Biology and control of the groundnut leafminer, *Aproaerema modicella* (Deventer) (Lepidoptera: Gelechiidae)

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Abstract The groundnut leafminer, *Aproaerema modicella* (Deventer) (Lepidoptera: Gelechiidae), is an important pest of several legume crops in South and South-East Asia. For groundnut, yield losses of >50% have been reported. In addition to groundnut and soybean (the main crops attacked), 12 alternative host plants have been reported. *A. modicella* is present throughout the region, although it has been studied most intensively in India and Thailand. Research conducted over the past 10 years has provided a good understanding of the biology, life cycle and natural enemies of this pest. Research on management has focused on chemical control. This paper reviews the literature on the host plants, distribution, biology and control of *A. modicella*, emphasizing research reported since 1980. Aspects of *A. modicella* ecology that need further study are also indicated.

Keywords Groundnut; *Arachis*; *Aproaerema modicella*; groundnut leafminer; natural enemies; biology; host plants

Taxonomy and distribution

The groundnut leafminer (GLM), *Aproaerema modicella* (Deventer) (Lepidoptera: Gelechiidae), is a serious pest of groundnut and soybean in South and South-East Asia (Wightman *et al.*, 1990). Amin (1983) has called it the most important groundnut pest in India. Originally described as *Anacampsis nerteria* Meyr. from specimens collected in India (Meyrick, 1906), five other binomials have referred to the same pest: *Biloba subsecivella* Zeller, *Stomopteryx nerteria* Meyr., *Stomopteryx nertaria* Meyr., *Stomopteryx subsecivella* Zeller, and *Aproaerema nerteria* Meyr. The uncertain taxonomy was due to the existence of two, non-congeneric leaf-miners: one from South Africa is now called *Stomopteryx subsecivella* (Zeller); the second is the Indian–Indonesian groundnut leaf-miner, *Aproaerema modicella* (Deventer) [J. D. Bradley, British Museum (Natural History) personal communication in Mohammad, 1981]. Deventer (1904, in Mohammad, 1981) originally described *A. modicella* from a moth collected in Java, Indonesia.

The geographical range of *A. modicella* is restricted to South and South-East Asia, from Pakistan to China and as far south as the Philippines and Sri Lanka. It has been reported from Pakistan, India, Sri Lanka, Bangladesh, Myanmar, Thailand, Laos, Kampuchea, Vietnam, China, the Philippines, Indonesia and Malaysia (Mohammad, 1981; Campbell, 1983; Islam *et al.*, 1983; Crowe, 1985). In India, where GLM has been studied most extensively, it is found in Tamil Nadu, Andhra Pradesh, Karnataka, Maharashtra, Madhya Pradesh, Gujarat, Punjab, Delhi, Rajasthan, Orissa and West Bengal (Mohammad, 1981).

With the exception of *Boreria hispida* (Rubiaceae), GLM feeds only on leguminous host plants (*Table 1*).

Table 1. Host plants of *Aproaerema modicella*

Scientific name	Reference
Arachis hypogaea L.	Maxwell-Lefroy and Howlett, 1909
Glycine max (L.) Merr.	Ramakrishna Ayyar, 1940
Vigna radiata (L.) Wilzeck (=*Phaseolus aureus*)	Prasad *et al.*, 1971
Cajanus cajan (L.) Millsp.	Bainbridge-Fletcher, 1920
Medicago sativa L.	Sandhu, 1977
Psoralea corylifolia L.	Maxwell-Lefroy and Howlett, 1909
Inigofera hirsuta L.	Jai Rao and Thirumalachar, 1977
Vigna umbellata (Thunb.) Ohwi and Ohashi (=*Phaseolus calacaratus*	Jai Rao and Thirumalachar, 1977
Glycine soja Sieb. & Zucc.	Vanhall, 1922 (in Mohammad, 1981)
Trifolium alexandrium L.	Thontadarya, Jai Rao and Kumar, 1979
Teramnus labiolis (L.) Spreng	Das and Misra, 1984
Lablab purpureus L.	Das and Misra, 1984
Rhynchosia minima Dc.	Srinivasan and Siva Rao, 1984
Boreria hispida K. Sch.	Srinivasan and Siva Rao, 1984

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Several are crop plants, the most important being groundnut (*Arachis hypogaea* L.), soybean [*Glycine max* (L.) Merr.], pigeonpea [*Cajanus cajan* (L.) Millsp.] and alfalfa (*Medicago sativa* L.). Phisitkul (1985) tried unsuccessfully to rear GLM on a variety of other plants, sunhemp (*Crotalaria juncea* L.), winged bean [*Psophocarpus tetragonolobus* (L.) D.C.], yard long bean [*Vigna sinensis* (L.) Saviex Hask subsp. *sesquipedalis* Fruwirth], siratro (*Macroptilium atropurpureum* L.), hamata (*Stylosanthes hamata* L.), cowpea [*Vigna sinensis* (L.) Saviex Hask], showy crotolaria (*Crotalaria pallida* Ait.), and sword bean (*Canavalia gladiata* D.C.). Females oviposited on these plants at a much lower rate than on groundnut and soybean, and larvae did not survive beyond the first instar.

Life-cycle and population dynamics

Maxwell-Lefroy and Howlett (1909) and Bainbridge-Fletcher (1920) were among the first to describe and document the life cycle of GLM. Cherian and Basheer (1942), Kapadia, Bharodia and Vora (1982) and Phisitkul (1985) also give detailed accounts of GLM biology. Small (<1.0 mm) oval eggs are laid on the undersides of groundnut leaflets, stems and petioles. Fecundity averages between 86.6 and 185.8 eggs per female, although in one study a single female produced 473 eggs (Cherian and Basheer, 1942; Gujrati, Kapoor and Gangrade, 1973). Egg production has been shown to be temperature dependent with significantly lower production at 15 and 35°C than at 30°C (Shanower, 1989). The surface of the egg is covered with longitudinal pits which reminded one author of the pits on groundnut pods (reference in Bainbridge-Fletcher, 1920). Sixty degree-days above 12.4°C are required for GLM egg development (Shanower, 1989). Under field conditions, eggs generally hatch in 3–4 days but may require 6–8 days at lower temperatures (Kapadia *et al.*, 1982).

First-instar larvae typically chew through the epidermis to reach the leaf mesophyll upon hatching. Early instars create short serpentine mines, which widen into blotches as the larvae grow. Later instars leave the mine and web together two or more leaflets. Final-instar larvae are approximately 6.0 mm long and very active. Males and females can be distinguished in the larval stage by the distinctive pink gonads of the male which are visible through the cuticle. Larval development requires approximately 325 degree-days above a threshold temperature of 11.3°C (Shanower, 1989). Under field conditions at ambient temperature, larval development lasts between nine and 28 days (Cherian and Basheer, 1942; Sandhu, 1978; Kapadia *et al.*, 1982).

Different numbers of instars have been reported in the literature. Kapadia *et al.* (1982) reported three, Gujrati *et al.* (1973) four, Amin (1987) five, and Islam *et al.* (1983) six larval instars. Head capsule measurements indicate that, in peninsular India, GLM larvae pass through five instars (Shanower, 1989).

Pupation occurs within the webbed leaflets and requires 72 degree-days above a threshold of 14.7°C (Shanower, 1989) and can be completed in 3–10 days at ambient temperatures (Cherian and Basheer, 1942; Sandhu, 1978). The egg-to-adult life cycle is completed in roughly 450 degree-days (Shanower, 1989) or 15–28 days in southern India (Cherian and Basheer, 1942). In northern India, when mean temperatures range between 14 and 22°C, the life cycle may require 37–45 days (Sandhu, 1978).

Seasonal population dynamics

A. modicella has been an important pest of groundnut in India for >20 years (Amin and Mohammad, 1980). Continuous cultivation of groundnut using irrigation, or a groundnut/soybean rotation, allow GLM populations to build up (Wightman and Amin, 1988). Even in the absence of groundnut or soybean, GLM populations can persist on one of several wild hosts (*Table 1*). More than 3000 GLM larvae have been found on a single *Psoralea corylifolia* L. shrub, indicating the potential of this plant as an alternate host (Manoharan and Chandramohan, 1986). Alternatively, GLM may survive the extremely hot, dry Indian summer in pupal diapause or aestivation (Jagtap, Bothe and Deokar, 1985).

Leafminer populations peak in July and August in Thailand (Campbell, 1983), although other authors also report high population densities in November and December (Mohammad, 1981). In Bangladesh and India the densest populations of GLM occur at the end of the postrainy season, March and April (Amin and Mohammad, 1980; Islam *et al.*, 1983). In India, GLM is often a problem towards the end of the rainy season (September and October), especially in drought or low-rainfall years (Amin, 1983). GLM populations fluctuate widely between seasons. At ICRISAT, in peninsular India, GLM population densities have been recorded regularly since 1980, in unsprayed groundnut (cv. Kadiri 3) trials with three or four observations per season and up to 100 plants per sample (unpublished data). Population densities ranged from one to >320 larvae per plant. Extremely high densities (>50 larvae per plant) were recorded in two rainy seasons (1984 and 1987) and two postrainy seasons (1981 and 1982). In the other seasons, densities ranged between 10 and 20 larvae per plant.

Two GLM generations per crop are typical in Thailand (Campbell, 1983), whereas in China seven generations have been reported on a single soybean crop (Yang and Liu, 1966). Three to four generations per season are common on groundnut in India, although five generations have been reported during the rainy season in south India (Logiswaran and Mohanasundaram, 1986).

Climatic factors

Abiotic factors, principally rainfall, humidity and temperature, are frequently suggested as causes of population fluctuations. Khan and Raodeo (1987) observed GLM populations over two years in Tamil Nadu. High populations were recorded from August through February, but in March declined to a low level. The authors claimed that high rainfall was the key factor regulating GLM populations, although their data do not support this conclusion. The high populations observed in August–September occurred during a high rainfall period; populations declined in March when no rain was recorded (Khan and Raodeo, 1987).

Amin (1987) has suggested that heavy rainfall reduces leafminer populations, although Wheatley *et al.* (1989) found that water from an overhead irrigation system did not lower GLM density. Lewin *et al.* (1979) found a significant negative correlation between GLM incidence and rainfall: higher GLM incidence was correlated with lower rainfall. Temperature, within the range experienced in the trial, was also positively correlated with GLM incidence and accounted for more of the variation than rainfall (Lewin *et al.*, 1979). Another study at the same location revealed a significant negative correlation between infestation and temperature (Logiswaran *et al.*, 1982). Experiments using a rain simulator indicated that the physical impact of rainfall on GLM eggs and larvae does not significantly increase mortality (Shanower, 1989). However, rainfall may have a more subtle influence (e.g. increasing humidity and favouring fungal pathogens) on GLM population dynamics.

Damage and yield loss

The groundnut leafminer reduces groundnut and soybean yields by feeding on leaves, thereby reducing the photosynthetically active leaf area. Islam *et al.* (1983) reported that the feeding activity of a single larva will destroy 34.8 cm^2 of leaf tissue. This is equivalent to consuming 6–10 groundnut leaflets, depending on the genotype, and seems excessive for such a small caterpillar. Shanower (1989) measured the consumption of individual larvae and calculated that on average 179.3 mm^2 of leaf area was eaten.

Jagtap, Ghule and Deokar (1984) found that insect pests, principally GLM and *Aphis craccivora* Koch, accounted for a 16% reduction in pod dry weight in variety JL 24 over a 3-year period (equivalent to 303 kg ha^{-1}). Logiswaran and Mohanasundaram (1985) reported pod yield losses of >50% in Tamil Nadu. Yield increases of up to 65% have been obtained in sprayed plots compared with unsprayed (check) plots (Sivasubramanian and Palaniswamy, 1983; Rajput, Dalaya and Awate, 1985). However, using this technique it is difficult to separate the losses attributable to GLM from those caused by other insects.

Tej Kumar and Devaraj Urs (1983) used screen cages and artificially infested groundnut plants with different levels of GLM. A regression of yield loss versus infestation revealed that each 1% infestation of GLM resulted in 1.2% yield loss. Data from screen cages can be misleading because the cages reduce sunlight, thus possibly confounding the results.

The impact of GLM on groundnut growth and yield is in part determined by the time of infestation. An infestation of five larvae per plant 10 days after emergence has a much greater impact than 20 larvae per plant at 75 days after emergence. Ghule *et al.* (1987b) found that groundnuts need protection from GLM between 45 and 75 days after emergence; however, this is true only if GLM populations are low, early in the season. A recommended action threshold in India is 61–70 larvae per 100 leaflets (Ghewande, Nandagopal and Reddy, 1987).

Cultural control and host-plant resistance

Several cultural methods have been recommended for control of GLM, although only intercropping and manipulation of planting date have been tested. Logiswaran and Mohanasundaram (1985) found lower GLM larval densities when groundnut was intercropped with sorghum, millet or cowpea, than in monoculture groundnut at 30 × 10 cm spacing. However, the lowest GLM larval densities in this trial were recorded in monoculture groundnut at close spacing (15 × 10 cm). Mulching with rice straw had no effect on GLM levels but did have a positive effect on parasitism levels: monocropped groundnut at 30 × 10 cm spacing had the lowest level of parasitism whereas a similar monocrop at 15 × 10 cm spacing had the highest; intercrop treatments all had intermediate levels of parasitization (Logiswaran and Mohanasundaram, 1985). The authors did not discuss the differences between treatments nor did they suggest the mechanism involved.

The effect of sowing date on GLM infestations has been the focus of two studies: the first study (Lewin *et al.*, 1979) showed that early sowing led to higher infestations of GLM, whereas the second study (Logiswaran *et al.*, 1982) concluded that later plantings were more heavily attacked.

Progress has been made in developing GLM-resistant or -tolerant cultivars. GLM resistance has been demonstrated in a wide range of genotypes, including spreading, Spanish bunch, and Valencia growth habits (ICRISAT, 1986). One variety, ICGV 86031, has shown good tolerance to GLM as well as to other defoliators (ICRISAT, 1991). ICGV 86031 is an improved genotype that may be grown in GLM-endemic areas and may be used as a suitable parent for germplasm enhancement by national agricultural research centres (ICRISAT, 1991).

Bunch varieties are generally considered to be less susceptible to GLM, although Motka, Bhalani and Bharodia (1985) have shown enhanced growth and development of GLM on these types. Growth rate, body weight and percentage survival of larvae and pupae, and weight and longevity of adults were compared in 10 varieties: larval, pupal and adult weights were significantly higher on the bunch variety JL 24 than on other varieties. Larval survival rate was also higher and adults lived significantly longer when reared on this variety (Motka *et al.*, 1985).

GLM-resistant soybean varieties have not, as yet, been found. Mundhe (1980) compared 20 varieties and found no differences in GLM populations until 75 days after sowing. In another trial 18 varieties were compared (Shetgar and Thombre, 1984), but again no differences in leafminer populations were observed. More recently, 40 soybean varieties were evaluated during two rainy seasons and all were attacked by GLM, although three varieties had significantly lower larval populations (Shrivastava, Srivastava and Deole, 1988).

Natural control

Natural control, by diseases, predators and parasitoids, is important in suppressing GLM population growth. At least three disease agents (nematodes, viruses and fungi) infect GLM larvae in India. Unidentified mermithid nematodes have been found infecting larvae (Kothai, 1974 in Mohammad, 1981; Srinivasan and Siva Rao, 1986), as was a new nuclear polyhedrosis virus (Godse and Patil, 1981). The fungus *Aspergillus flavus* has also been recovered from GLM larvae (Oblisami, Ramamoorthi and Rangaswami, 1969). In some generations up to 30% of the larvae are killed by viral and fungal pathogens (Shanower *et al.*, 1993).

Several predators have been identified that attack GLM larvae but their impact has not been quantified. Maxwell-Lefroy and Howlett (1909) reported that *Odynerus punctum* Fabr. (Hymenoptera: Eumenidae) would attack GLM larvae and carry them away. The larvae of a carabid (*Chlaenius* sp.) have been observed attacking GLM larvae in the field (Shanower and Ranga Rao, 1990). Predation by spiders and robber flies (Diptera: Asilidae) has also been reported (Srinivasan and Siva Rao, 1986).

The most important and abundant GLM natural enemies are parasitic Hymenoptera (*Table 2*). The parasitoid community associated with GLM is large and complex, involving at least two trophic levels. *Table 2* includes both primary and secondary parasitoids reared from GLM. Shanower *et al.* (1993) found nine primary

Table 2. Parasitoids reared from *Aproaerema modicella*[a]

Family Parasitoid	Host plant	Stage attacked
Bethylidae		
Goniozus sp.	Groundnut and soybean	Larva
G. stomopterycis Ram & Subba Rao	Groundnut	Larva
Perisierola sp.	Groundnut	Larva
Braconidae		
Apanteles sp.	Groundnut and soybean	Larva
A. javensis Rohwer	Groundnut	Larva
A. singaporensis Szep.	Groundnut	Larva
A. litae Nixon	Soybean	Larva
Avga choaspes Nixon	Groundnut	Larva
A. nixoni Subba Rao & Sharma	Groundnut	Larva
Bracon sp.	Groundnut	Larva
B. brevicornis Wesm.	Groundnut	Larva
B. gelechiae Ashm.	Groundnut and soybean	Larva
B. (Microbracon) hebetor Say	Groundnut	Larva
Chelonus (Microchelonus) sp.	Groundnut and soybean	Larva
C. blackburni Cam.	Groundnut	Larva
C. curvimaculatus Cam.	Groundnut	Larva
Phanerotoma sp.	Groundnut	Larva
Ceraphronidae		
Aphanagmus fijiensis (Ferriere)	Groundnut	Larva
Ceraphron sp.	Groundnut	Larva
Chalcididae		
Brachymeria sp.	Groundnut	Larva and pupa
B. plutellophaga Gir.	Groundnut	Larva and pupa
B. minuta (L.)	Groundnut	Larva
B. wittei Schmitz	Groundnut	Larva
Eucepsis (sp.)	Groundnut	Larva
Elasmidae		
Elasmus anticles Walker	Groundnut	Larva
E. brevicornis Gahan	Soybean	Larva
E. sp. nr. *luteus* Crawford	Groundnut	Larva
Encyrtidae		
Capidosoma sp.	Groundnut	Larva
Eulophidae		
Euryscotolynx coimbatorensis Rohw.	Groundnut	Larva
Oomyzus sp.	Groundnut	Larva
Pediobius sp.	Groundnut	Larva
Stenomesioideus ashmeadi Subba Rao & Sharma	Groundnut and soybean	Larva
Stenomesius sp.	Groundnut	Larva
S. japonicus (Ashmead)	Groundnut	Larva
Sympiesis (Asympiesiella) sp.	Groundnut	Larva
S. dolichogaster Ashmead	Groundnut	Larva
S. india Gir.	Groundnut	Larva
Tetrastichus sp.	Groundnut	Larva
Eupelmidae		
Eupelmus sp.	Groundnut	Larva and pupa
E. sp.nr. *anpingensis*	Groundnut	Larva and pupa
Eurytomidae		
Eurytoma sp.	Groundnut	Larva
Plutarchia giraulti Subba Rao	Groundnut	Larva
Ichneumonidae		
Temelucha sp.	Groundnut	Larva
Pteromalidae		
Dibrachys sp.	Groundnut	Larva
Habrocytus sp.	Groundnut	Larva
Pteromalus sp.	Groundnut	Larva
Trichogrammatidae		
Trichogramma sp.	Groundnut	Egg

[a] Sources: Krishnamurthi and Usman, 1954; Subba Rao *et al.*, 1965, Subba Rao and Sharma, 1966; Phisitkul, 1985; Srinivasan and Siva Rao, 1986, Muthiah, 1991; Shanower *et al.*, 1993

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