Management of *Aproaerema modicella* (Lepidoptera: Gelechiidae) in India and Africa: A Review

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ABSTRACT

Groundnut leaf miner (GLM) *Aproaerema modicella* (Lepidoptera: Gelechiidae), a major pest of leguminous plants in Asia, poses a serious threat to groundnut *Arachis hypogaea* (L.) and soya bean *Glycine max*. (L.) Merr in Africa since 1998. Research on the control strategies against GLM in Asia has focused on chemical, biological, cultural control and integrated pest management (IPM), similar efforts have been underway in Africa. However, further research is needed to develop effective control strategies for Africa. This review synthesizes management approaches from both continents, highlighting biological, cultural, chemical control, resistant cultivar screening and intercropping, while identifying research gaps in Africa. Information used to compile this review was gathered from published materials including books, journal articles, research reports, international newsletters and dissertations. Since more research on the management of GLM has been done in Asia than in Africa, a significant portion of the information in this review is derived from studies conducted in Asia.

Key words: Neem oil, Parasitoids, Predators, Resistant cultivars, Sex pheromones.

The groundnut leaf miner (GLM), *Aproaerema modicella*, also known as the soya bean moth in Australia (*Aproaerema simplexella*) was predominantly a significant pest of groundnut (*Arachis hypogaea*) and soya bean (*Glycine max*) in Asia. It was first reported in Africa in 1998 (Page *et al.,* 2000). Its presence has since raised concerns in groundnut and soya bean production. The GLM is distributed across multiple countries in Asia, Africa and Australasia (CAB International, 2014; Buthelezi *et al.,* 2021). The pest's ability to thrive in diverse agroecological environments, ranging from regions with warm summers and cold winters to those with consistently warm climates, indicates its adaptability to various climatic conditions (Buthelezi *et al.,* 2021). Groundnut leaf miner larvae cause significant damage by feeding on the leaf mesophyll, leading to leaf browning, abscission and reduced photosynthetic capacity, which directly affects crop yields (Kolhe *et al.,* 2015; Kenis and Cugala, 2006). In India, GLM infestations were reported to cause up to 90% losses in groundnut yield (Reddy *et al.,* 1978; Sumithramma, 1998). In Africa, 100% losses in groundnut and soybean crops have been recorded in countries such as Uganda, Mozambique and South Africa (Cugala *et al.,* 2010; Buthelezi *et al.,* 2013; Ibanda *et al.,* 2018).

Groundnut is a crucial legume crop for smallholder farmers in Africa, providing both subsistence and income (Janila *et al.,* 2013). Soya bean is an essential source of protein for human consumption as well as for animal feed. Its susceptibility to GLM poses a serious threat to food security (Bhor *et al.,* 2014; Tukamuhabwa and Oloka, 2016).

This review synthesizes management strategies for GLM in Africa and Asia, focusing on biological, cultural, resistant cultivar screening and chemical controls. The majority of studies on GLM management have been conducted in Asia, although efforts to manage the pest in Africa are ongoing through similar approaches.

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The distribution of GLM

The prevalence of GLM has been documented across various regions in Asia, Africa and Australasia. In Asia, it has been reported in India, Bangladesh, Cambodia, China, Indonesia, Java, Malaysia, Myanmar, Nepal, Pakistan, the Philippines, Sri Lanka, Thailand, Vietnam and the Indian state of Orissa. In Africa, GLM is known to occur in Uganda, the Democratic Republic of Congo (DRC), Malawi, Mozambique, Kenya, South Africa, Egypt, as well as on the Indian Ocean islands of Madagascar, Réunion and Mauritius. In Australasia, GLM is prevalent in Australia specifically in Western Australia, the Northern Territory, Queensland, New South Wales, Victoria, Tasmania, South Australia and Norfolk Island and in New Zealand (CAB International, 2014; Buthelezi *et al.,* 2021).

The biology of GLM

Groundnut leaf miner is classified under family Gelechiidae and the subfamily Anacampsinae within the Lepidoptera order. Among the 12 species in the genus *Aproaerema*, *A. modicella* is the most studied due to its pest status on groundnut and soya bean in Asia and Africa (Hall *et al.,* 1993; Jyothi *et al.,* 2008).

Description and damage symptoms of GLM on the leaves of the host plant

The GLM adult moth is grey, with a wingspan reaching up to 18 mm (Shanower *et al.,* 1993a). Female GLM moth lays small, shiny white eggs that are oval in shape. The larva of GLM is greyish-green with a glossy black head and feed on the leaf mesophyll, forming winding mines that eventually expand into blotches (Chanthy *et al.,* 2010). These mines result in leaf distortion, browning and desiccation, causing early leaf drop and yield losses (Kenis and Cugala, 2006). In its lifetime, one larva can destroy 34.8 to 179.3 cm^2 of leaf area (Shanower, 1989). In South Africa, GLM infestations correspond with the flowering and pegging stages of groundnut, typically occurring 5 to 6 weeks after the crop emerges (Buthelezi *et al.,* 2017; 2021).

Groundnut leaf miner life cycle

Female GLM moths lay between 87 and 473 eggs on the underneath surface of leaves, stems, or petioles (Cherian and Basheer, 1942). The life cycle duration depends on environmental conditions, particularly temperature, ranging from 15 to 80 days (Shanower *et al.,* 1993b). Under warmer conditions, the full life cycle can take 15-28 days, while in cooler conditions, it extends to 37-45 days (Cherian and Basheer, 1942; Sandhu, 1978). In South Africa, GLM has a generation cycle of 28-30 days, with two peaks per season (Buthelezi *et al.,* 2017).

Effects of climatic factors on GLM incidence

Climatic factors like temperature, humidity and rainfall significantly influence GLM populations. Studies in South Africa showed higher moth catches during periods of high temperatures and low rainfall, while rainy periods saw a drop in population density (Buthelezi *et al.,* 2017). These findings align with observations in India, where GLM infestation peaks coincide with high temperatures and reduced humidity (Arunachalam and Kavitha, 2012). Furthermore, GLM infestations in India have also been predominantly recorded in rainfed cropping systems (Reddy *et al.,* 1978).

Host plants of GLM

Soya bean is the primary shared host for GLM populations in Asia, Australasia and Africa (Common, 1990; Bailey, 2007; Buthelezi *et al.,* 2013). In Africa and India, GLM also infests groundnut (Buthelezi *et al.,* 2013). In Australia, it affects *Cullen tenax*, *Psoralea patens* and clover (*Trifolium* spp.) (Bailey, 2007). In South Africa, GLM infests various leguminous crops and wild hosts but not in winter (Buthelezi *et al.,* 2013). Table 1 details the known host plants of *A. modicella* in India (Shanower *et al.,* 1993a) and South Africa (Van der Walt, 2007; Buthelezi *et al.,* 2013), showing shared hosts between Asian and African populations. Groundnut leaf miner is generally absent during winter months in South Africa. Studies have shown that it reappears in high numbers during the rainy season, suggesting an unknown overwintering strategy (Buthelezi *et al.,* 2013). In India, there is no documented evidence on how GLM survives the off-season, warranting future research into its survival strategies during non-cropping periods.

Economic imapct of the GLM

Groundnut leaf miner is a significant pest for groundnut and soya bean in South and Southeast Asia and Africa (Shanower *et al.,* 1993a; Kenis and Cugala, 2006). In regions like India, GLM causes up to 90% yield loss, particularly in the absence of natural predators, resulting in prevalent outbreaks (Reddy *et al.,* 1978; Sumithramma, 1998). Africa has also reported severe damage, with total crop loss in countries such as Mozambique, Uganda and South Africa (Cugala *et al.,* 2010; Buthelezi *et al.,* 2013; Ibanda *et al.,* 2018). The established economic threshold for GLM in South Africa is 2 larvae per plant, while in Mozambique, it is 38 larvae per plant (Kenis and Cugala, 2006; Van der Walt *et al.,* 2009). These threshold levels, along with environmental conditions, guide control measures for managing GLM outbreaks.

Control measures for GLM

Cultural control

Crop rotation

Rotating groundnut with non-leguminous crops, such as maize, cotton or sorghum, reduces GLM infestations. These crops disrupt the pest's lifecycle and decrease populations (Thakur, 2013).

Intercropping

Mixed cropping systems, like groundnut with sorghum or cowpea, have shown reduced GLM populations (Rajagopal and Hanumanthaswamy, 2000).

Irrigation

Drought stress exacerbates GLM infestations. Irrigated crops display lower infestation rates, as seen in South Africa (Buthelezi *et al.,* 2017).

Planting dates

Adjusting planting times reduces GLM attack. In South Africa, early planting (November) is less vulnerable than late planting (January) (Buthelezi *et al.,* 2017).

Biological control

Predators

Several predators of GLM have been documented in India, with some of these species listed in Table 2. Polyphagous predators such as lacewings (*Chrysoperla carnea*) and

Table 1: Host plants GLM obtained from various literature sources across its geographic range.

Host plants family	Host plants for *A. modicella* (Shanower *et al.,* 1993a)	Host plants for *S. subsecivella* (Van der Walt, 2007)	Host plants for *S. subsecivella* (Buthelezi *et al.,* 2013)
Leguminosae	*Arachis hypogea* (L.) (groundnut) *Glycine max* (Merril), (L.) (soy bean) *Vigna radiata* (L.) Willzeek (= *Phaseolus aureus*) (mung bean) *Cajanus cajan* (L.) Millsp. (pigeon pea) *Medicago sativa* L. (lucerne) *Psolarea corylifolia* (L.) (babchi) *Indigofera hirsuta* (L.) (hairy indigo) *Vigna umbellata* (Thunb) Ohwi and Ohashi (= *Phaseolus calcaratus*) (rice bean) (L.) *Glycine soja* Sieb. and Zucc. (wild soya bean) (L.) *Trifolium alexandeium* (L.) (berseem clover) *Teramnus labialis* (L.) Spreng (blue wiss) *Lablab purpureus* (L.) (lablab bean) *Rhynchosia minima* DC. (*jumby bean*) (L)	*Arachis hypogea* (L.) (groundnut) *Glycine max* (Merril), (L.) (soy bean) *Medicago sativa* (L.) (lucerne) *Hibiscus* sp., *Senna obtusifotia* (L.) Irwin and Bamaby *S. occidenialis* (L.) Link (L.) *Indigofera astragalina* (DC.) (L.) *Crotalaria vasculosa* Wall, ex Benth.) (L.)	*Arachis hypogea* (L.) (groundnut) *Glycine max* (Merril), (L.) (soy bean) *Cajanus cajan* (L.) Millsp. (pigeon pea) *Medicago sativa* (L.) (lucerne) *Indigofera hirsuta* (Linn.) (L.) *Desmodium tortuosum* (Sw.) DC. (L.) *Glycine wightii* L. Merr. (wild soya bean)
Rubiaceae	*Boreria hispida* (shaggy button weed)		
Convolvulaceae		*Ipomoea sinensis* (Desr.) Choisy subsp. blepharosepala (Hochst. ex A. Rich) Verde ex A. Meeuse) (Convolvulaceae)	*Ipomoea sinensis* (Desr.) Choisy subsp. blepharosepala Hochst. ex A. Rich. (Convolvulaceae) Ipomoea wightii (Wall) Choisy (Convolvulaceae)
Malvaceae			*Malvastrum coromandelianum* subsp. coromandelianum (L.) (Garcke) (Malvaceae) *Pavonia burchellii* (DC.) (Dyer) (Malvaceae)
Asteraceae			*Acanthospermum hispidum* DC. (Asteraceae)
Lamiaceae			*Ocinum canum* (Sims) (Lamiaceae) (African basil)
Capparaceae		*Cleome monophylla* L. (Capparaceae)	
Pedaliaceae		*Sesamum alaium Thonn* (Pedaliaceae)	
Tiliaceae		*Corchonis tridens* L. (Tiliaceae)	

(Source: Buthelezi *et al.,* 2021). *A. modicella* = Indian GLM; *S. subsecivella*= African GLM.

Table 2: Parasitoids of GLM (Source: Kennis and Cugala, 2006; Van der Walt *et al.,* 2009; Murugasridevi *et al.,* 2022).

Family and species	Stage	Country	Host
Bethylidae			
Goniozus sp. (syn. Perisierola sp.)	L	India	GN, SB
Goniozus indicus Ashmead	L	India	GN
Goniozus stomopterycis Ram and Subba Rao	L	India	GN
Goniozus sp.	L,P	South Africa	GN
Braconidae			
Apanteles sp. (syn. *Dolichogenidea* sp.)	L	India, Indonesia,Thailand	GN, SB
Apanteles javensis Rohwer	L	India	GN
Apanteles litae Nixon	L	India	SB
Unidentified Pupae	L	South Africa	GN
Apanteles sp.			
Avga choaspes Nixon	L	India	GN
Avga nixoni Subba Rao and Sharma	L	India	GN
Bracon sp.	L	India, Thailand	GN
Bracon brevicornis Wesmael	L	India	GN
Bracon gelechiae Ashmead	L	India	GN, SB
Bracon (syn. Microbracon) hebetor (Say)	L	India	GN
Chelonus sp.	E-L	India	GN, SB
Chelonus blackburni Cameron	E-L	India	GN
Cotesia sp.	L	South Africa	GN
E-LL*Hypomicrogaster* sp.	L,P	South Africa	GN
Phanerotoma sp.	E-L	India	GN
Calcididae			
Brachymeria sp.	P	South Africa	GN
Ceraphronidae			
Aphanogmus fijiensis (Ferrie‘ re)	hyp	India	GN
Ceraphron sp.	hyp	India	GN
Chalcididae			
Brachymeria sp.	L, P	India	GN
Brachymeria lasus (Walker)	L, P	Thailand	GN
Brachymeria marmonti (Girault) (syn. *wittei* Schmitz)	L	India	GN
Brachymeria minuta (L.)	P	Thailand	GN
Brachymeria phya (Walker) (syn. *plutellophaga (Girault))*	L, P	India	GN
Kriechbaumerella sp. (syn. *Eucepsis* sp.)	P	Thailand	GN
Encyrtidae			
Copidosoma sp.	L	India	GN
Homalotylus flaminius Dalman	L	Thailand	
Eulophidae			
Baryscapus sp.	P	South Africa	GN
Elasmus sp.	L, hyp	India, Thailand	GN
Elasmus anticles Walker	hyp	India	GN
Elasmus brevicornis Gahan	L, hyp	India	SB
	hyp	India	GN
Oomyzus sp.	hyp	India	GN
Pediobius sp.	L, hyp	India	GN
Stenomesius sp.	L, hyp	India	GN
Stenomesius japonicus (Ashmead) (syn. *Stenomesioideus ashmeadi* Subba Rao and Sharma, syn. *Euryscotolinx coimbatorensis* Rohwer)	L	India, Thailand	GN, SB
Stenomesius modicellus Khan	L	India	GN

Table 2: Continue....

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Sympiesis sp.	L	India	GN
Sympiesis dolichogaster Ashmead (syn. *Asympiesiella india Girault*)	L	India, Thailand	GN
Tetrastichus sp.	L, hyp	India, Thailand	GN
Eupelmidae			
Eupelmus sp.	L, P, hyp	India	GN
Eurytomidae			
Eurytoma sp.	L	India	GN
Eupelmus (Macroneura) sp.	P	South Africa	GN
*Plutarchia girault*i Subba Rao	L	Thailand	GN
Pteromalidae *Pteromalus* sp.	L, P	South Africa	GN
Anagrus sp.3	L	India	GN
Pteromalidae			
Dibrachys sp.	L	Thailand	GN
Macromesus sp.3	L	Thailand	
Pteromalus (syn. *Habrocytus*) sp.	hyp	India	GN
Trichogrammatidae*Trichogramma* sp.	E	India	GN

Host stage parasitised as mentioned in the publications. E=egg parasitoid; E-L= Egg-larval parasitoid; L= Larval parasitoid; P= Pupal parasitoid; hyp = Mentioned at least once as hyperparasitoid. GN= Groundnut; SB= Soybean.

Table 3: Predators of GLM.

Name of the predator	Reference source
Asilidae	
Asilidae Robber flies	Srinivasan and Siva Rao, 1986
Carabidae	
Chlaenius sp. (Bonelli)	Shanower and Ranga Rao, 1990
Eumenidae	
Odynerus punctum (Fabricius)	Crop Pest Compendium, 2005
Coccinellidae	
Cheilomenes sexmaculata (Fabricius)	
Coccinella septempunctata (Linnaeus)	
Chrysopidae	
Chrysoperla carnea (Stephens)	

ladybirds (*Cheilomenes sexmaculata*) have been reported to feed on GLM (Crop Pest Compendium, 2005). However, their effects on GLM populations in Africa have yet to be thoroughly studied (Kenis and Cugala, 2006).

Parasitoids

The number of GLM parasitoids which have been recorded in different countries are listed in Table 3. Several parasitoids, particularly from the families Braconidae, Ichneumonidae, Hymenoptera, Pteromalidae, Eupelmidae, Bethylidae, Chalcididae, Eurytomidae and Trichogrammatidae are effective against GLM larvae in South Africa and India (Murugasridevi *et al.,* 2022; Van der Walt *et al.,* 2009; Shanower *et al.,* 1993a). However, more research is needed to explore their potential in Africa.

Pathogens and nematodes

Entomopathogenic fungi like *Beauveria bassiana* (Joshi and Patel, 2011) and nematodes such as *Steinernema* have been observed to attack GLM larvae (Rajagopal *et al.,* 1988). Their use as biological control agents in Africa requires further investigation.

Chemical control

There are several insecticides used to provide control for GLM. Some of these are listed in Table 4. Several chemicals previously reported as effective for controlling GLM in India, such as Dimethoate 30 EC, Monocrotophos 36 EC, Carbaryl 50 WP, Endosulfan 35 EC, Methoxyfenozide 24 SC and Profenofos, are now banned or have restricted usage in various regions. Pazhanisamy and Hariprasad (2013) evaluated newer alternatives for GLM control, whereas Pavviya and Muthukrishnan (2016) confirmed the effectiveness of Methoxyfenozide 24 SC in controlling GLM (Table 4). In Africa, cypermethrin has been effective in Mozambique and South Africa (Cugala *et al.,* 2010; Buthelezi *et al.,* 2013). However, the indiscriminate use of chemicals could lead to resistance, emphasizing the need for integrated pest management approaches.

Monitoring GLM populations using pheromones

Sex pheromones are chemicals emitted by one sex to attract the other. Sex pheromones are crucial in managing GLM, as they aid in monitoring pest activity (Ghewande and Nandagopal, 1997). Nandagopal and Reddy (1990) identified the female sex pheromone of GLM and is used in traps as a blend of three chemical components; [(Z)-7, 9-decadienyl acetate, (E)-7-decenyl acetate and (Z)-7-decenyl acetate in the ratio10:2:1.4]. This mixture has been used effectively in monitoring flight activity of GLM in India (Das, 1999; Radhika *et al.,* 2014) and South Africa (Buthelezi *et al.,* 2013; 2017).

Table 4: Chemicals used to control GLM.

Chemical	Application rate	Reference source
*Dimethoate 30 EC and	0.03% and 0.5%	Muthaiah and Hussain, 1991;
monocrotophos 36 EC	both applied at 500-700l ha^{-1}	Pavviya and Muthukrishnan, 2017.
**Carbaryl 50 WP	0.1% and 0.2%	Nataraja *et al.,* 2014.
**endosulfan 35 EC	0.05%	
**methoxyfenozide 24 SC	240ga.i./ha (4.8%/plants)	Pavviya and Muthukrishnan, 2016
**50 EC Profenofos	2 ml/L	
Spinosad 45 SC	0.3/0.1 ml/L,	
Fiubendiamide 480 SC	0.2 ml/L,	
Quinalphos 25 EC	2 ml/L	
Indoxacarb 14.5 SC	0.3 ml/l	Pazhanisamy and Hariprasad, 2013
Buprofezin 25 SC	1 ml/l	
Acephate 75 SP	1 g/l	
Thiodicarb 75 WSP	0.6 g/l	
Thiamethoxam 25 WG	0.2 g/l	Cugala *et al.,* 2010; Epieru, 2004;
Cypermethrin	2 ml/l of water	Buthelezi *et al.,* 2013.
Nano scale (Zn) coated NSKE formulation	30 g/l	Lakshminarayana *et al.,* 2018.
NSKE formulations	50 g/l	
quinalphos	2.0 ml/l	

*Banned for use on fruits and vegetables.

**Not approved for use in the European Union.

Screening groundnut and soya bean genotypes for resistance to GLM

Several groundnut breeding lines resistant to GLM have been released by ICRISAT in Hyderabad, India (Nigam, 2014). Groundnut varieties like ICGV 86031 show resistance to GLM. These genotypes could be used in breeding programs to develop more resistant groundnut lines, particularly in high-risk regions (Reddy, 2001).

In India, soya bean varieties MAUS 62-2, DS 97-12 and HIS 01 were most resistant to GLM. Groundnut leaf miner infestation recorded in these cultivars ranged from 5.2%, 6.74% and 7.44% respectively (Shirale and Uttamrao, 2010). In Uganda, a soya bean screening study revealed that three soya bean genotypes were resistant to GLM; VI046160, VI046165 and VI046167 (Ibadan *et al.,* 2018). It was proposed that these varieties could serve as parents in breeding programs aimed at developing resistance to GSLM in soya bean (Ibadan *et al.,* 2018).

Integrated pest management (IPM) methods for GLM

Integrated Pest Management (IPM) employs various methods to reduce or replace synthetic pesticides. Effective approaches to managing GLM in India include using trap crops like soya bean, pheromone traps and intercropping groundnut with suitable soya bean varieties. Additionally, timed insecticide applications at 30-35, 45-50 and 60-65 days after sowing and botanical insecticides, such as 2% crude neem oil, have proven to be effective (Nandagopal and Ghewande, 2004). Muthiah (2000) highlights other successful methods, including the use of GLM sex pheromones, *Bacillus thuringiensis* and an insecticide combination of phosphamidon (0.02%), endosulfan (0.04%) and neem oil (2%), which can be applied alone or with pheromone traps in both base and trap crops. Agurla *et al.* (2023) evaluated IPM strategy to control GLM which comprised of practices such as summer deep ploughing, soya bean as a trap crop and pheromone traps for GLM control. This strategy effectively managed the GLM, resulting in reduced pest incidence and increased yields.

Recommendations for future research

Future studies should focus on:

- Identifying GLM overwintering strategies across different agroecological zones.
- Investigating the genetic basis for host preferences in GLM populations from Australia, New Zealand, South Africa and Asia.
- Exploring indigenous biological control agents for potential use in classical or augmented biological control.
- Determining GLM infestation threshold levels for better pest management.
- Developing and screening GLM-resistant cultivars.

CONCLUSION

Managing GLM requires a combination of biological, chemical and cultural strategies, with an emphasis on IPM to reduce pesticide use. While insecticides are effective, they are often unaffordable for smallholder farmers in Africa, necessitating a shift towards more sustainable IPM approaches. Biological control agents, resistant varieties and optimized cropping systems, combined with field

monitoring and pheromone traps, are recommended for efficient GLM control.

Conflict of interest

The authors declare no conflict of interest related to the publication of this article.

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