid community is dominated by one or two species, with one usually accounting for more than 50 per cent of the total. Later, and especially at the end of the season, four or five species are present and no one species accounts for more than 35 per cent of the total.

Three states in India had evidence of peaks in parasitism up to 90 per cent (Khan and Raodeo, 1978; Srinivasan and Siva Rao, 1986; Yadav *et al.*, 1987). This high rate is in accord with our experience at ICRISAT. It supports our belief that farmers should use insecticides judiciously so that they do not interfere with the natural control of this species. ICRISAT data have demonstrated the influence of insecticides on the rate of parasitism (Table 5.14) and the potential for integrating natural control with insecticide application.

Cultural: We know virtually nothing about how cropping pattern and methods of cultivation influence the incidence of groundnut leafminer. The experiments that have been attempted at ICRISAT to help fill this void coincided with negligible leafminer populations.

However, an observation that has elicited interest is that leafminer populations were considerably lower on unweeded plots than on weed-free plots. This observation is being followed up, with studies on the levels of natural enemies in the weedy area. We have also observed that growing groundnut crops in a relay works against farmers. This practice is common where irrigation is available. In these circumstances, groundnut crops may overlap for up to 10 months of the year.

Although there is a chance that natural enemies will proliferate in such areas and exert natural control, farmers ofen interfere with this process by applying insecticides to kill groundnut leafminers or other species of insects at population levels well below the economic threshold. This results in flare-ups, exacerbated by the continuum of host pants made available to these insects by the cropping pattern.

Groundnut Leaf Webber

Groundnut leaf webber, *Anarsia ephippias*, is a gelechiid that causes concern to groundnut farmers in northern India (Bakhetia, 1976). It makes 'shot holes' in the leaves and webs the growing points. Every plant in a field on a university research farm in the Punjab was once found to be attacked. The life cycle lasts from 26 to 53 days.

A number of parasites, including a chalcid *Brachymeria* sp., attacked 24 per cent of the larvae in Bakhetia's study area. The caterpillars were killed by a range of insecticides, endrin and parathion being superior, although fenitrothion might be selected on grounds of safety.

Leaf Roller

Leaf roller, *Lamprosema abstitalis*, appears to have habits similar to *A. ephippias* but is found in north Thailand. It was part of a complex of Lepidoptera that was found in the experimental area of Schiller *et al.* (1982). The data indicated that, if insecticides were to be applied, best results were achieved in combinations with fungicides.

NOCTUIDAE

The tobacco cutworm or armyworm, *Spodoptera litura*, extends throughout Asia and Oceania, including New Zealand and Japan (to 45°S and N), but also Oman, Malagasy Republic, Mauritius and Colombia. It has 78 hosts of economic importance. Its range abuts that of *S. littoralis* 60° east of Greenwich (in Pakistan and Afghanistan). The genus has been and is known as *Prodenia* and the proximity of *S. litura* and *S. littoralis* may have led to references to *Prodenia 'littoralis'*.

Cotton leaf worm, *Spodoptera littoralis*, is found throughout Africa and the Middle East. It is usually a leaf eater of minor importance, but occasional flare-ups occur, for instance in Malawi in 1988. These may be associated with insecticide-caused outbreaks on other crops. This species shares many features with its Asian counterpart, including a pod-boring habit.

Biology

The female moth of *S. litura* lays batches of 200–1000 eggs in egg 'masses' on the leaflets, and she may lay 3–10 of them. She covers the eggs in silk webbing and her body scales, colouring the mass a golden bronze. Larvae hatch in about 3 days in the tropical zone. They are aggregated initially and then disperse, feeding largely by night and hiding at the base of the plant during the day. Fully grown larvae are 3–4 cm long.

The larvae have a greenish appearance but this can vary considerably. Key characteristics are the dark marks on the first abdominal segment and the light yellow line running the length of the body. Pupation takes place in the soil. The moths eclose after about 1 week. They may undergo a migratory flight before commencing oviposition. Flight activity is highest from dusk to about 2200 h. Their seasonal flight pattern is being monitored with pheromone traps, mainly in India but also in Burma, Nepal and Sri Lanka.

Information collected at ICRISAT centre has shown that, in the Hyderabad area, 12 peaks occur during the year, each one presumably indicating a new generation. This synchronization was not previously apparent. However, the monthly cycle is disrupted from February to May when activity of this species is greatest and overlapping of generations is apparent (Ranga Rao *et al.*, in preparation).

Damage

Spodoptera is primarily a defoliator. The first and second instars 'scratch' the leaf surface, a sign that more serious damage is to come. The older larvae strip the laminae from the leaflets. Under heavy population pressure, only the midribs remain. At this stage, the larvae leave the crop *en masse* to seek more food in neighbouring fields, hence the common name of armyworm. This species also takes on a pod-boring habit in the light soils of northern India. Presumably, when it seeks shelter during the day it is able to follow the pegs to the pods through the friable soil.

Several authors have judged the effect of defoliators on the yield of groundnut crops by ablation techniques (Enyi, 1975; Mercer, 1976; Santos and Sutton, 1983; Wilkerson *et al.*, 1984). We are not satisfied that this approach can simulate the effect of defoliating insects because it gives the plant an abrupt metabolic shock, especially in drought conditions. In contrast, defoliation by insects is gradual. We have, therefore, devised a method for working with *S. litura* at ICRISAT centre, releasing fourth-instar caterpillars into enclosures containing groundnut plants. During the final three instars, the larvae eat more than 95 per cent of their total consumption.

Table 5.15. Effect on pod yield of larvae of *Spodoptera litura* when introduced to a groundnut crop (TMV 2) at four densities and four growth stages at ICRISAT, 1986–87, post rainy season, and 1987, rainy season (data are means of five replicates)

Crop stage (days after emergence) Larvae (no./plant)	Post rainy season[a]		Rainy season[a]	
	Defoliation (%)	Yield loss (%)	Defoliation (%)	Yield loss (%)
Seedling (10)				
1	54 (47)	22 (22)	57 (49)	12 (14)
2	60 (51)	28 (29)	68 (56)	10 (12)
5	100 (90)	67 (56)	100 (90)	70 (57)
10	100 (90)	68 (56)	100 (90)	78 (62)
Flowering (30)				
1	40 (39)	18 (22)	15 (23)	9 (15)
2	46 (43)	18 (22)	53 (47)	11 (13)
5	72 (58)	49 (45)	65 (54)	11 (13)
10	88 (77)	61 (51)	72 (58)	11 (13)
Pegging (50)				
1	23 (29)	10 (12)	17 (25)	3 (6)
2	30 (33)	14 (18)	41 (40)	4 (7)
5	32 (34)	20 (21)	57 (49)	14 (16)
10	36 (36)	13 (14)	65 (54)	19 (26)
Pod formation (70)				
1	32 (34)	7 (9)	21 (27)	5 (8)
2	46 (42)	13 (14)	37 (37)	7 (9)
5	61 (52)	15 (18)	56 (49)	6 (9)
10	63 (52)	12 (16)	62 (52)	10 (18)
SE ±	(4)	(4)	(3)	(5)
CV (%)	15	35	12	5

[a] Data in parentheses are arc-sine transformations.

Although our research has not been completed, the effects of defoliation on yield are clearly seasonal, damage having a more serious effect in the postrainy season (December–April). The pattern is believed to occur because the plants are not able to outgrow the defoliation caused during the cool period (December–January) (Tables 5.15-5.17). The groundnut plant is clearly able to recover from complete defoliation at the seedling stage and from heavy defoliation later in development. A plant with 30 per cent defoliation looks doomed but can, in fact, recover. We have known farmers who spray insecticide on their crops when they find only one or two feeding notches on several plants.

Control

Chemical: If insecticides are to be applied for the control of this species on groundnut crops, they should be directed at the youngest larvae. At this stage, little or no defoliation would have occurred, and the small larvae can be killed with less insecticide (or at least lower concentrations) than can larger larvae. Farmers are often unsuccessful in their attempts to kill larvae that are approaching maximum size. Also, insecticides with a low environmental impact, such as diflurbenzuron, dichlorvos or lannate, would be sufficiently potent to kill small but not large larvae.

Our data, which, we stress, are subject to refinement, suggest that the most effective time for application is 6 days after 50 or more male moths are found in a pheromone trap for more than 3 nights or 2–3 days after crop inspection reveals more than three egg masses per metre of row.

Table 5.16. Yield losses in groundnuts when damage caused by *Spodoptera litura* occurs at different stages and for different periods in 1986–87, post rainy season, and 1987, rainy season. Fourth-instar larvae were introduced at a rate of two per plant to cultivar TMV 2 (means of five replicates)

Crop age when larvae introduced (days after emergence)	Post rainy season		Rainy season	
	Pod yield (g/plant)	Yield loss (%)[a]	Pod yield (g/plant)	Yield loss (%)[a]
10	9.7	28 (29)	4.8	10 (18)
30	10.7	18 (22)	5.0	11 (15)
50	11.3	14 (18)	5.6	4 (7)
70	12.7	13 (14)	5.2	7 (9)
10 + 30 + 50 + 70	6.5	50 (45)	2.3	56 (49)
30 + 50 + 70	11.6	16 (18)	5.0	10 (16)
50 + 70	15.0	2 (3)	5.7	3 (5)
No larvae (control)	13.4	-	5.4	-
SE ±	0.9	(4)	0.3	(5)
CV (%)	18	46	15	65

[a] Data in parentheses are arc-sine transformations.

Foliar sprays of many insecticides — endosulfan, carbaryl, fenvalerate, monocrotophos, etc. — have been recommended for the efficient control of *S. litura* (Ayyanna *et al.*, 1982) especially, if formulated with mineral oil (Onayama *et al.*, 1985). Neem preparations may also be effective as a larval growth retardant or as a moth repellent (Joshi and Sitaramaiah, 1979; Opender Koul, 1985). Difficulty in killing the large larvae still remains a major problem and may reflect deficiencies in the spray mixture or inefficient application.

However, reports of insecticide resistance in this species from both ends of Asia — China and India — serve as a warning. Ramakrishnan *et al.* (1984) found that larvae from Andhra Pradesh were resistant to malathion (5.7 fold), pyrethrum (14.7 fold), lindane (16.3 fold) and endosulfan (85.9 fold). The comparable data from China (Chou *et al.*, 1984) indicated variable levels of resistance, depending on location. The worst examples were resistance to fenvalerate (4.1 fold), permethrin 13.0 fold), mevinphos (63.0 fold) and carbofuran (79.0 fold). As this species spends the days at ground level, there is scope for attempting to control it with baits containing insecticides, but the results of such attempts are difficult to interpret.

Natural enemies: Spodoptera litura is found in many habitats, so it is not surprising that the literature abounds with references to natural control agents on a range of crops. G. V. Ranga Rao has listed, in an unpublished review, 118 species of parasites (including nematodes) and predators from Asia and the Pacific.

Among the egg parasites, *Trichogramma* spp. predominate, with reports by Chiu and Chiu in 1976 for China, Chu (1979) for Indonesia, Joshi *et al.* (1979) and Patel *et al.* (1971) for India. However, scientists and others who have attempted to induce natural control by mass-releasing egg parasites have not been particularly successful. The parasites are influenced by the host plant, and the whole operation seems to bear no relationship to the economics of pest control. Furthermore, there can be little to gain from exerting an extra control on a stage where natural mortality is already high.

Braune (1982) found that *Telenomus remus* achieved 54 per cent egg parasitism. He found an inverse relationship between egg mass size and per cent parasitism. The thickness of the mass was also important, most parasitism occurring among eggs on the top layer. Joshi *et al.* (1982) found that a 2 per cent neem extract did not repel *T. remus* when applied to the eggs. This points to the possibility of an integrated control scheme based on neem and egg parasites.

Larval and pupal parasites are more diverse and numerous than the egg parasites, especially among the braconids (54 per cent of the species), mainly *Apanteles* spp. and *Bracon* spp. The rest are tachinid flies (14 per cent) such as *Paribaea orbata*, ichneumonids (14 per cent), plus relatively few eulopids, chalcids, scelionids, encyrtids and muscids (Battu, 1977; Zaz and Kushwaha, 1983; Jayanth and Nagarkatti, 1984; Michael *et al.*, 1984; Rao and Satyanarayana, 1984; Jalali *et al.*, 1987; Sathe, 1987). The pupal stage seems to be relatively unaffected by parasites, perhaps because it is usually underground. The reports available do not indicate that the levels of larval parasitism are ever very high: they never approach those encountered with other lepidopteran species such as *A. modicella*. The nocturnal habits of *S. litura* may be involved.

Table 5.17. Effect of defoliation by *Spodoptera litura* on yield of six groundnut genotypes. Fourth-instar larvae were introduced in 1986–87, post rainy season, and 1987, rainy season (means of five replicates)

Crop stage (days after emergence) and genotype	Post rainy season[a] Defoliation (%)	Post rainy season[a] Pod yield (g/plant)	Rainy season[b] Defoliation (%)	Rainy season[b] Pod yield (g/plant)
Seedling (10)				
ICGV 86031	86 (71)	10.0	100 (90)	4.5
ICG 5240	61 (52)	8.4	100 (90)	10.5
ICGV 86030	87 (74)	5.8	100 (90)	4.6
ICGV 86535	83 (75)	10.2	100 (90)	3.9
ICG 156	100 (90)	6.1	100 (90)	4.7
ICG 221	100 (90)	4.4	100 (90)	1.7
Flowering (30)				
ICGV 86031	58 (50)	11.7	45 (42)	9.2
ICG 5240	70 (57)	8.3	54 (47)	10.0
ICGV 86030	59 (51)	6.4	58 (50)	12.4
ICGV 86535	68 (55)	11.7	47 (43)	9.2
ICG 156	75 (61)	13.3	44 (41)	10.0
ICG 221	91 (76)	7.9	50 (45)	4.0
Pegging (50)				
ICGV 86031	37 (37)	15.0	64 (53)	10.8
ICG 5240	44 (41)	6.9	67 (55)	13.3
ICGV 86030	47 (44)	7.2	68 (56)	11.6
ICGV 86535	54 (48)	10.4	64 (53)	10.9
ICG 156	41 (39)	13.1	60 (51)	10.2
ICG 221	50 (45)	10.0	69 (56)	5.3
Pod filling (70)				
ICGV 86031	22 (30)	18.8	35 (36)	10.8
ICG 5240	11 (16)	14.5	24 (29)	12.0
ICGV 86030	14 (17)	12.2	36 (37)	12.3
ICGV 86535	12 (17)	12.8	26 (25)	9.6
ICG 156	28 (31)	17.1	38 (38)	12.5
ICG 221	18 (25)	12.8	39 (39)	5.4
Insect-free controls				
ICGV 86031	–	18.3	–	11.4
ICG 5240	–	14.5	–	14.7
ICGV 86030	–	11.1	–	11.1
ICGV 86535	–	12.5	–	12.0
ICG 156	–	17.9	–	10.4
ICG 221	–	13.7	–	5.4
SE ±	(7.3)	1.3	(4.0)	1.1
CV (%)	(26.6)	19.4	(12.7)	20.6

[a] ICGV 86031 = GBPRS 312, ICG 5240 = EC 36892, ICG 86030 = GBPRS 66, ICGV 86535 = GBPRS 15, ICG 156 = M 13, and ICG 221 = TMV 2.

[b] Data in parentheses are arc-sine transformations.

Leaf damage caused by *S. litura* is rarely severe at ICRISAT centre, but we consistently have noted that damage is increased in areas where insecticides have been applied (Wightman and Amin, 1988). We have also found considerably less damage caused by *Spodoptera* sp. and other defoliators in farmers' fields where insecticides have not been applied.

Arthropod predators of *S. litura* abound. They include reduviids (Sitaramaiah *et al.*, 1975), pentatomids (Kapoor *et al.*, 1975; Pawar, 1976), predatory wasps (Nakasuji *et al.*, 1976), carabids and staphylinids (Chu, 1979). There are also some reports of spiders attacking *S. litura* (Kapoor *et al.*, 1975). Birds, such as cattle egrets, eat the larvae, and bats, frogs (J.A.W., personal observation), lizards (Bhanotar and Srivastava, 1985) are vertebrates that consume the moths. There appears to be no quantitative information about the role or efficiency of various natural enemies on the control of this species.

Noctuids appear to be susceptible to many diseases especially the cytoplasmic and nuclear polyhedrosis viruses (Asayama and Osaki, 1970). Although this has been known to be true for *S. litura* for some time, scientists in the national agricultural research services of the semi-arid tropics have not exploited the knowledge. The one exception was by Krishnaiah *et al.* (1985) who used two sprays of a virus suspension to kill *S. litura* on black gram in Andhra Pradesh. We hope that this kind of information will extend to other crops and that farmers will initiate such practices for themselves.

Bhatnagar *et al.* (1985) found that *S. litura* is parasitized by mermithid nematodes. In addition, they showed that the rate of parasitism was higher on black soils than on red soils. Kondo and Ishibashi (1984) provided information about the parasitism of this pest by *Steinernema* sp. in Japan. A number of bacteria and fungi, e.g. *Beauveria bassiana* and *Serratia marcescens*, attack *S. litura* larvae in nature (Zaz and Kushwaha 1983; Ansari *et al.*, 1987). However, this does not seem to have much applied significance.

Host-plant resistance: We do not know of many genotypes with resistance to *S. litura*, but our experiments have revealed that it exists at levels that can be exploited. Under laboratory conditions, more than half (56 per cent) *S. litura* died during the first instar when fed on ICGV 86031 (= GBPRS 312), whereas mortality on ICG 221 was only 12 per cent. The percentage of adults emerging from larvae fed on ICGV 86031 was 29, compared with 46 for those fed on ICG 221. Clearly, ICGV 86031 has resistance to the first-instar larvae and is tolerant to *Spodoptera* sp. attack in farmers' fields, although the efficacy can be influenced by the season (Table 5.17). The aphid-resistant genotype EC 36892 may also be resistant to *S. litura* (Table 5.17).

Cultural: Farmers sow castor plants in their groundnut fields to attract *Spodoptera* moths because they lay eggs preferentially on the leaves of the trap crop where they and the larvae are easy to find and destroy. Farmers in coastal Andhra Pradesh dig ditches around their fields to trap migrating larvae. The effects of such practices are not known.

Helicoverpa armigera

Helicoverpa (= *Heliothis*) *armigera* is found on all tropical and sub-tropical land masses, except the Americas, where other members of the genus cause problems. It has many common names including boll worm, pod borer, and gram borer — a reflection of its many hosts. It feeds primarily on flowers and fruits of the host but is known to eat groundnut foliage, causing signs of damage that are indistinguishable from those of *Spodoptera*.

In the cotton-growing areas of Andhra Pradesh, which are close to major groundnut-growing districts, pesticides have figured heavily in crop management (one could say 'pest mismanagement') in recent years and have led to insecticide-resistant *Helicoverpa* and severe crop losses caused by the pest. A spill-over to groundnut appears to be a result. J.A.W. observed this species on groundnut foliage in Botswana and Tanzania but only where insecticides had been applied. Jepson (1948) observed that groundnut is most likely to be attacked by this species when maize is included in the rotation.

Cut Worms

Cut worms, *Agrotis* sp., are found mainly in African groundnut fields around the bases of the plants, especially in districts where *Phaseolus* beans are grown. They feed at ground level and damage the crown and lower stems. The feeding itself probably causes little yield loss but affords an entry for fungal diseases and *Odontotermes* spp.

PYRALIDAE

The species of Lepidoptera that commonly infest stored groundnuts belong to the family Pyralidae and all have similar life cycles. The adult moths do not feed so they live for only 1–2 weeks. Females lay their eggs in cracks or grooves in the surface of groundnut pods or kernels.

The larvae either feed on the seed surface or tunnel into the cotyledons. They move freely through the groundnuts, contaminating them with a tough, silken fibre that eventually binds together kernels, frass and exuviae. This type of contamination is easily distinguishable from the fine dust that results from beetle infestation and may be economically more important than the weight loss caused by larval feeding.

Often the larvae leave the groundnuts to find pupation sites in the storage structures or in the sacking. The adult moths emerge, disperse throughout a store before mating on the surface of the stored product. Oviposition occurs chiefly in the surface layers of a bag or bulk of groundnuts. Thus, even though the larvae are mobile, heavy infestations are generally concentrated within the top 10–20 cm of a bulk store or the outside layers of a stack (TDRI, 1984).

The rice moth, *Corcyra cephalonica* (Stainton) Pyralidae (Galleriinae), has the ability to develop at low humidities (<20 per cent) and is more prevalent than the other stored-product caterpillars in the semi-arid tropics (Hodges, 1979). The adults are pale brown and 12–15 mm long when at rest. Females have long labial palps that point directly forward, whereas males have short inconspicuous palps.

Generally, the larvae are white except for the head capsule and prothoracic tergite, which are brown. On abdominal segments 3–6 and 10, there are well-developed pro-legs. The larval spiracles are characteristically thickened on their posterior rim. The setae arise from clear areas of cuticle surrounded by a dark ring. At 28°C and 70 per cent RH, the life cycle from egg to adult takes 40–50 days. Male moths emerge, on average, 1–2 days before females.

Like other lepidopteran species, *C. cephalonica* is generally regarded as a secondary pest of in-shell groundnuts, unable to penetrate sound pods (Table 5.18). However, in laboratory studies, larvae hatching from eggs laid on apparently sound pods penetrated the shell to feed on the kernels and chewed their way out of the pod once the food supply was exhausted (K. M. Dick, personal observation).

The tropical warehouse moth or almond moth — *Ephestia cautella* — is a pest of many stored commodities and is common throughout the tropics and sub-tropics. Its life cycle is similar to that of *C. cephalonica*.

The adults are 6–9 mm long at rest and greyish-brown, with an indistinct pattern on the forewings. The labial palps in both the male and the female point upwards. The larvae can be distinguished from those of *C. cephalonica* both by the spiracles, the rims of which are evenly thickened, and by the setae, which arise from dark brown spots on the cuticle. At 28°C and 70 per cent RH, the life cycle takes 40–50 days. Although this species is regarded as a secondary pest of in-shell groundnuts, populations increasing by a factor of 37 per cent monthly have been recorded in a warehouse containing groundnut pods (Hagstrum and Stanley, 1979).

The Indian meal moth, *Plodia interpunctella* (Hübner) Pyralidae (Phycitinae), seems to be most prevalent in cool areas of the tropics, e.g., highland regions. Its habits and life history are similar to that of the moth species already described. The adults are 8–12 mm long when at rest and are easily recognized by the markings on their forewings: the basal third is cream-coloured while the rest is reddish-brown. The labial palps point directly forward. The larvae are pale yellow and can be distinguished from those of other stored-product Pyralidae by the absence of any pigmentation at the base of the setae.

Under adverse conditions, e.g., extreme temperatures or high population densities, the life cycle of *P. interpunctella* may be prolonged by a larval diapause. During diapause, normal applications of insecticides, including fumigants, may prove ineffective.

Monitoring Infestation Levels

Although it is the larvae of lepidopteran pests that damage groundnuts, monitoring trap catches of adult moths is the most effective way of detecting low-density infestation. Pheromone traps now provide a cheap and simple alternative to light traps or suction traps for flying insects and have greatly increased the feasibility of monitoring moth populations in tropical stores. The sex pheromones released by all female Phycitinae have a chemical component that will attract males of *P. interpunctella* and *Ephestia* spp.

At least two designs — a funnel trap and a delta-shaped sticky trap — are commercially available for monitoring *P. interpunctella* and *E. cautella*. The addition of specific synergists increases the attractiveness of the pheromone to individual species while reducing its attractiveness to other Phycitinae. In *C. cephalonica*, both male and female moths release a pheromone (Singh and Sidhu, 1976); however, chemical communication between sexes appears to be less important in this species than in phycitine species.

Spangler (1987) has shown that, like other galleriine moths, male *C. cephalonica* produce ultrasonic pulses that affect the behaviour of both males and females. This ultrasonic communication may be more influential than pheromone emission and may thus prevent development of a trap based on pheromones for *Corcyra* sp.

Control

Insecticides: When groundnut stocks are stored immediately after drying, they probably have not yet been infested by pyralid moths. Infestation is a result of the movement of moths from infested stocks or crop residues to newly harvested material. To prevent this from occurring, one should treat stores the same way as for pests of in-shell groundnuts. Empty stores that can be made relatively gastight can be treated with dichlorvos, either in aerosol form (requires the use of an aerosol generator) or impregnated in strips of PVC. The latter act as slow-release dispensers and provide a cheap and convenient method of controlling moth populations in stores. Hung up in stores at a rate of 1 strip/30 m^3, these strips should control adult-moth populations for 12–14 weeks (Redlinger and Davis, 1982).

The possibility of replacing conventional insecticide applications with methoprene, an insect-growth regulator, has been examined in warehouse trials in the southern USA (Vick *et al.*, 1985). Used as a bulk treatment on in-shell groundnuts, methoprene reduced numbers of F_1 adult *E. cautella* to <10 per cent of those in an untreated control. However, it disrupts nothemal metamorphosis from the larvae to the pupae so did not eliminate damage to kernels by larval feeding (reduced a maximum of only 60 per cent). Nevertheless, the authors concluded that if methoprene were applied to uninfested stocks at the beginning of storage, it would prove a satisfactory alternative to conventional insecticides.

Fumigation of individual stacks within a warehouse is unlikely to eradicate the pest because adult moths resting on the walls of the storage structure will escape exposure to the fumigant and rapidly reinfest the stacks. If the structure can be made airtight, whole-store fumigation will be effective.

Natural enemies and entomopathogens: Parasitic wasps are common natural enemies of the moths throughout the tropics (Myers, 1929: Ayyar, 1934; Risbec, 1950; Rawnsley, 1959). Under optimum conditions, populations of parasites, such as *Bracon hebetor* Say, increase faster than their moth hosts — generation time is only half that of the host (Hagstrum, 1984), and several parasites can develop within a single host larva (Keever *et al.*, 1985). However, a rapid increase in parasite numbers is unlikely to occur without large numbers of unparasitized moth larvae.

If parasitic wasps were to control moth pests, their numbers would have to be augmented before large numbers of larval hosts become available. A number of laboratory and warehouse tests have been carried out to investigate the potential of this approach (Arbogast, 1984), and in laboratory cultures of *P. interpunctella*, a single introduction of *B. hebetor* reduced emergence of F_1 adults by 74 per cent (Press *et al.*, 1974). Semi-weekly releases of *B. hebetor* into a warehouse containing simulated crop debris infested with *E. cautella* resulted in more than 90 per cent reduction in emergence of adult moths, compared with predator-free, control populations (Press *et al.*, 1982).

Keever *et al.* (1986) augmented natural populations of *B. hebetor* and the predatory anthocorid bug *Xylocoris flavipes* in bulk stores of groundnuts, releasing the natural enemies from culture jars immediately after the warehouse was filled and every 2 weeks thereafter. Although the effect of the individual species could not be determined, the two together controlled moth populations better than conventional bulk treatment with malathion.

The ability of *X. flavipes* to survive on residual pest populations has also been demonstrated (LeCato *et al.*, 1977): the release of 30 pairs prevented increases for 14 weeks in a warehouse where populations of *E. cautella* were breeding on small quantities of culture medium left to simulate debris from the previous crop. In contrast, a predator-free moth population increased by a factor of 100 during the same period.

Although releases of parasites, such as *B. hebetor* and *X. flavipes*, suppress the numbers of adult moths in the F_1 generation, enough active larvae may survive to cause unacceptable damage to the kernels. A study on bulk, in-shell groundnuts indicated that populations of *E. cautella* and *P. interpunctella* adults were suppressed naturally by *B. hebetor* after 1–2 months. By this time, however, 10–12 per cent of the kernels had been damaged by moth larvae (Keever *et al.*, 1985).

One way that kernel damage could be reduced while larval parasites are establishing control is to release larval and egg parasites simultaneously. Brower (1984) demonstrated the potential use of egg parasites of the genus *Trichogramma* as biological control agents in groundnut stores. At monthly intervals, 200 eggs of *E. cautella* and *P. interpunctella* were released into a number of identical stores containing 200 kg of in-shell groundnuts. Simultaneously, moth eggs parasitized by *T. pretiosum* were placed in the stores, the number of eggs and the timing of the releases varying for different stores. Successful suppression of both moth species was obtained for up to 4 months, with release rates of 1000 parasitized eggs, three times each week.

Another natural enemy of phycitine moths in tropical stores is the mesostigmatan mite *Blattisocius tarsalis*. Both laboratory and warehouse studies have shown that in specific circumstances, *B. tarsalis* can control populations of *E. cautella* (Graham, 1970; Haines, 1981). Stored-product moths can be suppressed also by naturally occurring epizootics of *Bacillus thuringiensis* Berliner (Hagstrum and Sharp, 1975), and, currently, both dust and wettable powder formulations of *B. thuringiensis* can be obtained commercially (McGauhey, 1982). The bacillus provides effective control of *E. cautella* and *P. interpunctella* when applied either to the bulk store or to the surface layers of groundnuts; it persists under storage conditions, without a noticeable decrease in insecticidal activity, for at least a year (Arbogast, 1984).

At present, no viral formulations have been registered for use on stored groundnuts, because granulosis viruses (GV) such as *Plodia* GV are effective in controlling only single species of moth populations (Hunter *et al.*, 1973a) and, hence, are not alternatives to conventional insecticides. Nuclear polyhedrosis viruses isolated from *E. cautella* may prove more commercially exploitable as they have been shown to be almost as toxic to *P. interpunctella* (Hunter *et al.*, 1973b) as to *E. cautella*.

Host-plant resistance: Few studies have explored whether genotypes of groundnut vary in their susceptibility to attack by stored-product moths. Mbata (1987) carried out a number of experiments with *P. interpunctella* and newly released groundnut varieties in Nigeria. Adult females, given a choice of kernels of different varieties, showed significant oviposition preferences for certain of them.

Significant genotypic variation was also shown to exist in the developmental period from egg-hatch to adult emergence and the percentage survival to adult emergence of first-instar larvae. These differences were not related to the size or colour of the kernels. There was considerable variation in genotype responses in an experiment carried out at ICRISAT centre (Table 5.18) with a wide range of advanced breeding material, germ plasm and cultivars.

Similar results emerged in experimental studies of the susceptibility of selected Indian groundnut varieties to attack by *E. cautella* (Pandey *et al.*, 1977). In both studies, broken kernels were more susceptible to infestation than were whole kernels of the same variety. This indicates that the testa itself provides some measure of protection against first-instar larvae. Variability in characteristics of the testa may make some genotypes significantly more resistant to attack, although this possibility could be confirmed only by large-scale screening.

Table 5.18. The survival of late larval and pupal *Corcyra cephalonica* after one generation on the kernels of advanced groundnut breeding lines (ICGV), genotypes and cultivars (50 eggs were introduced to 50 g of kernels; data are the means of 20 replicates of each genotype)

Genotype	F_1 larvae and pupae (% survival)	Weight loss (g)
TMV 2	6.1	5.4
JL 24	6.6	7.2
ICGV 86056	10.3	7.4
M 13	17.9	11.9
ICGV 86015	16.0	12.4
ICGV 86014	24.7	13.0
ICGV (FDRS) 43	20.1	13.2
NCAc 343	23.0	13.9
ICG (FDRS) 10	20.3	14.9
ICGV 86042	20.8	15.2
ICGV 86016	26.7	17.0
2133	22.6	17.4
ICGV 86055	31.2	18.8
ICGV 5	30.6	18.8
ICGS 11	38.8	21.6
Robut 33-1	42.2	22.6
ICGS 44	39.4	22.8
ICGS 1	42.4	25.0
ICGV 86127	47.2	26.8
ICGV 86124	48.4	29.7
NCAc 17090	48.2	31.3
ICG (FDRS) 4	53.4	31.4
SE ±	6.8	3.3

Diplopoda

MILLEPEDES

Millepedes join the other key members of the soil fauna — white grubs and termites — as being among the most problematic and serious groundnut pests. As they are pod borers, their activity can lead to the invasion of the pod by soil fungi, including *Aspergillus flavus*, the source of aflatoxin.

The species that can be encountered in groundnut fields in West Africa — mainly Senegal — are (Demange, 1975):

- Stemmiuloidea: *Diopsiulus*
- Spirostreptoidea (= 'Iules'): *Graphidostreptus tumuliporus, Urotropis perpunctata, Peridontopyge conanci, Peridontopyge pervittata, Peridontopyge rubescens, Peridontopyge spinosissima, Peridontopyge trauni, Haplothysanus chapellei, Syndesmogenus mimeuri*
- Polydesmoidea: *Streptogonopus aethiopicus, Habrodesmus duboscqui, Sphenodesmus occidentalis.*

The iuliform species are cylindrical in section and can be 30 cm or so long and include the pest species. The polydesmids have a flattened section and are not groundnut pests, but their presence can lead to concern.

Distribution

A survey of the literature leads to the conclusion that millepedes are a West African problem. However, millepedes also contribute to pod loss in Southern Africa. Soil samples taken during J.A.W.'s survey showed that in some areas (central Malawi and east Zambia — especially in the silty soils of the Luangwa valley) there were more than 20 millepedes/100 plants. They appeared to be causing 5–10 per cent pod loss across Southern Africa as a whole.

Biology

This account is based on Demange (1975) and Gillon and Gillon (1979a,b). Millepedes avoid light and desiccation. This means that they live in the soil, in termitaria or under litter during the day. The nature of the shelter sought is somewhat species specific. For instance, *G. tumuliporus* aggregates at the bases of trees and in termite mounds but is not found in the open field. *Peridontopyge spinosissima* is most likely to be found under trees, and *P. rubescens* and *S. mimeuri* are rarely found in termitaria. However, these generalizations are subject to seasonal variation, as most species, *G. tumuliporus* being the exception, spend the dry season in the soil of the open field.

In a study by Gillon and Gillon (1979a), carried out in a groundnut-based system near Darou, Sine-Saloum, *P. rubescens* and *S. mimeuri* were the dominant species, the former accounting for one-third of the numbers and the biomass of millepedes. A finding by these authors (1979b) was that aestivation activity was essential in future population studies of this taxon. During the rainy season (July–October), most millepedes were in the top 10 cm of soil, but during the dry season, most were 23–30 cm deep and some as deep as 70 cm.

Another characteristic of millepedes is that they aggregate and migrate en masse over night. This means that a study of the relations between population density and pod damage would need to be on an extensive scale.

Damage and Economic Importance

Millepedes attack the pods from the time they are a swelling on the tip of the peg until the shell begins to harden. It is likely that their importance has been underestimated. Even though they only make a characteristic neat, round hole in the pod this results in the rapid decay of the pod and peg that will have disappeared by harvest. Their affinity for the soft pods probably is associated with Demange's (1975) observation that millepedes constantly seek a source of moisture. Groundnut pods provide water as well as a diet with a high nutrient content.

There are relatively few accounts of the degree of pod damage. Demange (1975) found that in northeast Nigeria damage by *Peridontopyge* sp. was localized and severe but was about 10 per cent over all. This may not sound like much, but at that time Nigeria ranked high among groundnut producers, at a national production of 600 000 t, and most of it came from this region.

A more recent groundnut pest-monitoring exercise in Bengou, Niger, showed that the millepede population built up when the pods started to form in mid-July. It 'increased dramatically' until the pods hardened when it declined leaving 39 per cent of the pods damaged. Millepedes were considered to be the most important biotic constraint to production (ICRISAT, 1988).

Control

Insecticides: There is no known method of controlling millepedes with pesticides (Wightman and Amin, 1988), although Appert (1966) found that fungicides repelled them.

In field tests of insecticides carried out in Malawi, J.A.W. found not even a suggestion that insecticides, such as dieldrin, chlorpyriphos and carbofuran, reduced millepedes. Plots treated with phorate had 2.5 times the millepedes found on control plots.

We do not know the reasons, but we can see several possibilities:

Millepedes are not susceptible to insecticides because they are not insects; we could find no account of toxicologic effects of insecticides on millepedes in laboratory conditions.

- Large millepedes have to ingest or absorb a relatively large amount of insecticide to die compared with the amount that would kill the first instar of white grubs.
- They have a thick (calcified?) carapace that may protect them from absorption during contact with insecticides.
- Their mobility and their propensity to migrate suggests that the individuals in field is constantly changing and dead millepedes are being constantly replaced.

Several questions need to be answered about the possible use of toxins for controlling millepedes. If suitable toxins were identified and formulated for application prophylactically in 'hot spots', would they be made available by government agencies? Could farmers afford them? What would be their impact on the soil fauna such as predatory ants that keep termites and white grubs under some kind of control?

Natural enemies: Demange (1975) found that millepedes have a number of parasitic nematodes, protozoa and bacteria in their gut but gave not indication of their pathogenicity. he also pointed to the existence of parasitic flies and reduviid bugs that attack millepedes but, again, no specifics. Millepedes are able to defend themselves from attack with the secretions of their repugnatorial glands.

Host-plant resistance: No sources of host-plant resistance to millepedes have been identified.

Future Strategies for Control

To recommend suitable strategies for control of groundnut pests in the field, one would need to know more about the pests. The results of J.A.W.'s survey in Southern Africa indicate the depths of ignorance on this subject. Of the 40 or more white grub species collected, most had not been previously described as larvae. This collection was made from about 100 sites, mainly in Malawi, Zambia and Zimbabwe. The implication is that further surveys will turn up even more unknown species.

We believe similar surveys should be carried out in other parts of Africa and in most of Asia. We suggest that surveys concentrate on soil insects in Africa where defoliators are not a problem and on the whole fauna in Asia where both defoliators and soil insects reportedly cause losses. An exercise like this, though large, would define the nature, intensity and distribution of the problems we face. It should be regarded as a first step in an IPM programme.

We do not even know whether the soil insects have always been a problem but have been unheralded until recently because no one has looked for them. The problem may have been induced by the change to systems of permanent agriculture. J.A.W. had the impression that fewer insects were in soils that had been in fallow or that had been uncovered by shifting agriculture than were in soils cropped in a long-term rotation system. This impression should be tested because it implies that the cropping system induced the problem.

We know that white grubs, wire-worms and termites are pests of not only groundnuts but maize. We don't know whether some crop combinations of fallowing would reduce the prevalence of the pests.

We have reported resistance to termite scarification, but perhaps other sources of resistance — such as antibiotic substances in the roots — exist in some genotypes. We believe the wild *Arachis* species are a good place to begin a search because they have high levels of resistance to other pests. Also, the marked differences in the response of storage pests to the lines tested at ICRISAT indicate resistance that has yet to be exploited in the pods and seeds of *A. hypogaea*.

In Asia, the overuse of insecticides must be addressed. Researchers must establish the thresholds at which defoliators cause yield losses to groundnut crops and then ensure that colleagues in the extension service understand the implications. They — we — must also collect and collate data about insecticide resistance among groundnut pests in the field and in storage.

Groundnuts are a valuable cash crop, and insecticides are widely used to prevent losses during storage, particularly when stocks are intended for the confectionary trade. As a result, in many parts of West Africa, resistance to commonly used insecticides had developed more than 10 years ago (Deuse and Pointel, 1975; Gillier and Bockelee-Morvan, 1979). The development stimulated interest in alternative methods of protecting stored groundnuts, particularly in the southern USA, where insecticide use is most intense and the problem is most serious (Zettler, 1982).

A cheap and effective refuge trap, containing an oil-based food attractant, is commercially available for monitoring the three main beetle pests of shelled groundnuts (Barak and Burkholder, 1985). The efficiency and selectivity of this trap can be increased by the addition of genus-specific pheromone lures. A male-produced aggregation pheromone, which attracts *Tribolium* adults of both sexes, and a female-produced sex pheromone, which attracts adult male *Trogoderma* sp., are both commercially available (Chambers, 1987). An aggregation pheromone has been isolated in the genus *Oryzaephilus* but is not yet available for use in traps (Pierce *et al.*, 1984).

A number of studies have attempted to optimize pheromone application in the protection of stored groundnuts, e.g., by mass trapping (Reichmuth *et al.*, 1976) or by disrupting reproductive behaviour with pheromone-saturated air (Brady *et al.*, 1975; Sower and Whitmer, 1977). Recent research has

Plate I. Empoasca *sp. damage (photo ICRISAT)*

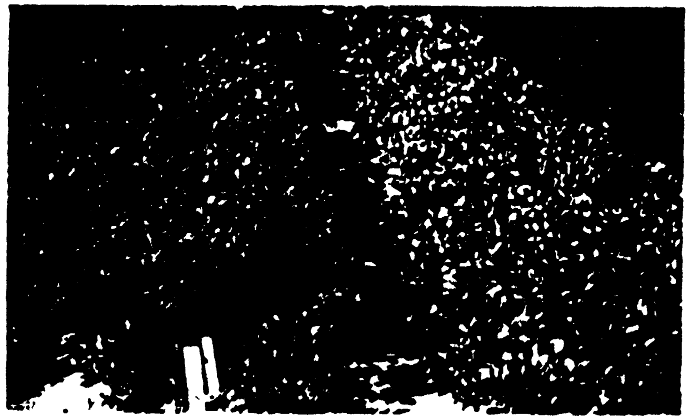

Plate II. Empoasca *sp. resistant and susceptible varieties (photo ICRISAT)*

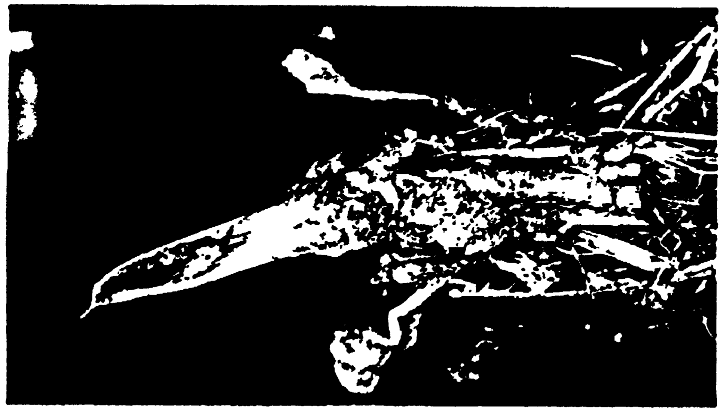

Plate III. Microtermes *damage (photo ICRISAT)*

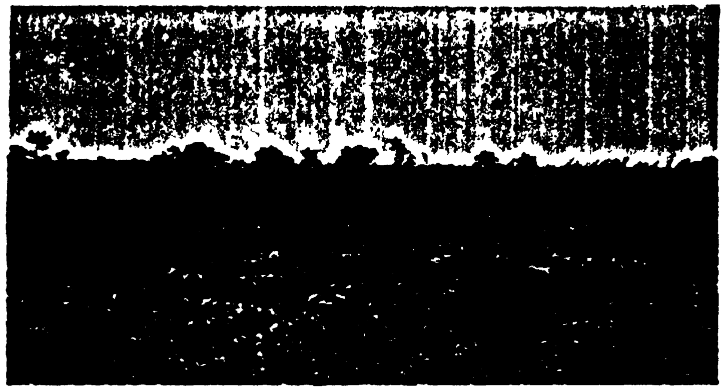

Plate IV. Microtermes *damage over a large field (photo ICRISAT)*

Plate V. Spodoptera litura *larvae (photo ICRISAT)*

Plate VI. Spodoptera litura *resistant and susceptible varieties (photo ICRISAT)*

Plate VII. Caryedon serratus *damage (photo ICRISAT)* focused on the integration of pheromones with other methods of control. Pheromones can be used to lure insects to a pathogen such as the protozoan *Mattesia trogodermae*, which attacks populations of *Trogoderma glabrum* (Shapas *et al.*, 1977), and granulosis virus, which is effective against populations of *P. interpunctella* (Kellen and Hoffman, 1987). In both these cases, adult males, attracted to a pheromone source, became infected and subsequently spread the disease to females. The larvae of the F_1 generation became infected by consuming the cadavers of diseased adults. This system may be cheaper than spraying pathogens directly on to groundnut stocks but may require the use of more than one pheromone/pathogen source to control the range of species likely to be present.

Some studies have examined the compatibility of biological control agents with conventional control techniques. Most of the natural enemies of stored-product moths are susceptible to conventional insecticides (Haines, 1984). However, insecticides vary in their toxicity to parasitic Hymenoptera. Less toxic insecticides, such as permethrin, can be used without a reduction in effective control of moth larvae (Press *et al.*, 1981).

The timing of insecticidal applications is important. The toxic effect of insecticides on *Trichogramma*-parasitized eggs of *E. cephalonica* decreases with the increasing age of the eggs (Varma and Singh, 1987). First-instar larvae of *C. cephalonica* are more susceptible to malathion and pirimiphos-methyl than *B. hebetor*, but later instars are less susceptible than the wasps (Witethom, 1980). Thus, with the use of selective insecticides and the careful timing of applications, the adverse effects on natural enemies can be minimized. Similarly, insect pathogens may be used with conventional insecticides. For example, phosphine fumigations can be carried out without impairing the activity of *Plodia granulosis* virus (PGV) or *B. thuringiensis* (McGauhey, 1975). Hunter *et al.* (1975) have shown that bulk treatment with PGV and malathion provided better control of *P. interpunctella* in an almond nut warehouse than did either treatment alone.

Controlling or modifying the atmosphere in groundnut stores has been examined in both laboratory and warehouse trials. For instance, a nitrogen-compensated vacuum prevented insect infestation of groundnut kernels held as emergency seed supplies during 18 months of storage in Senegal (Rouzière, 1986). Gas mixtures containing 30–80 per cent carbon dioxide and 20 per cent oxygen, with any balance as nitrogen or air, are lethal to eggs of *E. cautella* exposed for 48 h, at 25°C (Bell, 1984). The admixture of carbon dioxide with phosphine or methyl bromide also increases the speed and efficiency of fumigations against *Tribolium* spp. and *Trogoderma* spp. (Desmarchelier and Wohlgemuth, 1984). Although controlled-atmosphere storage seems to offer a highly effective method of insect control, its use in the tropics would probably be limited by the need for bottled gases.

Much of the work on the integration of biological, physical and chemical control of groundnut pests has been carried out in the USA. Those strategies shown to provide acceptable levels of control should now be tested in tropical stores in areas such as West Africa where alternatives to conventional insecticides are most urgently required.

Insect Pes[illegible] Food Legumes
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Vectors of Virus and Mycoplasma Diseases: An Overview

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Among the numerous pathogens affecting legumes in the tropics, viruses are perhaps the major production constraint. Virus diseases were recorded in cultivated crops more than 300 years ago. However, little was known about their properties until the turn of this century. Now it is known that a virus is an infectious nucleoprotein capable of multiplying only in living cells. On the basis of signs, graft transmission, and size of entities, diseases caused by viruses can be distinguished from those induced by fungi, bacteria, and nematodes. Evidence of infectiousness through, for example graft transmission, is required to differentiate a virus disease from a physiologic disorder, and evidence of multiplication is necessary to distinguish disorders induced by toxins from diseases caused by viruses. For many years, 'yellows' type diseases were thought also to be caused by viruses because of the signs of infection, the transmission by vectors and the failure to isolate fungal or bacterial pathogens. Currently, most of these diseases are known to be caused by procaryotic microorganisms related to members of the Mycoplasmatales and Rickettsiales. In the past many attempts to isolate and cultivate these organisms failed, and their characterization is still difficult.