



Insecticide resistance in *Helicoverpa armigera* (Hübner): status and prospects for its management in India

N.J. Armes¹, D.R. Jadhav² and P.A. Lonergan³

¹Natural Resources Institute, Chatham Maritime, Kent, UK

²International Crops Research Institute for the Semi-Arid Tropics, Hyderabad, INDIA

³c/o Insecticide Resistance Action Committee of Groupement International des Associations Nationales de Fabricants de Produits Agrochimiques, Brussels, BELGIUM

ABSTRACT

Insecticide resistance and concomitant field failures to control the cotton bollworm, *Helicoverpa armigera* (Hübner), were first recorded in south India in 1987. During the 1992–93 cropping season a discriminating dose technique was used to routinely monitor resistance in four major cotton- and pulse-growing areas of Andhra Pradesh State. Very high levels of resistance to pyrethroids, and significant endosulfan and organophosphate resistance were a feature of all regions monitored. The intensity of expression was determined by local selection pressure and mixing of populations by windborne migration against a changing background of insecticide use across seasons. Levels of piperonyl butoxide-insensitive pyrethroid resistance were higher in the more intensive insecticide-use regions. Farmers are applying more frequent and higher doses of insecticides, often as mixtures, in an attempt to control implementation of insecticide-resistance management (IRM) rationale, resulting in greater control over the use of insecticides, is urgently needed to reduce the resistance selection pressure on conventional insecticides and to conserve susceptibility to newer insecticides and biorationals with novel modes of action. Constraints and prospects for IRM implementation in India are discussed.

Introduction

Insecticide-resistant cotton bollworm, *Helicoverpa* (= *Heliothis*) *armigera* (Hübner), populations were first reported in India in September 1987, when farmers in the coastal districts of Andhra Pradesh were unable to control the very high populations of *H. armigera* on their cotton crops with conventional insecticides. Many farmers applied over 30 insecticide sprays but were unable to contain the pest. Later in the season, pigeonpea and chickpea crops were also badly attacked and insecticides were mostly ineffective against *H. armigera*, even in inland regions 200–300 km remote from the coastal cotton belt (Sawicki, 1989). High levels of resistance to the synthetic pyrethroids were subsequently confirmed by Dhingra *et al.* (1988) and McCaffery *et al.* (1989) as a major cause of control failures. In economic terms, resistant *H. armigera* caused an estimated loss of 15% of the total 1987–88 season income of Andhra Pradesh State, equivalent to some US\$150 million (Kishor, 1992).

In human terms, more than 20 farmers committed suicide in the major Andhra Pradesh cotton growing districts of Guntur, Krishna and Prakasam during 1987–88 because of financial difficulties arising from loss of income and inability to repay agricultural loans. Since 1988, cotton farmers have largely been coping with poor control of *H. armigera* by applying insecticide more frequently, generally at higher than recommended rates, and as mixtures of 2–4 insecticides. Spray failures have become a way of life and casual labour is employed to 'hand-pick' large larvae. Recent resistance monitoring has shown that pyrethroid resistance is now widespread in south and central India and appreciable levels of cyclodiene, organophosphate and carbamate resistance are present in many regions (Armes *et al.*, 1992; Armes, unpublished data).

Fortunately, there has not been a recurrence of the disastrous situation of the 1987–88 and 1988–89 seasons, when severe *H. armigera* attack coupled with drought provided little

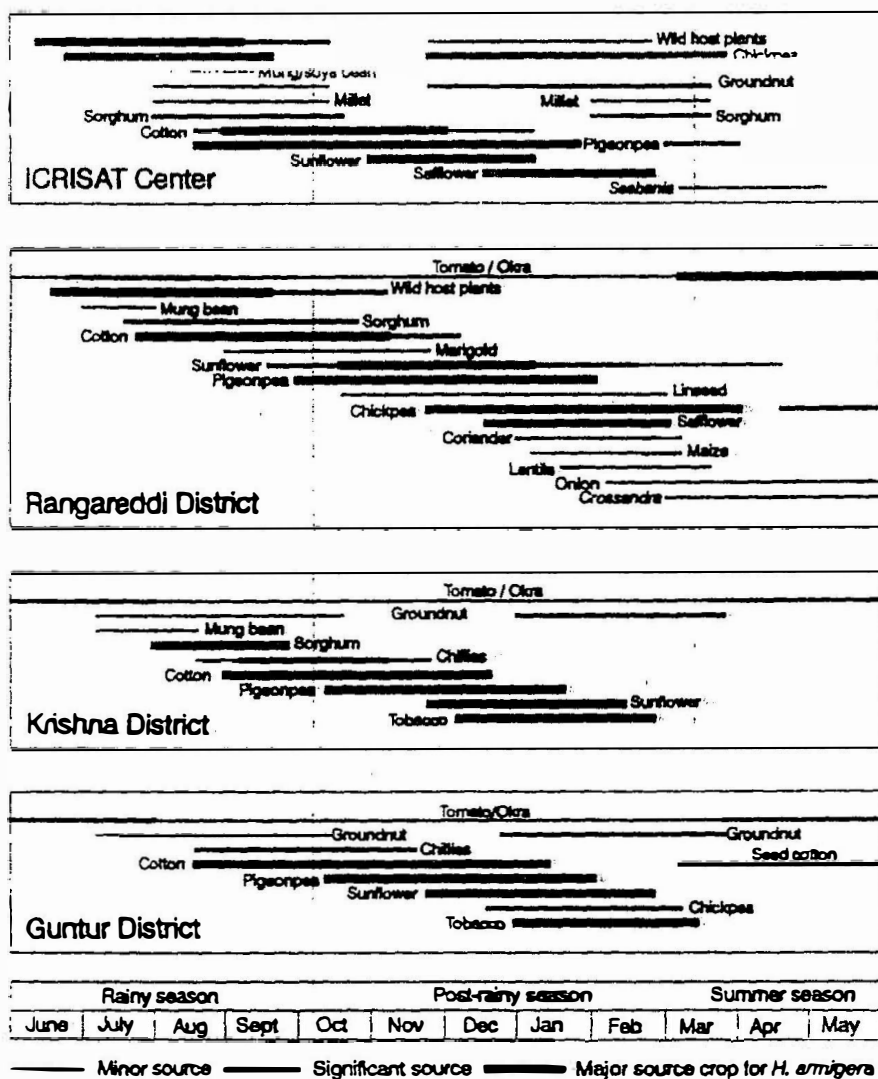


Fig. 2. Host plant profiles showing approximate timings of plant susceptibility to *H. armigera* infestation at the four monitoring locations during the 1992-93 cropping season.

The resulting 3rd-4th instar larvae in the weight range 30-40 mg, were randomly assigned to one of the following discriminating dose screens (these five or six treatments were undertaken weekly unless egg numbers were low):

- Cypermethrin 0.1 µg/µL: Approximate LD₉₉ for homozygous pyrethroid-susceptible *H. armigera* from Australia (Gunning *et al.*, 1984) and the Sudan (Armes *et al.*, 1992).
- Cypermethrin 1.0 µg/µL: Precise kill of heterozygotes or homozygotes is unknown, but this dose was introduced as a 'twin' cypermethrin dose because of the very high survival at the 0.1 g discriminating dose.
- Cypermethrin 0.1 µg + Pbo 50.0 µg/µL: The amount of suppression of cypermethrin resistance by piperonyl butoxide (Pbo) is an indicator of the significance of metabolic detoxification in pyrethroid resistance.
- Fenvalerate 0.2 µg/µL: LD₉₉ for pyrethroid-susceptible *H. armigera* calibrated in Australia (Forrester and Cahill, 1987).
- Endosulfan 10.0 µg/µL: Approximate LD₉₉ for endosulfan-susceptible *H. armigera* calibrated in Australia (Forrester *et al.*, 1993).

- Quinalphos 0.75 µg/µL: LD₉₉ for homozygous organophosphate susceptible *H. armigera* calibrated against a laboratory susceptible strain maintained in the UK (Armes *et al.*, 1992), and recently confirmed against OP-susceptible field strains from Nepal (Armes, unpublished data).

One microlitre of insecticide solution (technical insecticide dissolved in acetone at the required discriminating dose), was applied to the thoracic dorsum of larvae with a Hamilton repeating dispenser. End point mortality was assessed at six days after treatment. A larva was considered dead if it was unable to move in a co-ordinated manner when prodded. Periodically, control groups of larvae were dosed with 1.0 µL of acetone alone. No control mortality was observed throughout the season (egg-larval parasitoids were found in some larvae after dosing, but these could easily be distinguished and were removed from the assay prior to final mortality assessment). All rearing and insecticide assays were conducted at 25±2°C under natural photoperiod (approximately 12 h light:12 h dark).

Table 1. Average resistance frequencies to cypermethrin and cypermethrin + piperonyl butoxide and percentage of cypermethrin resistance suppressible by Pbo in *H. armigera* collected in coincident weeks at the four sampling locations during the 1992–93 cropping season

	ICRISAT (%)	Krishna (%)	Guntur (%)
First analysis: Five coincident weeks data between mid-October and late November 1993 for three sampling locations			
Average survival at cypermethrin 0.1 mg discriminating dose	91.3	94.7	96.4
Average survival at cypermethrin 0.1 mg + Pbo 50 µg discriminating dose	49.9	66.6	72.7
Average suppression of cypermethrin resistance by Pbo	45.3	29.7	24.6
	ICRISAT (%)	Rangareddi (%)	Guntur (%)
Second analysis: Eight coincident weeks data between mid-September 1992 and mid-January 1993 for three sampling locations			
Average survival at cypermethrin 0.1 µg discriminating dose	87.6	90.1	95.4
Average survival at cypermethrin 0.1 mg + Pbo 50 µg discriminating dose	53.8	57.6	72.5
Average suppression of cypermethrin resistance by Pbo	38.6	36.1	24.0

Pyrethroid resistance

Cypermethrin 0.1 µg (Fig. 4)

At ICRISAT Centre, early season pyrethroid resistance in populations from unsprayed wild hosts from June to August was prevalent with 70–80% survival of individuals at the discriminating dose. Resistance frequencies rose steadily over the cropping season, reaching 100% by mid-November. The situations in Rangareddi and Krishna Districts were similar; pyrethroid resistance was already prevalent (80% survival) at the start of the respective cropping seasons in early August and September. Over 90% survival was attained by mid-November and remained more or less at this level for the remainder of the cropping season. Guntur District showed the most severe resistance levels at this discriminating dose. Early season resistance frequencies in September were over 80%, and 100% levels were attained by mid-October for the remainder of the season.

Cypermethrin 0.1 µg + Pbo 50 µg (Fig. 4)

At ICRISAT Centre, frequencies of cypermethrin + Pbo resistant phenotypes increased steadily over the cropping season from August (at a low of 29% survival) to February (peak of 91% survival). The slight decrease in resistance frequencies between mid-July and late August (29–41% survival), most probably occurred because the major *H. armigera* hosts at the start of the rainy season in June–July are wild plants, where no insecticide selection is operating. By early August, local farmers started applying insecticides to field crops and this correlates with a steady rise in frequency of Pbo insensitive resistance from early September on. In Rangareddi District, Pbo suppression was less, with resistance frequencies ranging from 52 to 80%. Samples from Krishna District were only sufficiently large during the October–November period to assay for Pbo suppression. Over the 7 week period, Pbo-insensitive resistance frequencies ranged from 36 to 73%. Of the four locations, Guntur District samples exhibited the least Pbo suppression.

Resistance frequencies increased steadily over the cropping season from 46% in September to 92% by January. The data clearly indicate that the frequencies of Pbo-insensitive pyrethroid resistance are higher in the more intensive insecticide use districts of Krishna and Guntur and this is concomitant with lower Pbo suppression in the same areas (Table 1).

Cypermethrin 1.0 µg (Fig. 5)

Data have been collected for two seasons at ICRISAT Centre and some interesting trends are starting to appear. Early season resistance frequencies were higher in 1991–92 than in 1992–93 (50 versus 30%). Resistance increased steadily over each season a peak being reached in egg collections from chickpea in March (approximately 90% frequency) in both years. Chickpea is the last crop of the season before the onset of the summer when no crops are grown on the ICRISAT farm. In both years, subsequent egg collections during April were from isolated patches of wild hosts growing on soils with residual moisture after sporadic summer thunderstorms. In 1992, resistance frequency declined from 81% in late March to 37% in late April, and in 1993, from 90% in mid-March to 55% in mid-April. In Rangareddi District, resistance frequency started at 30% in August, rising to 50% by January. From early February there was a marked increase in frequency, peaking at 93% survival by the end of the cropping season in late March. The resistance profiles for Krishna and Guntur were similar. Both exhibited a rapid increase in pyrethroid resistance frequency from September (16–27% survival) to November (78–82% survival), during which time spray applications on cotton were maximum. Far fewer farmers sprayed cotton after December and this correlates with a decrease in resistance from late December onwards.

Although the coastal Andhra Pradesh region has historically been considered to have a more severe *H. armigera* pyrethroid resistance problem, the end of season resistance

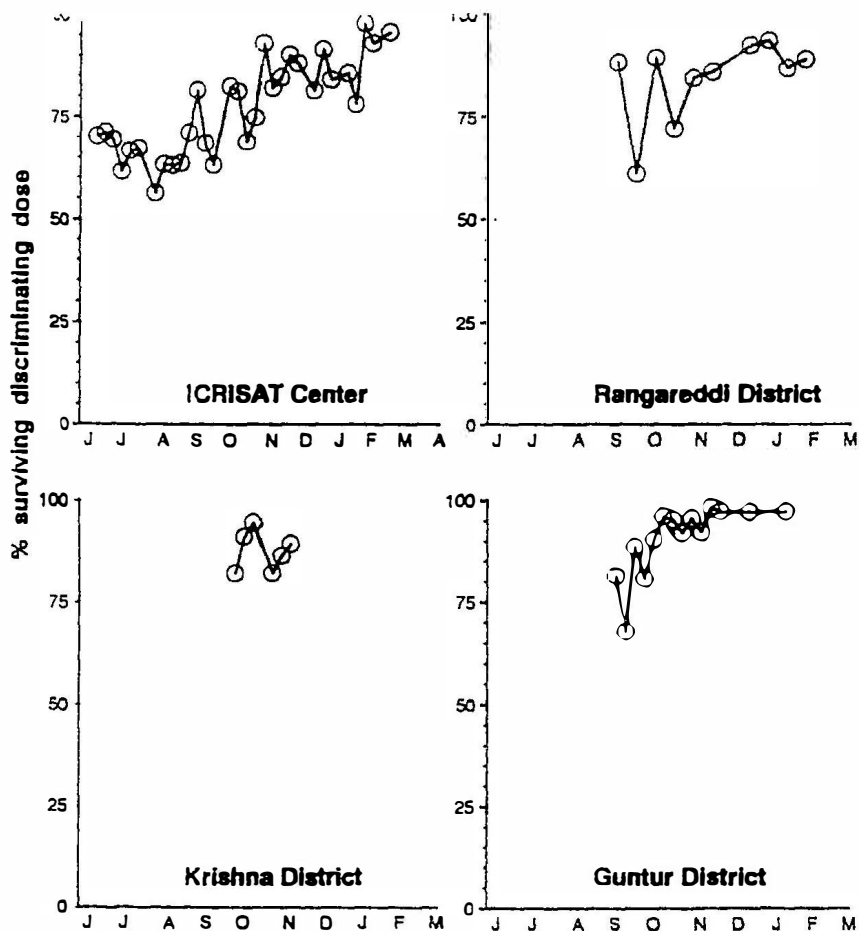


Fig. 6. Average weekly pyrethroid resistance frequencies in *H. armigera* at the four monitoring locations during the 1992-93 cropping season (based on percentage of 30-40 mg larvae surviving the fenvalerate 0.2 µg discriminating dose).

frequencies at ICRISAT and Rangareddi were higher (approximately 90 versus 80%). A possible reason for this is that the cropping season in the inland areas is longer than in coastal regions because small farmers continue to grow a patchwork of irrigated vegetable crops (invariably treated with insecticides), during the post rainy and summer seasons. This extends the availability of host plants which may augment selection for resistance over more generations. In the coastal sampling areas, far fewer farmers grow summer vegetables and increasing areas of land become fallow from February until the start of the next monsoon in June.

The utility of 'twin' discriminating doses in situations where insecticide resistance is very high has been demonstrated in this work. Had only the cypermethrin 0.1 µg dose (approximately LD₉₉ for susceptible *H. armigera*), been used for monitoring pyrethroid resistance, much information on seasonal changes in resistance would have been lost because of the rapid attainment of full resistance to cypermethrin 0.1 µg within a few weeks of the start of the cropping season - particularly in the intensively sprayed cotton areas.

Fenvalerate 0.2 µg (Fig. 6)

The fenvalerate profiles were similar to those of cypermethrin 0.1 µg, which is probably not surprising because both doses are approximations to their respective LD₉₉ for pyrethroid-susceptible *H. armigera*. At all four

monitoring locations, fenvalerate resistance frequencies were on average 5-9% lower than for cypermethrin, but differences were not statistically significant (χ^2 , $P > 0.05$). The main reason for including fenvalerate in the monitoring program is to provide a comparison of the severity of pyrethroid resistance in India with that in eastern Australia where an effective IRM program is in operation (Forrester and Cahill, 1987; Forrester *et al.*, 1993).

Endosulfan resistance

Endosulfan 10.0 µg (Fig. 7)

The seasonal picture of changes in resistance and maximum resistance frequencies (up to 70-85% survival) were similar at all four locations. The rate of increase of resistance in the more intensive insecticide-use areas of Krishna and Guntur was greater than at ICRISAT and Rangareddi, over the period from August to December when insecticide selection pressure was at its peak. Similarly, *H. armigera* at all locations showed some reversion towards lower resistance at the end of the cropping season. This was more obvious in the Krishna and Guntur samples where cotton was the main source for *H. armigera*, and few farmers sprayed this crop after mid-December.

Organophosphate resistance

Quinalphos 0.75 µg (Fig. 8)

Resistance to quinalphos was monitored from mid October

pyrethroid resistance was high at the commencement of the rainy season (70–85% survival at fenvalerate 0.2 µg). This differs from the Namoi–Gwydir situation where early season resistance frequencies in most seasons starts at only 10–30% (at fenvalerate 0.2 µg). This difference is probably attributable to the fact that insecticide selection on *H. armigera* populations differs between the two countries. In south India there is little evidence for diapause over the summer period (Jadhav and Armes, pers. comm.), and the small areas of irrigated vegetables and summer-grown cotton which harbour residual *H. armigera* populations at this time, are intensively sprayed. Therefore, selection pressure is continuous throughout the year. In eastern Australia, fewer generations are completed each year as a result of pupal diapause during the winter period (Fitt and Daly, 1990), and therefore resistance selection is over a much shorter period.

Endosulfan resistance frequencies were high at all locations and increased over the season with increasing selection pressure. Compared with the situation in Australia, India is experiencing a greater endosulfan resistance problem, with on average 27% higher resistance levels than the Namoi–Gwydir (N. Forrester, pers. comm.) At all monitoring locations there was slight recovery of susceptibility towards the end of the cropping season, by which time insecticide application to field crops had declined. This indicates some instability in endosulfan resistance, which could arise through immigration of susceptible moths breeding with local populations thereby reducing the frequency of resistant homozygotes, and/or because of fitness costs associated with specific cyclodiene resistance mechanisms. The former seems unlikely in view of the apparent ubiquity of endosulfan resistance in *H. armigera* in south India (Armes *et al.*, 1992; Armes *et al.*, unpublished data), making the likelihood of large influxes of susceptible moths unlikely. Fitness deficits are plausible but not researched for Indian *H. armigera*. Forrester *et al.* (1993) found that in Australia endosulfan-resistant *H. armigera* larvae were slower to develop, but it has not been shown that this contributes to fitness disadvantage under field conditions. In mosquitoes, however, there is good evidence that the nerve insensitivity resistance mechanism confers reduced male mating success in HCH/dieldrin-resistant strains (Rowland, 1991).

Organophosphate resistance levels were higher in Guntur District than in the ICRISAT Centre. From the limited data available for Guntur, there were indications of a decline in resistance toward the end of the season when most farmers had ceased spraying field crops and cotton in particular. The mechanisms of OP resistance are unknown at this stage, but the possibility of cross resistance with endosulfan needs to be looked at because of the potential role of glutathione S-transferase in both OP (Dautermann, 1985) and endosulfan (Kern *et al.*, 1991) resistance.

A very interesting result from the study is that at ICRISAT Centre pyrethroid resistance was as severe as in farmers' fields in Rangareddi District, approximately 50 km remote from

ICRISAT, even though pyrethroids were little used on the ICRISAT farm for *H. armigera* control. Widespread mixing of populations through migration is a common feature of *H. armigera* (Daly and Gregg, 1985; Farrow and Daly, 1987; Riley *et al.*, 1992), and this clearly highlights that it is only feasible to manage resistance and demonstrate impact of an IRM strategy if the majority of farmers over large areas take collective action. If only a few farmers co-operate then their efforts will be swamped by the over-whelming immigration of insecticide selected moths from crops where farmers have not adopted IRM practices.

The end of season drop in resistance frequencies, more or less apparent for all chemical groups, is significant as it indicates that resistance, or at least some of the mechanisms involved in resistance, may exhibit a competitive disadvantage in the absence of insecticide selection pressure. Dilution of resistance by immigration of susceptibles at the tail-end of the cropping season seems remote in view of the widespread occurrence of pyrethroid and endosulfan and possibly also OP resistance in south India (Armes *et al.*, 1992; Armes *et al.*, unpublished data). If this is the case, then at least partial management of resistance should be feasible simply by a reduction in selection pressure through more judicious use of insecticides on cotton and pulse crops. That is not to say that IRM will bring about reversion to susceptibility, but at least lower, and possibly 'stable' levels of resistance will allow for greater predictability of control and hopefully reduce resistance selection pressures on newer insecticide groups.

IRM constraints

There is clearly an urgent need for implementation of curative IRM for *H. armigera*. However, despite resistance first being detected in 1987, workable IRM strategies have yet to be demonstrated in India. Some of the major constraints to rapid implementation posed at the farmer, researcher and extension level are highlighted.

Lack of community action

In India, farms are small and farmers individualistic and generally poorly educated. As mentioned earlier, IRM can only be successful through group action. At present no mechanism exists to co-ordinate the actions of farmers to bring about a collective responsibility for reducing insecticide use.

Education/extension

These two areas are the key to effective IRM programs. Dissemination of research results to farmers should be undertaken by well-trained extension officers. In general, linkages between research scientists and extension officers are weak and as a result soundly researched pest control practices are slow to reach farmers, if at all, and may not be passed on accurately to extension staff. Perhaps even more of a constraint is the lack of resources and support for extension

Varietal preferences

In south India, most farmers prefer to grow long-maturing varieties, partly because, historically, they have shown good compensatory ability providing insurance against early season pest attack and drought, and partly because such varieties tend to produce long and extra long staple cotton, which fetches premium market prices. These varieties are notoriously pest susceptible, often growing to unmanageable heights and their long duration allows for multiple pest generations. It is not surprising therefore that high insecticide inputs are needed. Despite repeated crop failures, most farmers in the region are loath to grow shorter staple length-shorter duration varieties/hybrids and this makes IRM implementation problematic in such regions.

IRM Prospects

Having listed the most immediate practical constraints to IRM, it is pertinent to ask the question: 'Is it feasible to implement IRM in a developing country like India where knowledge, expertise and infrastructure are lacking because of inadequate and under financed research and extension operations?' There has been a reluctance in some quarters to accept insecticide resistance as a problem, control difficulties are attributed to weather factors and sub-standard insecticides, and this has hampered research and development into IRM initiatives by national institutes. However, this attitude is changing and an awareness of the need for IRM in cotton, in particular, is reaching senior decision makers. At the other end of the spectrum, farmers are also starting to question the role of insecticides in pest management. In Maharashtra and Tamil Nadu, in particular, farmers are becoming increasingly receptive to the concepts of IPM and many are realising the financial benefits of reduced conventional insecticide inputs. The industry sector, concerned over loss of susceptibility to their products and attendant decline in sales, is also emphasising the role of IPM and promoting more 'environmentally friendly' pest-management options and diversification into biorationals.

A lot of emphasis in national agricultural research stations in recent years has been placed on developing cotton varieties and hybrids with many of the desirable traits for improved management of bollworms: pest and disease tolerance; pest damage compensation; shorter duration (fewer insecticide inputs); stature (more efficient insecticide application); reduced fertiliser requirements, etc.

Whether curative IRM succeeds in India will largely depend upon whether research and extension workers can meet the challenge to develop practically based resistance management protocols with options appropriate to a range of agroclimatic conditions and economic backgrounds. Clearly a classical IRM strategy involving restriction of use of chemicals to certain times in the season and reliance on voluntary compliance (Forrester, 1990) would not be practical here. More immediate benefit could be achieved from

implementation of crop management packages including improvements in cotton agronomy and cotton varieties/hybrids, pest scouting systems and robust need-based insecticide use schedules. Indian farmers are shrewd and once they are convinced of the benefits through demonstrations and training, there is no question that uptake of IRM techniques in cotton will take-off – convincing the politicians will have to come later!

Acknowledgments

We are indebted to the Insecticide Resistance Action Committee (IRAC) of Groupement International des Associations Nationales de Fabricants de Produits Agrochimiques, Belgium, for financial support to P.A. Lonergan at a critical phase in the implementation of the resistance monitoring program, for N.J. Armes to attend this conference and for their support towards IRM research in India. Special thanks to Dr Neil Forrester, NSW Agriculture, Australia, for his invaluable advice on establishing a resistance monitoring program and for promoting our research activities. Patronage of the International Organisation for Resistant Pest Management (IOPRM) is gratefully acknowledged. We also wish to acknowledge the continued support of the Crop Protection Division, ICRISAT Asia Centre, particularly Drs D. McDonald and J.A. Wightman for provision of facilities. Messrs K.V.S. Satyanaryana and M. Satyanaryana (of ICRISAT) provided invaluable technical assistance. The NRI/ICRISAT collaborative IRM project was funded under the Adaptive Research Initiative of the British Government's Overseas Development Administration.

References

- Armes, N.J., Jadhav, D.R., Bond, G.S. and King, A.B.S. (1992). Insecticide resistance in *Helicoverpa armigera* in India. *Pestic Sci.* 34, 355–364.
- Daly, J.C. and Gregg, P. (1985). Genetic variation in *Heliothis* in Australia: species identification and gene flow in the two pest species *H. armigera* (Hübner) and *H. punctigera* Wallengren (Lepidoptera: Noctuidae). *Bull. ent. Res.* 75, 169–184.
- Daly, J.C., Fisk, J.H. and Forrester, N.W. (1988). Selective mortality in field trials between strains of *Heliothis armigera* (Lepidoptera: Noctuidae) resistant and susceptible to pyrethroids: functional dominance of resistance and age class. *J. Econ. Entomol.* 81, 1000–1007.
- Dautermann, W.C. (1985). Insect metabolism: extramicrosomal. In Kerkut, G.A. and Gilbert, L.I. (Eds) *Comprehensive Insect Physiology, Biochemistry and Pharmacology*. Vol. 12, Insect Control. pp. 713–730. Pergamon Press, Oxford.
- Dhingra, S., Phokela, A. and Mehrotra, K.N. (1988). Cypermethrin resistance in the populations of *Heliothis armigera* Hübner. *Natl Acad. Sci. Letters* 11, 123–125.
- Farrow, R.A. and Daly, J.C. (1987). Long-range movements as an adaptive strategy in the genus *Heliothis* (Lepidoptera: Noctuidae): a review of its occurrence and detection in four pest species. *Ann. J. Zool.* 35, 1–24.