Comparative status of insecticide resistance in the *Helicoverpa* and *Heliothis* species (Lepidoptera: Noctuidae) of south India

Deepak R. Jadhav

International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India

Nigel J. Armes

Natural Resources Institute, Chatham Maritime, UK

Abstract

Helicoverpa armigera (Hubner), *H. assulta* Guenée and *Heliothis peltigera* (Denis & Schiffermuller) were collected as mixed populations from safflower and the wild host *Datura metel*, from Patancheru Andhra Pradesh, India, in 1992 and 1993, and their toxicological responses to insecticides determined. Both *Helicoverpa armigera* strains were highly resistant to cypermethrin, fenvalerate, endosulfan and quinalphos insecticides based on resistance ratios relative to laboratory reared susceptible strains. There was no evidence of resistance development in *H. assulta* and *Heliothis peltigera* to the same chemicals. Light trap data collected from 1974 to 1987 showed that *Helicoverpa armigera* was at least 100× more abundant than the other two species over most of the cropping season. Peak catches of *H. assulta* and *Heliothis peltigera* were confined to defined times in the season, corresponding with the flowering and fruiting periods of their respective host plants: August–October for *Helicoverpa assulta* and November–December for *Heliothis peltigera*. *Helicoverpa armigera* on the other hand, because of its high polyphagy on commercial and wild hosts, was abundant between August and April. Resistance has not developed in *H. assulta* and *Heliothis peltigera* in southern India, probably because of their restricted host range, limiting exposure to insecticides.

Introduction

Heliothine moths of the family Noctuidae include some of the most damaging agricultural pests worldwide. In India, three *Heliothis* species (taken in this context to include the *Helicoverpa* species) have been recorded, viz. *Helicoverpa armigera* (Hübner), *Helicoverpa assulta* Guenée and *Heliothis peltigera* (Denis & Schiffermüller).

The highly polyphagous species *Helicoverpa armigera*, is widely distributed from southern Europe through Africa and Asia to Australasia and the South Pacific. It is the most serious pest of the three described, having been reported as feeding on over 180 host plants from 45 plant families in India alone (Manjunath *et al.*, 1989). It is a particularly important pest of cotton, legumes and tomatoes where crop losses are considerable. It commonly destroys more than half the yield with estimates of annual losses in India amounting to US$300–500 million to cotton and pulses alone (King, 1994). In recent years, it has developed resistance to certain molecules in all the established chemical groups of insecticides available to Indian farmers for bollworm control (McCaffery *et al.*, 1989; Armes *et al.*, 1992a), and field control failures are now common. Overuse of insecticides against insecticide resistant *H. armigera* has exacerbated the problem by suppressing natural enemies,

Correspondence: N.J. Armes, Crop Protection Division, ICRISAT Patancheru PO, Hyderabad, Andhra Pradesh 502 324, India

thereby allowing much larger populations to develop on field crops. It is likely that the impact of a succession of suitable host plants, insecticide resistance and natural enemy suppression has made *H. armigera* the dominant pest in cotton agro-ecosystems in the Indian subcontinent over the past ten years.

Helicoverpa assulta is found throughout Africa, Asia, parts of Australasia and the South Pacific, but unlike *H. armigera*, it is oligophagous with larvae primarily feeding on solanaceous plants. In India the principal hosts are tobacco and wild hosts in the genus *Datura* (Bhatnagar & Davies, 1978; Manjunath *et al.*, 1989). Potato has been reported as an occasional host but we could not confirm this during five years of intensive field surveys in southern India (Jadhav, unpublished data). In the Far East it is an important pest of chillies and bell peppers (*Capsicum* spp.) (Cho & Boo, 1988), but, in India, *H. armigera* is the usual species found on *Capsicum* spp. *Helicoverpa assulta* is considered to be a minor pest, but its importance may be underestimated because of the similarity of both larvae and moths to those of *H. armigera*. There are no reports of control difficulties or insecticide resistance development in this species in the Indian subcontinent. However, in South Korea, control failures on *Capsicum* crops have been attributed to insecticide resistance (Lee & Boo, 1985).

Heliothis peltigera is polyphagous with a wide geographic distribution from central and southern Europe, the Canary Islands, Asia Minor and India. In India, it has been reported on seven host plants from five families (Manjunath *et al.*, 1976, 1989). The only commercial host is safflower, *Carthamus tinctorius* (Compositae). In Israel it is a pest of ornamental and medicinal plants, safflower, tobacco, cotton, chickpea, fodder crops, grapevines and various fruit trees (Yathom, 1971; Avidov & Harpaz, 1989; Ibrahim & Fayad, 1989). There have been no published reports of insecticide resistance developing in this species.

During field collections of *Helicoverpa armigera* larvae in India over twenty years, it was quite common to come across mixed populations of *H. armigera* and *Heliothis peltigera* on safflower (Pawar *et al.*, 1985) and *Helicoverpa armigera* and *H. assulta* on tobacco, and all three species together on wild hosts in the family Solanaceae. In view of this overlapping host range and the possibility of confusing *H. armigera* with other heliothine species over much of its geographic range (e.g. Mohyuddin, 1989), this study was undertaken to determine the status of insecticide susceptibility in the three species in the southern Indian State of Andhra Pradesh. Further, we felt it was important to draw attention to the importance of correctly identifying *Heliothis* species in situations where management decisions for insecticide resistant and susceptible species may differ appreciably because of the widespread occurrence of resistance in *Helicoverpa armigera* in Asia.

Materials and methods

Insects

All species were collected as third to sixth instar larvae from host plants on the 1400 ha research farm of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), ICRISAT Asia Center, Patancheru, Andhra Pradesh, India, between November 1992 and July 1993. *Heliothis peltigera* larvae were collected randomly from fields of unsprayed safflower covering an area of approximately 1.5 ha in November 1992. Two other collections were made from the wild host, *Datura metel* (Solanaceae), in April and July 1993. In April, mixed populations of *Helicoverpa assulta* and *H. armigera* were found on *Datura*. In July all three species coexisted on *Datura*. Collections comprised at least two hundred larvae from any one host.

In the laboratory, larvae were transferred to a chickpea based semi-synthetic diet (Armes *et al.*, 1992b). Species were determined at the adult stage (see below) and laboratory cultures of each species established from at least sixty individuals. Rearing and bioassay procedures were carried out at 25 ± 2°C under natural photoperiod (*c.* 13:11 h light:dark).

Insecticides

The following technical grade insecticides were used for bioassays: *c.* 50:50 *cis*:*trans* cypermethrin (900 g/kg; Zeneca Agrochemicals, UK); fenvalerate (976 g/kg; Sumitomo Corp., Japan); endosulfan (960 g/kg; Hoechst, India); quinalphos (720 g/kg; Sandoz, India); monocrotophos (680 g/kg; Khatau Junker, India). The synergists piperonyl butoxide (pbo) and s,s,s,-tributyl phosphorotrithioate (DEF) were obtained from Goodeed Chemical Co. Ltd, UK., and Mobay Chemical Co., USA, respectively.

Bioassay

Serial dilutions of technical grade insecticides in acetone were applied topically as 1.0 µl drops to the dorsal mesothoracic region of individual F1 generation larvae weighing between 30–40 mg as described by Anon. (1970). Control larvae were treated with acetone alone. In assays including the synergists pbo and DEF, these were applied as 1.0 µl drops to the mesothorax 15-20 min prior to the insecticide, at rates of 50 µg/larva and 20 µg/larva respectively. These rates were known to be sufficiently high to cause maximal inhibition of the metabolic system without causing mortality from the synergist alone. Each treatment and control group comprised at least 48 insects. After dosing, larvae were held individually on chickpea based diet in 7.5-ml cells of 12-well tissue culture plates (Linbro, ICN Flow Ltd.). Mortality was assessed 144 h after treatment as previously described (Armes *et al.*, 1992a). Control mortality was rare but, where necessary, corrections were made using Abbott's formula (Abbott, 1925). Dose-mortality regressions were computed by Probit analysis (Finney, 1971). Significance of differences between probit lines were determined from Position χ^2 test (to determine whether relative potencies differ from unity), and Parallelism χ^2 test (to determine whether a common slope is adequate). Heterogeneity χ^2 tests were performed on all probit lines to determine whether or not residual variation was consistent with binomial sampling (Ross, 1987).

Light traps

Two, or more usually three, Robinson pattern UV light traps were operated continuously on the ICRISAT Asia Center (IAC) farm between August 1974 and May 1987. Catches were sorted daily and the major pest species identified and counted. The identification of *Helicoverpa*

Table 1. Log dose probit parameters for topically applied insecticides either alone or in combination with synergists, to 30–40 mg *Helicoverpa armigera* larvae for two strains collected from the ICRISAT farm in 1993.

Insecticide treatment	n	LD_{50} (95% C.I.)	LD_{90}	Slope ± SE	χ^{2a}
Collection date: April 1993; Host plant: *Datura*					
Cypermethrin	432	1.4 (1.0–1.8)	19	1.1 ± 0.1	NS
Cypermethrin + Pbo	336	0.13 (0.10–0.16)	0.57	2.0 ± 0.2	NS
Fenvalerate	432	1.4 (1.0–1.8)	16	1.2 ± 0.1	*
Fenvalerate + Pbo	288	0.090 (0.08–0.11)	0.25	2.9 ± 0.3	NS
Endosulfan	384	10.0 (7.3–13)	135	1.1 ± 0.1	NS
Quinalphos	336	0.66 (0.51–0.82)	3.5	1.8 ± 0.2	*
Monocrotophos	432	1.8 (1.2–2.6)	46	0.9 ± 0.1	NS
Collection date: July 1993; Host plant: *Datura*					
Cypermethrin	288	0.28 (0.21–0.37)	2.4	1.4 ± 0.2	NS
Cypermethrin + Pbo	255	0.070 (0.05–0.09)	0.39	1.7 ± 0.2	NS
Fenvalerate	224	0.93 (0.65–1.4)	10	1.2 ± 0.2	NS
Fenvalerate + Pbo	240	0.028 (0.02–0.04)	0.16	1.7 ± 0.3	NS
Endosulfan	279	3.0 (2.4–3.8)	15	1.9 ± 0.2	NS
Quinalphos	312	0.29 (0.24–0.37)	1.7	1.7 ± 0.2	NS
Quinalphos + DEF	336	0.10 (0.07–0.12)	0.76	1.4 ± 0.1	NS
Monocrotophos	404	0.66 (0.49–0.84)	6.2	1.3 ± 0.2	NS
Monocrotophos + DEF	254	0.76 (0.48–1.1)	11	1.1 ± 0.2	NS

[a]Heterogeneity Chi-square test; NS = not significant, * = $P < 0.05$.

armigera, *H. assulta* and *Heliothis peltigera* was checked against type specimens lodged in the IAC insect collection. the identities of which had been confirmed by the Commonwealth Institute of Entomology, UK., identification service and by D.F. Hardwick (formerly of the Biosystematics Research Institute, Ottawa, Canada).

Results

Helicoverpa armigera *bioassays*

LD_{50}'s for the pyrethroid insecticides were very high and variable between strains; with 5 and 1.5-fold differences in cypermethrin and fenvalerate toxicities respectively between the April and July collections (Position χ^2, $P < 0.001$) (table 1). Slopes were low (range: 1.1–1.4) compared to log dose probit (ldp) statistics for the other two species and for insecticide susceptible *H. armigera* (Armes *et al.*, 1992a). Pbo significantly synergized both cypermethrin and fenvalerate, recording synergist ratios of 4- to 11- and 19- to 33-fold respectively (Position χ^2s, $P < 0.001$).

Similarly, values for endosulfan, quinalphos and monocrotophos LD_{50}s were significantly higher in April compared to July (Position χ^2s, $P < 0.01$). High LD_{50}s and relatively low slopes indicate that both *H. armigera* strains were resistant to endosulfan and the two organophosphate insecticides. DEF significantly synergized quinalphos (Position χ^2, $P < 0.01$) but not monocrotophos (Position χ^2, $P > 0.05$).

Table 2. Log dose probit parameters for topically applied insecticides either alone or in combination with synergists, to 30–40 mg *Helicoverpa assulta* larvae for two strains collected from the ICRISAT farm in 1993.

Insecticide treatment	n	LD_{50} (95% C.I.)	LD_{90}	Slope ± SE	χ^{2a}
Collection date: April 1993; Host plant: *Datura*					
Cypermethrin	336	0.009 (0.006–0.010)	0.045	1.8 ± 0.2	NS
Cypermethrin + Pbo	336	0.010 (0.008–0.01)	0.029	2.7 ± 0.3	NS
Fenvalerate	240	0.021 (0.02–0.02)	0.054	3.1 ± 0.3	NS
Fenvalerate + Pbo	240	0.023 (0.02–0.03)	0.062	3.0 ± 0.4	NS
Collection date: July 1993; Host plant: *Datura*					
Cypermethrin	336	0.006 (0.005–0.007)	0.020	2.4 ± 0.2	NS
Cypermethrin + Pbo	295	0.005 (0.004–0.005)	0.014	2.6 ± 0.3	*
Fenvalerate	269	0.013 (0.01–0.02)	0.049	2.2 ± 0.3	NS
Fenvalerate + Pbo	231	0.018 (0.01–0.02)	0.062	2.3 ± 0.3	NS
Endolsulfan	240	0.93 (0.77–1.1)	3.3	2.3 ± 0.3	NS
Quinalphos	240	0.067 (0.05–0.08)	0.26	2.2 ± 0.3	NS
Quinalphos + DEF	240	0.027 (0.02–0.03)	0.13	1.9 ± 0.3	NS
Monocrotophos	329	0.22 (0.17–0.27)	1.1	1.8 ± 0.2	NS
Monocrotophos + DEF	233	0.28 (0.22–0.36)	1.7	1.7 ± 0.2	NS

[a]Heterogeneity Chi-square test; NS = not significant; * = $P < 0.05$.

combination with synergists, to 30–40 mg *Heliothis peltigera* larvae for two strains collected from the ICRISAT farm in 1992 and 1993.

Insecticide treatment	n	LD_{50} (95% C.I.)	LD_{90}	Slope ± SE	χ^{2a}
Collection date: November 1992; Host plant: Safflower					
Cypermethrin	299	0.007 (0.006–0.008)	0.017	3.4 ± 0.4	NS
Cypermethrin + Pbo	299	0.007 (0.006–0.009)	0.035	1.9 ± 0.2	NS
Fenvalerate	288	0.022 (0.02–0.03)	0.052	3.3 ± 0.3	NS
Fenvalerate + Pbo	240	0.058 (0.05–0.07)	0.11	4.4 ± 0.5	NS
Endosulfan	246	3.6 (3.1–4.2)	9.0	3.2 ± 0.3	NS
Quinalphos	235	0.035 (0.03–0.04)	0.065	4.9 ± 0.7	NS
Monocrotophos	228	0.49 (0.35–0.63)	2.8	1.7 ± 0.3	NS
Collection date: July 1993; Host plant: *Datura*					
Cypermethrin	256	0.008 (0.006–0.01)	0.029	2.2 ± 0.3	NS
Cypermethrin + Pbo	240	0.012 (0.01–0.01)	0.032	3.0 ± 0.4	NS
Fenvalerate	232	0.027 (0.02–0.03)	0.067	3.3 ± 0.4	NS
Fenvalerate + Pbo	240	0.051 (0.04–0.06)	0.12	3.3 ± 0.4	NS
Endosulfan	240	2.1 (1.8–2.6)	6.5	2.7 ± 0.3	NS
Quinalphos	240	0.046 (0.04–0.05)	0.11	3.4 ± 0.5	NS
Quinalphos + DEF	272	0.040 (0.03–0.05)	0.15	2.2 ± 0.3	NS
Monocrotophos	303	0.76 (0.65–0.90)	3.9	1.8 ± 0.2	NS
Monocrotophos + DEF	328	0.54 (0.42–0.69)	3.8	1.5 ± 0.2	NS

[a]Heterogeneity Chi-square test; NS=not significant.

Helicoverpa assulta *bioassays*

Both the April 1993 and July 1993 strains collected from *Datura* were fully susceptible to the two test pyrethroids (table 2). Less than one-fold variation in LD_{50}s was recorded between the two strains when assayed with cypermethrin, and differences in probit parameters were only marginally significant (Position and Parallelism χ^2s, $P < 0.05$). No significant heterogeneity was recorded (χ^2, $P > 0.05$), and slopes at 1.8 and 2.4 were moderately high. For fenvalerate, inter-strain variation was slightly higher, with a 1.6-fold variation in LD_{50}s and significant differences in position and parallelism of ldp lines (χ^2s, $P < 0.001$ and $P < 0.05$ respectively). Slopes at 2.2 and 3.1 were high and the test populations were homogeneous with respect to fenvalerate susceptibility (Heterogeneity χ^2, $P > 0.05$). Pre-treatment with pbo did not synergize either cypermethrin or fenvalerate toxicity (Position χ^2, $P > 0.05$).

Only one strain was assayed with endosulfan, quinalphos and monocrotophos. The relatively steep ldp slopes, low LD_{50}s (in relation to the other two species), and lack of heterogeneity (χ^2, $P > 0.05$) indicated that this strain was susceptible to endosulfan and both organophosphate insecticides. Pre-treatment with DEF resulted in a low level (2.5-fold), but significant (Position χ^2, $P < 0.001$), synergism of quinalphos. Monocrotophos was not synergized by DEF (Position χ^2, $P > 0.05$).

Heliothis peltigera *bioassays*

Ldp parameters were indicative of full susceptibility to the two test pyrethroid insecticides (table 3). Neither cypermethrin nor fenvalerate recorded major inter-strain differences in toxicity between the November 1992 and July 1993 collections (Position χ^2, $P > 0.05$). Slopes were high, ranging from 2.2–3.4. In general, pbo acted as a significant pyrethroid inhibitor, decreasing the toxicity of cypermethrin and fenvalerate by 1- to 1.5-fold and 2- to 3-fold respectively (except for cypermethrin in 1992 where Position χ^2 was not significant, in all other cases χ^2, $P < 0.001$).

Endosulfan LD_{50}s at 2.1–3.6 µg/larva were surprisingly high, but steep ldp slopes (2.7–3.2) and lack of heterogeneity (Heterogeneity χ^2, $P > 0.05$), suggest that these data are indicative of the baseline susceptibility response for this species.

Tolerance to quinalphos and monocrotophos were 1.3- and 1.6-fold higher respectively in 1993 compared to 1992 (Position χ^2, $P < 0.01$). However, as there was no indication from the ldp lines of segregation of phenotypes and slopes were reasonably high (more so for quinalphos), there is no reason to assume that these data do not fall in the normal susceptible range. DEF did not significantly synergize quinalphos (Position χ^2, $P > 0.05$), but did cause a very low, 1.4-fold synergism of monocrotophos (Position χ^2, $P < 0.05$).

Light traps

Trap catches are given as mean numbers of moths per trap per month (fig. 1). *Helicoverpa armigera* was by far the most abundant of the three species. On average, trap catches were one hundred times greater than those of *H. assulta* and *Heliothis peltigera*. Averaging the thirteen years trap data showed that there were two distinct peaks of *Helicoverpa armigera* moth activity on the IAC farm each season. The first, smaller peak in September (av. 840 moths/trap/month) was associated with moths emerging from infestations on wild hosts which grew prolifically on the farm with the onset of the monsoon rains in June, and from early sown sorghum crops. The second, much larger peak in November to December (av. 1500–2300 moths/month), was attributed to moth emergence from medium and late duration pigeonpea cultivars which were major crops grown on the IAC farm during the years that the light traps were operated. Low catches (90–320 moths/month), between January and May were associated with moths emerging from chickpea,

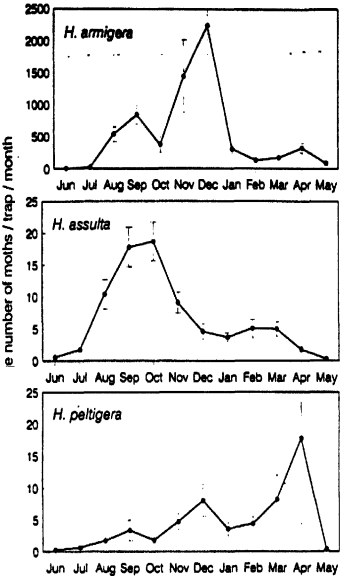

Fig. 1. Average monthly catches of *Helicoverpa armigera*, *H. assulta* and *Heliothis peltigera* in light traps at the ICRISAT farm, Hyderabad, from 1974–1987. Error bars represent standard errors.

groundnut and wild hosts. The lowest catches (< 7 moths/trap), occurred in June because of the dearth of locally available larval host plants on and around the IAC farm during the hot summer months of April and May.

Helicoverpa assulta catches were highest between August and November, peaking (av. 18–19 moths/trap/month) in September and October. It is likely that the abundance of *H. assulta* at this time was due to moths emerging from infestations on *Datura* between July and September. This host is present throughout the season, but peak growth and flowering occurs during the rainy season from July to September.

Heliothis peltigera catches were low throughout most of the year, only exceeding five moths/trap/month from December to April. The largest moth catches coincided with the vegetative and flowering periods of safflower crops from November to March and with the prescence of the wild host *Acanthospermum hispidum* (star burr), growing in irrigated groundnut fields on alfisols in February to March. *H. peltigera* catches were low during the rainy season (June to October), because larvae are highly parasitized by mermithid nematodes during this period. Bhatnagar *et al.* (1985) recorded up to 90% parasitism of *H. peltigera* by mermithids on short stature hosts, such as *A. hispidum* growing on well drained alfisols, between June and September in the late 1970s. We have recorded similar parasitism levels in the early 1990s (Jadhav, unpublished data). By late October to early November, mermithid parasitism becomes insignificant because the nematodes are inactive during the dry post-rainy season (Bhatnagar *et al.*, 1985).

Discussion

The high LD_{50} and LD_{90} values coupled with relatively low slopes for *Helicoverpa armigera* assayed against endosulfan and selected pyrethroid and organophosphate and insecticides, indicate that this species is resistant to endosulfan and at least some members of the pyrethroid and organophosphate groups in the Hyderabad region, as reported earlier by McCaffery *et al.* (1989) and Armes *et al.* (1992a). Baseline susceptible strain responses determined previously in our laboratory (Armes *et al.*, 1992a and Armes, unpublished data), show that resistance levels to cypermethrin, endosulfan and quinalphos in the April 1993 strain were of the order of 140-, 17- and 11-fold respectively, and 28-, 5- and 5-fold respectively for the July 1993 strain. The higher resistance levels recorded in the April strain compared to the July strain were expected, as larvae collected at the end of the cropping season (March to April), are the progeny of five to six generations that have been exposed to insecticide selection during the previous nine to ten months (Armes *et al.*, in press). As *H. armigera* populations are much reduced in density during the April to May summer period, as most crops have been harvested by this time, the net result is less insecticide being targeted against *H. armigera*. This reduced selection allows some reversion toward susceptibility between April and July each year.

The low LD values and relatively high ldp slopes recorded for *H. assulta* show that there was no sign of resistance having developed to any of the chemical groups tested on this species. Further, the lack of synergism, of pyrethroids with pbo and monocrotophos with DEF, indicates that metabolic insecticide detoxification mechanisms were not significant. The 2.5-fold synergism of quinalphos by DEF is sufficiently low to be indicative of the normal susceptible range. The lack of resistance in this species is not surprising because the only commercial host of *H. assulta* in India is tobacco. As it only feeds on the inflorescence and there is no leaf damage, it is therefore not considered an economic pest and consequently not subject to insecticide application. It is unlikely therefore that this species is subject to significant insecticide selection in India. This differs from some south-east Asian countries where *H. assulta* is a pest of *Capsicum* spp., and is frequently sprayed with all groups of commercially available insecticides; in South Korea for example, poor control of *H. assulta* has been attributed to the development of insecticide resistance (Lee & Boo, 1985).

The ldp data for *Heliothis peltigera* were indicative of full susceptibility to pyrethroid, endosulfan and organophosphate insecticides in 1992 and 1993. The low toxicity of endosulfan was not expected (2–3 times less than against susceptible *Helicoverpa armigera* (Armes *et al.*, 1992a)). Innate tolerance to this chemical, rather than resistance *per se* is suspected. Despite the high toxicity of both cypermethrin and fenvalerate and the steep slopes indicative of susceptibility, pbo acted as a significant (up to 3-fold) pyrethroid inhibitor in both strains. Whether or not this was due to pbo facilitating penetration of the insecticide through the cuticle

(Sun & Johnston, 1972), or to it inhibiting metabolic detoxification of the pyrethroid is not known. *Heliothis peltigera* has most probably remained susceptible to insecticides because the only commercial host where it may be subject to insecticide selection pressure is safflower. Usually this crop is unsprayed, but when *Helicoverpa armigera* and/or *Heliothis peltigera* populations are sufficiently high to cause economic damage, 1–3 sprays may be applied.

The ldp results for both *Helicoverpa assulta* and *Heliothis peltigera* provide important baseline toxicity data which can be used as standards against which future changes in susceptibility in these species in the Indian subcontinent, and to some degree elsewhere in Asia, can be compared.

Helicoverpa armigera has become resistant to insecticides because of its wide crop host range within agro-ecosystems and particularly high abundance on high value commercial crops where insecticides are extensively used (Reynolds & Armes, 1994). On the other hand, *H. assulta* and *Heliothis peltigera* are far less common species, and it is likely that their populations are moderated on wild hosts by natural enemies. Their very minor pest status on only one commercial crop each, means that they are not subject to intense insecticide selection pressure. This is not to say that the importance of these two species may not change in the future as cropping practices alter. For example, safflower production is increasing as the demand for polyunsaturated oils increases. In the major safflower producing state of Maharashtra, the area planted to safflower had increased from 494,000 ha in 1981–82 to 628,000 ha in 1989–90 (Anon., 1993). Escalating market prices for edible oils will induce farmers to grow larger areas and attempt to maximize yields by applying insecticides. If such a scenario does occur the pest status of *H. peltigera* could well change. *Helicoverpa armigera* is a case in point: less than twenty years ago it was not a significant pest on cotton in most seasons (e.g. Agarwal & Gupta, 1983), but is now the major pest on this crop throughout the Indian subcontinent. Increasing dependence on insecticides for cotton pest control, possibly also coupled with changes in cotton cultivars since the early 1970s, brought about a marked change in the cotton pest complex. Pest species such as *Spodoptera litura* (Fabricius) and *Earias* spp. (Lepidoptera: Noctuidae) are now minor pests, having largely been displaced by *H. armigera* in South India and a combination of *H. armigera* and *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae) in the North (Reed & Pawar, 1982; Anon., 1989).

Insecticide resistance management strategies for cotton pests are being developed in a number of countries in the Indian subcontinent and resistance monitoring has become an important component of these strategies, particularly in India (Armes *et al.*, 1994, in press) and Pakistan (Denholm, 1993). Clearly it is important to ensure correct species identification as management strategies for resistant and susceptible populations may differ appreciably (e.g. Dowling, 1993). Further, if mixed species samples are bioassayed inadvertently, this will significantly affect resistance frequency estimates in a discriminating dose monitoring programme or give misleading ldp assay results. At present the *Heliothis* species complex in the Indian subcontinent is not well understood. In Pakistan for example, *Helicoverpa armigera* and *H. assulta* are known to exist, but the two species are frequently confused, and the relative importance of the two species on field crops has not been documented (Mohyuddin, 1989; M. Cahill, personal communication). *Heliothis peltigera* has not been reported from Pakistan, but in view of its distribution across Asia Minor and India, is likely to be present. In India, there are published reports of *Helicoverpa assulta* and *Heliothis peltigera* on cotton and pigeonpea (*Cajanus cajan*) (Bilapate, 1984). However, in our intensive surveys of *Heliothis* on field crops in central and southern India over twenty years, we have never found either species on these hosts. It is likely that species determination is often incorrectly made on the basis of larval coloration without checking the taxonomic characters of the larvae or adults (Hardwick, 1965; Matthews, 1991). It is hoped that this paper may stimulate further studies on the distribution, host plant dynamics and resistance status of the *Heliothis* complex in the subcontinent.

Acknowledgements

Financial support was provided by the Natural Resources Institute, UK, through an Adaptive Research Initiative of the UK government's Overseas Development Administration. We thank K.V.S. Satyanaryana and M. Satyanaryana of ICRISAT's Crop Protection Division for technical assistance. Submitted as ICRISAT [redacted]

References

Abbott, W.S. (1925) A method for computing the effectiveness of an insecticide. *Journal of Economic Entomology* **18**, 265–267.

Agarwal, R.A. & Gupta, G.P. (1983) Insect pests of fibre crops. pp. 147–164 *in* Srivastava, P.D., Jotwani, M.G., Agarwal, R.A., Wadhi, S.R., Bhanotar, R.K. & Bhatnagar, R.K. (*Eds.*) *Agricultural Entomology Vol. 2.* New Delhi, India, All India Science Writer's Society.

Anon. (1970) Standard method for the detection of insecticide resistance in *Heliothis zea* (Boddie) and *H. virescens* (F.). *Bulletin of the Entomological Society of America* **16**, 147–153.

Anon. (1989) Management of whitefly, *Bemisia tabaci* G. on cotton. *Technical Bulletin No. 11.* Andhra Pradesh Agricultural University, Rajendranagar, Hyderabad, India.

Anon. (1993) Indian Agricultural Statistics 1985–86 to 1989–90. Issue 37, Vol. I. Directorate of Economics and Statistics, New Delhi.

Armes, N.J., Jadhav, D.R., Bond, G.S. & King, A.B.S. (1992a) Insecticide resistance in *Helicoverpa armigera* in South India. *Pesticide Science* **34**, 355–364.

Armes, N.J., Bond, G.S. & Cooter, R.J. (1992b) The laboratory culture and development of *Helicoverpa armigera*. *Natural Resources Institute Bulletin* **57**, Chatham, UK, Natural Resources Institute.

Armes, N.J., Banerjee, S.K., DeSouza, K.R., Jadhav, D.R., King, A.B.S., Kranthi, K.R., Regupathy, A., Surulivelu, T. & Venugopal Rao, N. (1994) Insecticide resistance in *Helicoverpa armigera* in India: recent developments. pp. 437–442 *in Brighton Crop Protection Conference – Pests and Diseases* 1994.

Armes, N.J., Jadhav, D.R. & Lonergan, P.A. (in press) Insecticide resistance in *Helicoverpa armigera* (Hübner): status and prospects for its management in India. *Proceedings of the World Cotton Research Conference – 1, 13–17 February* 1994, Brisbane, Australia.

Avidov, Z. & Harpaz, I. (1969) *Plant Pests of Israel.* Jerusalem, Israel University Press.

Bhatnagar, V.S. & Davies, J.C. (1978) Factors affecting populations of gram pod borer, *Heliothis armigera* (Hübner) (Lepidoptera, Noctuidae) in the period 1974–77 at Patancheru, India. *Bulletin of Entomology* **19**, 52–64.

Bhatnagar, V.S., Pawar, C.S., Jadhav, D.R. & Davies, J.C. (1985) Mermithid nematodes as parasites of *Heliothis* spp. and other crop pests in Andhra Pradesh, India. *Proceedings of the Indian Academy of Sciences (Animal Sciences)* **94**, 509–515.

Bilapate, G.G. (1984) *Heliothis* complex in India – a review. *Agricultural Review* **5**, 13–26.

Cho, J.R. & Boo, K.S. (1988) Behavior and circadian rhythm of emergence, copulation and oviposition in the Oriental tobacco budworm, *Heliothis assulta* Guenee. *Korean Journal of Applied Entomology* **27**, 103–110.

Denholm, I. (1993) ICP/JBL Insecticide resistance monitoring project in Pakistan. Unpublished consultant's report to the Insecticide Resistance Action Committee. Rothamsted Experimental Station, UK.

Dowling, D. (1993) New resistance strategy to hinge on *Heliothis* identification test. *The Australian Cotton Grower* **14**, 14–15.

Finney, D.J. (1971) *Probit analysis* (2nd edn). Cambridge, Cambridge University Press.

Hardwick, D.F. (1965) The corn earworm complex. *Memoirs of the Entomological Society of Canada* No. 40.

Ibrahim, A.A.-El-Hamid & Fayad, Y.H. (1989) Distribution and economic importance of *Heliothis* spp., their natural enemies, and host plants in Egypt. pp. 174–176 *in* King, E.G. & Jackson, R.D. (*Eds.*) *Proceedings of the Workshop on Biological Control of* Heliothis: *Increasing the Effectiveness of Natural Enemies. 11–15 Nov. 1985, New Delhi, India*. New Delhi, FERRO, USDA.

King, A.B.S. (1994) *Heliothis/Helicoverpa* (Lepidoptera: Noctuidae). pp. 39–106 *in*, Matthews, G.A. & Tunstall, J.P. (*Eds.*) *Insect pests of cotton*. Wallingford, UK, CAB International.

Lee, K. & Boo, K.S. (1985) Studies on biology and control program of the oriental tobacco budworm, *Heliothis assulta*, with insect growth regulators and sex pheromone. II. Effects of an insect growth regulator, diflubenzuron, on embryonic and postembryonic development. *Agricultural Research Seoul National University* **10**, Suppl. 1, 27–34.

Manjunath, T.M., Patel, R.C. & Yadav, D.N. (1976) Observations on *Heliothis peltigera* (Schiff.) (Lep., Noctuidae) and its natural enemies in Anand (Gujurat State, India). *Proceedings of the Indian Acadamy of Sciences* **83**, 55–65.

Manjunath, T.M., Bhatnagar, V.S., Pawar, C.S. & Sithanantham, S. (1989) Economic importance of *Heliothis* spp. in India and an assessment of their natural enemies and host plants. pp. 197–228 *in* King, E.G. & Jackson, R.D. (*Eds.*) *Proceedings of the Workshop on Biological Control of* Heliothis: *Increasing the Effectiveness of Natural Enemies. 11–15 Nov. 1985, New Delhi, India*. New Delhi, FERRO, USDA.

Matthews, M. (1991) Classification of the Heliothinae. *Natural Resources Institute Bulletin* **44**, Chatham, UK, Natural Resources Institute.

McCaffery, A.R., King, A.B.S., Walker, A.J. & El-Nayir, H. (1989) Resistance to synthetic pyrethroids in the bollworm, *Heliothis armigera* from Andhra Pradesh, India. *Pesticide Science* **27**, 65–76.

Mohyuddin, A.I. (1989) Distribution and economic importance of *Heliothis* spp. in Pakistan and their natural enemies and host plants. pp. 229–240 *in* King, E.G. & Jackson, R.D. (*Eds.*) *Proceedings of the Workshop on Biological Control of* Heliothis: *Increasing the Effectiveness of Natural Enemies. 11–15 Nov. 1985, New Delhi, India*. New Delhi, FERRO, USDA.

Pawar, C.S., Bhatnagar, V.S. & Jadhav, D.R. (1985) *Heliothis* species and their larval parasitoids on sole and intercrop safflower in India. *Insect Science and its Application* **6**, 701–704.

Reed, W. & Pawar, C.S. (1982) *Heliothis*: a global problem. pp. 9–14 in: *Proceedings of the International Workshop on Heliothis management, 15–20 November 1981*. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India.

Reynolds, D. & Armes, N. (1994) When insecticides fail: the case of the cotton bollworm in India. pp. 39–42 in *World Agriculture* 1994. London, Sterling Publications.

Ross, G.J.S. (1987) *MLP Maximum likelihood program*. The Numerical Algorithms Group, Rothamsted Experimental Station, UK.

Sun, Y.P. & Johnston, E.R. (1972) Quasi-synergism and penetration of insecticides. *Journal of Economic Entomology* **65**, 349–353.

Yathom, S. (1971) Distribution and flight period of Heliothidinae species in Israel in 1959–1969. *Israel Journal of Agricultural Research* **21**, 51–61.

(Accepted 16 January 1996)