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Groundnut pests and their control in the semi-arid tropics

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Abstract. White grubs, termites, millipedes, wireworms and earwigs bore holes in developing groundnut (*Arachis hypogaea* L.) pods throughout the semi-arid tropics. White grubs and termites also damage the roots. The above-ground pests include *Spodoptera litura* Fab. and the groundnut leaf miner *Aproaerema modicella* Deventer in Asia. Aphids transmit a number of virus diseases. A thrips *Frankliniella schultzei* (Trybom) is the vector of bud necrosis disease, which is a serious problem in Asia, southern USA and Australia. Jassids can cause much foliar damage, but their pest status is not certain, except as virus vectors. The pest control options lead away from insecticides, which are often available and are too expensive, towards exploiting host plant resistance and natural control and employing management techniques that restrict pest activity.

Introduction

It is doubtful if many citizens of the developed world realize how important the familiar peanut—or groundnut, *Arachis hypogaea* L.—is to the farmers, and the people they feed, in developing countries. In the West, peanuts are a dietary supplement that is either roasted and salted and eaten as a snack or is milled and used as a spread. In less developed countries, however, groundnuts are an important source of dietary protein and lipid, especially in the semi-arid tropics (SAT), i.e. tropical regions in which rainfall is highly seasonal and irregular. In Africa, S.E. Asia and China they are usually cooked before consumption. In India, the world's greatest producer of groundnuts, their oil content (45–50% v/w) is of prime importance as a cooking medium. They are, therefore, grown for cash rather than as a subsistence crop in this country. India grows 37% of the world crop from 7·5 10^6 ha (Table 1).

Africa, as a whole, grows 21% of the world total production but yields tend to be low—compare the stated average of 213 kg ha^{-1} for Zimbabwe with national mean yields of 5 t ha^{-1} in Israel and 2·7 t ha^{-1} in USA (FAO, 1983). Groundnuts rank second to soybean in terms of gross oilseed production. However, about 60% of the world's soybeans are grown in the developed world, mainly by farmers able to afford the inputs that give higher yields (Table 1).

The haulms of groundnut plants are important as stock food (Johnson *et al.*, 1981). The cake that is left after the oil has been extracted from the kernels has a high protein content and is sold as a component of stock food concentrates. It can be a valuable export commodity for the less-developed countries.

Thus groundnuts are an important crop in the SAT but yields are not as high as they could be. The constraints on yield are lack of water at the right time, nutrient deficiencies, poor seed quality, inappropriate genotypes, ineffective cultural practice, diseases, pests, weeds and storage problems.

In this paper we describe the major field pests and disease vectors of groundnuts in the SAT and then discuss strategies for controlling them. Feakin (1973) gave a world-wide view of groundnut pests; Smith and Barfield (1982) went deeper but with more emphasis on North American problems. We concentrate on control methods that are compatible with the technology and resources available to farmers who may be deficient in both. We refer to published results wherever possible but also quote data from research projects that are in progress at ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) near Hyderabad, India.

The pests

Smith and Barfield (1982) compiled a 'world' list of more than 360 species of arthropods attacking groundnut. Of these, we identify about 12 taxa as being key pests across the SAT.

Table 1. Production data for groundnuts and other major oilseed crops in 1983 (FAO, 1983).

		10^3 ha	10^3 MT	t ha^{-1}
Groundnuts	World[1]	18965	19792	1·04
	India	7500	7300	0·97
	Africa[2]	6232	4099	0·66
	Senegal	1100	650	0·59
	Nigeria	600	450	0·75
	Asia (including India)[3]	11574	13410	0·71
	China	2429	4036	1·66
	Burma	623	691	1·11
	USA	557	1485	2·67
Soybeans	World	49062	78556	1·6
	USA	25156	43421	1·7
Castor	World	1436	936	0·65
Sunflower	World	12779	15766	1·23
Rapeseed	World	13281	14342	1·08
Sesame	World	6716	2076	0·31

[1] 113 countries
[2] 44 countries
[3] 25 countries

Below-ground pests

Termites (Termitidae). Termites reduce the yield of groundnut crops throughout the SAT (Feakin, 1973). Verma and Kashyap (1980) list 20 species that are pests of this crop. When considering control strategies for this taxon the following aspects of their biology must be addressed:

—Nests can be huge, are often deep underground, are widely dispersed, and are, therefore, difficult to find and destroy.

—Some species form fungus gardens that are fed with organic matter collected by foragers and which in turn feed the colony, especially in times of food shortage.

—Most termite activity is underground and is not detected until plants die or are found to be damaged at harvest. Stems are sometimes attacked at ground level, by *Macrotermes* in particular.

—The genera most often encountered in African and Indian groundnut fields (*Microtermes* and *Odontotermes*) can kill plants directly by destroying (boring) the root system. Plant mortality due to this cause alone extends to 50% in India (Verma and Kashyap, 1980) and 30 to 40% in northern Nigeria (Sands, 1960; Johnson *et al.*, 1981). There are also records of total crop loss along the Red Sea Coast of North Africa (T. G. Wood, personal communication) and in Malawi (J. A. Wightman, personal observation).

—Scarification, and pod damage, in general, allow fungal pathogens to enter the pod. The consumer may then be exposed to toxins and carcinogens (aflatoxins) produced by *Aspergillus flavus*.

Johnson and Gumel (1981) found that, in northern Nigeria, 41–88% of the pods on plants with tap roots damaged by termites were scarified, compared to 8–32% in healthy plants. *Microtermes* can also increase harvest losses by cutting the pegs of mature pods.

Hilda patruelis *Stål. H. patruelis* is one of the most destructive groundnut pests in southern Africa (Cole, 1985; ICRISAT, 1984). The adult is 5 mm long and greenish brown. The eggs are white, and are laid on the roots, pods and pegs. The life cycle lasts about 40 days, so that there can be four generations per groundnut growing cycle (Feakin, 1973).

On groundnut, *H. patruelis* lives mainly below the soil surface and is tended by black ants (*Pheidole megacephala* F). Its affects are such that farmers are loath to sow groundnuts after one or two seasons of bad attacks.

The first signs of an infestation are wilting plants around the periphery of a field. Plants fed on by this species invariably die. Attacks are most severe in drought conditions (Taylor, 1981). The most likely cause of the rapid plant death is the injection of a salivary toxin (ICRISAT, 1984).

White grubs. White grubs, (scarabaeid beetle larvae) are a serious pest of groundnut in northern India (e.g. *Holotrichia* spp) where they have been known to completely destroy newly sown crops. Recent surveys in Malawi, Zambia and Zimbabwe showed that up to 75% of the plants in some fields had white grubs feeding on the roots. Older plants could probably survive this kind of damage, provided termites and fungal pathogens did not enter the plant through the damaged roots (J. A. Wightman, personal observation).

Pod borers. Once penetrated by insects, pods are of little commercial value because the kernels will be damaged or destroyed by the original insects, by members of another species, or because of invasion by soil fungi. Losses caused by boring insects can go undetected if they damage immature pods which rot and disappear before harvest.

Termites, especially *Microtermes*, are a major problem, (Johnson *et al.*, 1981). They make a 1 mm hole in the pod but eat more of the lining than of the kernel. *Microtermes* attacks pods approaching maturity.

Millipedes, e.g. *Peridontopyge* spp., are more likely to damage or destroy younger pods. Their penetration holes are between 1 and 4 mm in diameter. They are mainly a West African problem, although the authors have found millipedes associated with damaged pods in Malawi and Thailand (unpublished information). Demange (1975) gave an account of the 13 species known to damage groundnuts in Senegal.

Earwigs, *Anisolabis (Euborellia) stali* (Labiduridae), make holes in immature pods in Israel (Melamed-Madjar *et al.*, 1970) and India (Cherian and Basheer, 1979).

Ants, *Dorylus orientalis* Westwood (Formicidae), penetrate pods in Asia, including India (Roonwal, 1972). This species has caused extensive damage to groundnuts at ICRISAT Center. *Dorylus* (spp) is common throughout southern Africa. It causes the same damage symptoms as *D. orientalis*.

False wireworms, *Gonocephalum* spp (Tenebrionidae), penetrate pods in southern Africa (J. A. Wightman, personal observation). True wireworms (sp. unknown) (Elateridae) have also been found inside pods (and inside newly sown seed) at ICRISAT Center. *Spodoptera litura* F., which is normally a foliage feeder, can also feed on pods (G. V. Ranga Rao, personal communication).

Above-ground pests: defoliators and flower eaters

Groundnut leaf miner, Aproaerema modicella *Deventer (Gelechiidae).* The taxonomy, biology and control of the groundnut leafminer (GLM) have been reviewed by Mohammad (1981). It is oligophagous, with soybean *Glycine max* (L.) Mer., mung bean *Vigna radiata* (L.) Wilczek and lucerne *Medicago sativa* L. among its hosts, throughout Asia. Females lay 50–400 egs (ca 0·1 mm diam., white) singly beside the mid-rib on the upper side of a leaflet, on the petiole or on the stem. The young larva penetrates a leaflet and makes a blotch-type mine. When it is too large to remain in the mesophyl, it emerges from the mine and forms a refuge by webbing together two halves of a leaflet or two or more leaflets. It continues to feed on leaf tissue until it reaches a length of 6–8 mm. The larva pupates within the refuge. The grey moth lives for a week. As the life cycle lasts for about 3–4 weeks, there can be up to four generations per crop season. A heavy infestation results in the leaves developing a brown appearance. At ICRISAT, populations build up generation by generation and do not always reach damaging levels until the pod-filling stage.

GLM is more of a problem where irrigation permits groundnut cultivation beyond the rainy season. Newly-emerged crops are invaded by adults from nearby fields with more mature crops. This disadvantage must be weighed against the likelihood that this kind of cropping pattern will also sustain populations of the parasites of GLM. Mohammad (1981) lists 25 species of parasites.

Spodoptera *spp. 'armyworms' (Noctuidae). Spodoptera exigua* (Hb.) and *S. littoralis* (Boisd.) are, for the most part, minor defoliators in Africa (Hill, 1975). They are of little concern when compared with *S. litura* Fab., the geographical range of which extends from the Middle East to Japan. *S. litura* has a wide host range including groundnut, cotton, tobacco, green gram, Bengal gram and chilli. In India, 10 to 15 years ago, it was only considered to be a pest of tobacco. However, the move to post-rainy season cropping appears to have changed its host preferences, perhaps because of the continuous exposure to what, in the case of groundnut, was once only a slightly favoured crop.

Females lay about 2500 eggs in batches of 200–400 within 6 days of eclosion. The larval period is completed in 20 days at 25°C (G. V. Ranga Rao, personal communication). This means that the rapid and severe defoliation caused mainly by the fifth and sixth instars can take a farmer by surprise if crops are not monitored regularly. The larvae of *Spodoptera* species tend to migrate *en masse* in search of food when they have stripped the foliage from their field of origin.

Heliothis armigera *(Hub.) (Noctuidae). H. armigera* is distributed throughout the temperate, semi-tropical, and tropical zones of the Old World. It is primarily a flower, fruit, and seed eater, but does also eat groundnut foliage. Groundnut plants produce many short-lived flowers over a long period, so that this problem, even if it is widespread, will not cause much yield loss. Its most likely effect is to extend the fruiting period, which could result in yield loss if the crop is exposed to late drought or if pod borers are active.

Mylabris *spp.,* Epicanta *spp. (Meloidae).* These large beetles are commonly found in groundnut fields throughout Asia and Africa. They feed on flowers and have the same potential to cause damage as *H. armigera.*

Aphis craccivora *Koch, the groundnut aphid (Aphididae). A. craccivora* is cosmopolitan, with a host range extending to other leguminous crops and a number of non-crop species. Although it is of prime importance as a virus vector (below), its feeding activity may also cause yield reduction in India and West Africa (Sundara Babu, 1969; Mayeux, 1984). No information relating density to yield loss has been found. It forms colonies on upper leaves, flowers, stem apices, roots and pegs.

Thrips (Thripidae). Smith and Barfield (1982) list 10 species of thrips as pests of groundnuts and indicate that their economic status, other than as disease vectors, is open to debate. Amin and Palmer (1985) gave details of the four most important species in India. Thrips feeding activity causes scarring, wrinkling and distortion of the leaves (Senapati and Patnaik, 1973).

Jassids (leaf hoppers) (Jassidae = Cicadellidae). Jassids live on groundnut crops throughout the SAT (Smith and Barfield, 1982), seven of the 11 species in the SAT belonging to the genus *Empoasca.* Carter (1973, p. 219) wrote that "... members of this genus are notorious for their capacity to induce plant malformations as a result of their feeding". In the case of *E. kerri* in India, the first symptom of attack is a whitening of the veins on the underside of the leaves, which is where both adults and nymphs spend most of their time. Subsequently, the leaf tips become chlorotic and then necrotic. This condition is called hopper burn or leaf scorch because of the burnt appearance of an affected crop.

The presence of other insects has made the assessment of the relationships between jassid density, damage and yield loss difficult. Turner and Brier (1981) did not detect any yield loss caused by jassids in Australia even though the damage exceeded the level which farmers classified as severe. Similarly, Ellis (1984) only detected a yield loss attributable to jassids when they exceeded 40 per plant, a high population density. Thus, although jassids are widespread and often numerous, their pest status remains uncertain.

Above-ground pests: disease vectors

Groundnut crops are subject to a number of virus or related diseases, most of which are spread by aphids (Table 2). The most serious are the groundnut rosette virus complex (GRV) and the tomato spotted wilt virus (TSWV). The former is restricted to Africa, south of the Sahara, whereas TSWV is found throughout Asia, in Australia, and North and South America.

Aphis craccivora *and GRV. A. craccivora* is the most important vector of GRV. This virus produces damage symptoms in groundnut plants after sap inoculation but cannot be transmitted by the aphid unless an assistor virus GRAV is present (Hull and Adams, 1968). Reddy *et al.* (1985) have described GRV and GRAV.

A. craccivora over-winters on uncultivated hosts and migrates to groundnut crops in the summer (Farrell, 1976a). Dubern (1980) found that of the 67 wild and cultivated plant species tested, 12 could be infected with an Ivory Coast strain of GRV by either viruliferous aphids or mechanical inoculation. Evans (1954), Adams (1967) and Davies (1972) have stated that aphids acquire the disease from volunteer groundnut plants rather than from alternative hosts. However, volunteer plants are not the only source of inoculum although GRAV has not yet been found in any alternative host.

Typically, GRV symptoms appear on single plants within a crop, each point of infection representing the landing place and feeding site of a viruliferous winged aphid. This is the primary infection. Once an aphid has acquired the virus, which needs a minimum of 4·5 h access to an infected plant, it can be transmitted, within a minimum 3 min inoculation access period, after a minimum latent period of 18 h. More than 10 min access is needed to ensure 100% innoculation. Viruliferous aphids remain infective until they die, but do not pass the virus to their nymphs (Dubern, 1980).

Farrell (1976b) showed that migration was of prime importance among factors regulating population densities of *A. craccivora* on groundnuts in Malawi. Formation of winged aphids was initiated at low densities, i.e. 50% winged progeny at 200 aphids m^{-2} as compared to 10 000 m^{-2} for *A. fabae* on field beans (*Vicia fabae* L.).

Frankliniella schultzei *and Tomato Spotted Wilt Virus (TSWV).* Bud necrosis disease (BND), caused by TSWV, has become a serious disease of groundnuts in India, Australia and North America, (Reddy *et al.*, 1983). It is transmitted by thrips, especially *Frankliniella* spp. The symptoms include chlorotic ring spots on young leaves, stunting, general chlorosis, the proliferation of axillary shoots, necrosis of the stem apices, and plant death. The seeds of even late infected plants are shrivelled and mottled and are of little commercial value. The virus is persistent and can be transmitted by sap inoculation, but is not seedborne. Both virus and vector have a wide range of host plants.

The control of groundnut pests in the SAT

Pest or just an insect?

Defining the density at which an insect becomes a pest is one of the most difficult tasks facing an applied entomologist.

Table 2. Groundnut viruses: type, host range and transmission (based on Porter et al., *1984 and a personal communication from D. V. R. Reddy)*

Virus	Type	Hosts	Distribution	Vectors and transmission
Rosette	Two viruses one luteo the other dependent	mainly legumes	Africa south of the Sahara	*Aphis craccivora* *A. gossypii*, persistent; no seed transmission
Tomato Spotted Wilt	tospo virus	over 200 spp known	Probably all regions	*Frankliniella schultzei* *F. fusca*, *F. occidentalis, Thrips tabaci* Sap inoculation; no seed transmission
Mottle	potyvirus	cultivated and wild legumes	Probably all regions	*A. craccivora* *A. gossypii* *Hyperamyzus lactucae* *Myzus persicae* *Rhopalosiphum padi* *R. maidis* non-persistent via sap up to 8·5% seed transmission
Stunt	cucumovirus	many, mainly legumes	USA India Japan Thailand	*M. persicae* *A. craccivora* *A. spheraecola* non-persistent low seed transmission, mechanical
Clump	furovirus	wide range	India W. Africa	*Polymyxa graminis* seed and mechanical transmission
Yellowspot	tospo virus	wide range	India Thailand	*Scirtothrips dorsalis* sap transmission
Cowpea Mild Mottle (Crinkle)	carlavirus	wide range	Asia	*Bemisia tabaci* non-persistent; sap transmission
Stripe	potyvirus	wide range	wide	Aphids including *A. craccivora* non-persistent; mechanical and 4–30% seed transmission
Eyespot	potyvirus	not known	W. Africa	Aphids; non-persistent; sap transmission
Green/Mosaic	potyvirus	wide range	India	Aphids, non-persistent sap transmission
Rugose Leaf Curl	ricketsialike organism	not known	Australia	Jassids, persistent
Mosaic (veinal chlorisis)		not known	India Indonesia	Jassids
Witches' Broom	mycoplasma-like organism	not known	Asia	Jassids, persistent

The problems include isolating the activity of one species from the detrimental effects of a complex of insects, weeds, diseases, drought, nutrient deficiencies and poor cultural practices, as well as accounting for fluctuations caused by climatic variations and the influence of the genotype of the host.

Several authors have simulated defoliation by various mowing or ablation techniques (Greene and Gorbet, 1973; Enyi, 1975; Smith and Barfield, 1982). The consensus is that defoliation will only reduce yield during the pod-swelling phase, i.e. the final quarter of the life of a crop, and that the crop can withstand something like 25% defoliation before a loss in production is detected.

Unfortunately, these experiments may not simulate field conditions. Insects do not remove a lot of foliage at discrete time intervals. They take a little at a time. This may allow leaves to undergo compensatory growth so that the damage threshold density (the pest population density below which there is no loss in yield) is higher than estimated.

Secondly, the effect of defoliation will be strongly influenced by the genotype of the host-plant. Subrahmanyam *et al.* (1984) showed that there were wide differences in yield response to fungal diseases among the 20 genotypes they tested. In general, high yielding cultivars with little resistance to disease showed a rapid yield response as disease symptoms (equivalent to defoliation) built up. In contrast, the more resistant genotypes were able to withstand more destruction of photosynthetic tissue without a yield loss. The yield potential of the former was higher than of the latter.

To date, no attempts to relate the density of soil insects to root, peg or pod destruction and, in turn to, yields have been made. Soil-insects pose a special problem because they cannot be seen while they are causing damage, and by the time their depredations are manifested they have probably moved on to other plants, died or undergone metamorphosis.

Insecticides

All the pests discussed above can be killed by insecticides if a sufficient quantity of a suitable chemical is applied at the right time. In some cases, no alternative control method is available. This is especially true for pests that live in the soil. For instance, the standard procedure for protecting groundnut crops against termites in parts of Africa and India is to use a cyclodiene insecticide as a seed treatment or placed in the furrows or seed holes before the crop is sown. The crop (i.e. roots and pods) is protected but the termite nest is still there next season. This, combined with the dangers of handling cyclodienes and the probability of unacceptable insecticide residues accumulating in the nuts, has lead to a search for safer, more effective control methods.

To this end, the Tropical Development and Research Institute (now the Overseas Development and National Resources Institute), London, are examining three new approaches to termite control (TDRI, 1984a). The first involves evaluating controlled-release formulations of insecticide that, hitherto, have not persisted in the soil long enough to protect crops throughout the three or four months growing season. The other two approaches are based on the use of cellulose baits treated with a toxin. Slow acting stomach poisons are being tested to see if the foragers will carry contaminated bait back to the nest and transfer it to non-foragers, thereby poisoning part of or the whole colony. The second involves the use of fungicide impregnated baits. Here, foraging termites deposit fungicide-contaminated faeces on the fungus combs to kill the fungus directly so that the colony dies of starvation (TDRI, 1984b). The baiting techniques are currently under test in Sudan (in collaboration with the University of Khartoum) and India (in collaboration with ICRISAT) near Bangalore. The means of making it acceptable and available to farmers have yet to be explored.

Groundnut crops can be protected from white grubs by treating the seed bed with insecticide before sowing (Bakhetia *et al.*, 1982) or by using the seed as a medium for carrying the insecticide (Bakhetia, 1982; Ram and Yadava, 1982). Undoubtedly, a proportion of pod borers and termites will also be eliminated if persistent insecticides are interspersed in the root zone.

H. patruelis can also be controlled by insecticides (Feakin, 1973). However, small farmers in southern Africa may be unwilling or unable to buy and apply an insecticide. There is a need for the evaluation and implementation of other methods for the control of this species.

Field tests of insecticides for millipede control have been inconclusive. Rossion (1974, 1976) treated groundnut seed with methiocarb. He detected an 18% increase in yield but did not link it directly to millipede control. Masses (1981) induced heavy mortality to millipedes by using baits treated with propoxur and carbaryl, but did not determine the effect on yield.

Foliar pests can usually be controlled by a wide range of insecticides (Feakin, 1973). However, the application of an insecticide to a crop infested by *F. schultzei* can increase the incidence of TSWV (BND) (Table 3). The reasons for this anomaly are not known. It may be associated with the death of natural enemies: the thrips remains protected from spray within folded leaflets, and is not influenced by a systemic insecticide (dimethoate in the case cited) because of their shallow feeding probes. Alternatively, the insecticide may induce hyperactivity among the thrips population resulting in the wider distribution of viruliferous individuals.

Table 3. Effect of dimethoate application on BND incidence and groundnut pod yield at ICRISAT Center.

Dimethoate application g a.i. ha^{-1}	Frequency (days)	% BND at harvest[1]	Pod yield[2] kg ha^{-1}
400	3	42	1570
400	5	51	1550
400	7	62	1320
100	7	74	1140
100	10	78	1070
Control—no spray		54	1285
s.e.		±3·2	±55·9
CV%		10·5	8·4

[1] Plot size 100 m^2

[2] Mean of four replicates (NB: other pests present)

Another problem with insecticides is that they can induce outbreaks of red spider mites (Table 4). The field trial data showed that damage by *Tetranychus* sp. only occurred when dimethoate was applied to a crop. The heavy insecticide schedule was more intensive than a farmer in the SAT would (*need* to) adopt, but some might need to apply the light schedule. We have no indication of the economic significance of these observations (J. A. Wightman and D. V. Ranga Rao, unpublished data).

Table 4. Outbreaks of spider mite Tetranychus sp. and an indication of Spodoptera litura damage in a groundnut field trial following heavy and light insecticide schedules at ICRISAT Center.

Treatment	Mean number of outbreaks ha^{-1} ± s.e. (3 April)	Mean number of leaflets/plant damaged by *S. litura* ± s.e.	
		25 March	9 April
Heavy insecticide schedule 8 applications of dimethoate 350 g a.i. ha^{-1} in 350 l water	994 ±208	12·3 ±2·5	34·1 ±7·5
Light insecticide schedule 4 applications of dimethoate 200 g a.i. ha^{-1} in 350 l water	150 ± 47	7·2 2·7	14·0 2·3
Control: no treatment	0	3·8 ±1·2	6·2 ±0·3

Data are means of 5 replicates. The crop was harvested on 25 April 1985.

Resistance to some insecticides commonly used for the control of *S. litura* in Asia has developed. Reports from India (Ramakrishnan *et al.*, 1984) and China (Chou *et al.*, 1984) quote up to 86-fold resistance to carbaryl, with less dramatic, but, nevertheless, serious resistance to lindane and some organophosphates and pyrethroids. Clearly, there is a need for developing alternative control strategies for this pest.

Host resistance

Groundnut scientists searching for resistance to pests are fortunate that the gene pool represented by *A. hypogaea* and *Arachis* spp. is large (the Genetic Resources Unit at ICRISAT held in 1986 11,548 *A. hypogaea* accessions). Lines resistance to a number of SAT groundnut pests have been identified (Table 5).

Table 5. Results of screening for resistance to a range of groundnut pests at ICRISAT Centre.

Pests		Approximate number of genotypes screened	Number of genotypes with confirmed resistance
Jassid	*Empoasca kerri*	5000	17
Aphid	*Aphis craccivora*	6600	1
Thrips	*Frankliniella schultzei*	6000	29
Termite	*Odontotermes* spp	1500	15[1]
Leafminer	*Aproaerema modicella*	250	33

[1] resistance to scarification only.

Several lines have multiple pest resistance (Amin *et al.*, 1985) but unfortunately, not all have satisfactory agronomic features (e.g. NC Ac 2214, 2230, 2240 and 2243). NC Ac 343 was registered in 1970 in North Carolina (Campbell *et al*, 1971) because of the wide range of its pest resistance. However, in some cases (eg. NC Ac 2230 and 2214) characteristics associated with jassid resistance, i.e. length, density and disposition of leaf hairs, shows high heritability which gives them considerable value in breeding programmes (Dwivedi *et al.*, 1986).

Once it was realized that *F. schultzei* was the vector of TSWV, thrips resistance was sought and found. In a series of tests carried out in India, stands of Robut 33-1 (Kadiri 3) had 10–50% of the BND incidence that occurred in control plots of TMV 2, another cultivar commonly grown in India. This may be due to non-preference by thrips. It was not caused by resistance to the virus (Amin, 1985a). Since then, 14 other lines with similar characteristics have been identified (P. W. Amin, unpublished). Thrips resistance has been introduced into high yielding lines which have maintained their high yield potential.

Resistance to GLM has been detected in 33 of the 250 lines tested. A commercial cultivar, M 13, is included in this list.

Only one cultivar, EC 36892, is known to be resistant to *A. craccivora* in field conditions (K. R. Bock, P. W. Amin, J. A. Wightman, unpublished). Finding and breeding genotypes with resistance to aphids is of high priority because of their importance as disease vectors in Africa. Similarly, the role of *Aphis* spp. and jassids in the complex virus/mycoplasma problems of S.E. Asia and China also needs to be evaluated and appropriate resistant genotypes bred and released.

A number of other *Arachis* species are resistant to a range of pests (Amin, 1985b). Cytogeneticists have developed methods enabling breeders to incorporate these beneficial traits into agronomically acceptable lines (ICRISAT, 1985).

Plant breeders at ICRISAT have responded to the SAT farmers' requirement for short season (90 days or less) cultivars by selecting for 'earliness'. Genotypes with this characteristic will be tested for 'pest avoidance'. If a crop can be harvested before pest populations have built up, the damage caused will presumably be lower than in crops with longer seasons.

Biological control

Parasites and predators

Groundnuts grow on the largest land masses in the world, and the ecosystems of which they form a part are diverse. Therefore, conventional biological control programmes involving the release of introduced parasites or predators are probably not a viable proposition for the control of groundnut pests. The possibility of inundative releases of parasites is worthy of evaluation, but the cost of mass rearing, distributing and releasing insects in the SAT suggest that the implementation and continuation of such a scheme would depend upon guaranteed subsidies or external funding.

However, disturbing the 'natural control' of pests that already exists by introducing broad-spectrum insecticides into crop management procedures may also create pest problems. For instance, a number of species of defoliating caterpillars, including *Spodoptera*, which live on groundnut foliage in southern Africa rarely achieve population densities high enough to reduce crop yields. This is in contrast to the Indian situation where *S. litura* is frequently the cause of widespread defoliation but where insecticides are widely used on groundnuts crops—for example, in 1976 48·7% of the irrigated area under groundnuts and 16·4% of the unirrigated area (total 29·1%) was treated with insecticides (Patel *et al.*, 1983). David's (1986) data indicate that these figures have since increased. FAO data (FAO, 1983) in general corroborate the high usage of insecticides in India, but give negligible or zero returns for many African and S.E. Asian countries.

The deleterious effects of insecticides is demonstrated by data on the incidence of *S. litura* damage at ICRISAT under different insecticide regimes (Table 4). The number of leaflets with damage caused by *S. litura* was highest in the plots where insecticides were most used. Any recommendation to apply a nonselective insecticide, for instance for *A. craccivora* (and GRV) control, in Africa should be made with the knowledge that it could induce outbreaks of other pests by interfering with natural control processes (Cameron *et al.*, 1983).

The development of a control strategy for *A. modicella* has also to be approached with care because of the high potential level of parasitism. A series of experiments at ICRISAT Center (J. A. Wightman and D. V. Ranga Rao, unpublished) has shown that larval parasitism can reach 90%. There was no increase in larval population density from one generation to the next in these circumstances. However, the application of an insecticide (dimethoate, 350 g a.i. ha^{-1}) reduced the level of parasitism by about 40%. The implications of these observations on damage levels have yet to be worked out but they do indicate that natural control processes can regulate populations of this pest and that insecticides can interfere with them.

Pathogens

The knowledge that a wide range of pathogens can play an important part in reducing the density of insect populations has not been widely applied for the benefit of SAT groundnut farmers. The prime target for control by this approach is *S. litura*, because of the need to find an alternative to conventional insecticides. Santharam *et al.* (1978) and Santharam and Balasubramanian (1980) showed that a nuclear polyhedrosis virus (NPV) applied to banana trees and tobacco plants controlled *S. litura*. In both cases the virus did not persist more than a few days. Krishnaiah *et al.* (1984) killed *S. litura* on groundnut and black gram with an NPV but needed five applications at weekly intervals to do so. A formulation enhancing the persistence of NPV in field conditions is needed.

Cultural control

Cultural control covers all aspects of pest management not involving insecticide application, natural enemies including pathogens and host plant resistance. The simplest is hand collection and physical destruction. Such a practice can only be attempted when labour is cheap and plentiful. It has been tried with success in northern India for eliminating the adult stage (chafer) of white grubs, on a community basis (Raodeo and Deshpande, 1981).

Similarly, hand collection seems to be the only way of eliminating adult meloiids such as *Mylabris* from groundnut and other leguminous crops. Insecticides are usually neither effective not economic. The food of these large beetles, which are highly mobile and have a wide host range, is shortlived (groundnut flowers last little more than a day) so that a high rate of insecticide application at frequent intervals during the flowering period which lasts for more than one month, would be necessary to eliminate this problem.

The worst effects of GRV can be avoided by sowing crops early and densely (Storey and Bottomley, 1927; Storey and Ryland, 1957; A. Brook, 1964; Booker, 1963; and Farrell, 1976a). This approach has clearly been known for some time, but the farmers' need to sow staple food crops as early as possible in the rainy season means that this advice is not always heeded. Furthermore, the high cost of groundnut seed encourages farmers to sow less densely than they should.

The incidence of BND is also reduced when crops are sown as soon as the rainy season starts or in the case of irrigated crops early in the post-rainy season. Close spacing also lessens the impact of this disease (Reddy *et al.*, 1983).

It is common practice in many parts of the SAT to intercrop or multicrop groundnuts with cereals (e.g. millet and maize). This procedure can reduce plant mortality caused by BND by about 10% (P. W. Amin, C. K. Ong, unpublished), but further research is required to clarify this subject.

Discussion and conclusions

It is not possible to generalize about the pest problems in groundnut crops growing in the SAT—except to say that we do not know enough about them. In India, insecticide usage is high and perhaps should be lower if resistance is to be avoided or reduced. In Africa, more insecticides could be used for the control of soil insects. However, the economic benefits of such a proposal would have to be examined ,with care. We also need a clear picture of what is happening with reference to groundnut pests in S.E. Asia. This is particularly true with regard to the vectors of diseases that are rife in this region.

There has been considerable success in identifying genotypes resistant to a number of pests in *A. hypogaea* and other *Arachis* species. The co-operative efforts of entomologists and breeders, at national and international levels, can only lead to success. As far as BND is concerned, it is currently the main hope of reducing yield losses caused by this disease in India.

We need to know more about the interaction of microclimate, genotype and natural enemies in the various intercropping and multicropping systems that are either traditionally employed or under evaluation. This is where entomologists need to integrate with other crop scientists in their quest to help farmers live with pests without having to spend money and time on control inputs.

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