CSIRO PUBLISHING

Australian Journal of Experimental Agriculture

Volume 38, 1998

… a journal publishing papers (in the soil, plant and animal sciences) at the cutting edge of applied agricultural research

www.publish.csiro.au/journals/ajea

All enquiries and manuscripts should be directed to
Australian Journal of Experimental Agriculture
CSIRO PUBLISHING
PO Box 1139 (150 Oxford St)
Collingwood
Vic. 3066
Australia

Telephone: 61 3 9662 7614
Facsimile: 61 3 9662 7611
Email: chris.anderson@publish.csiro.au
lalina.muir@publish.csiro.au

CSIRO

Published by
CSIRO PUBLISHING
in co-operation with the
Standing Committee on Agriculture and Resource Management (SCARM)

An evaluation of selective *Helicoverpa armigera* control options in sweet corn

B. C. G. Scholz[A], *C. J. Monsour*[BC] *and M. P. Zalucki*[B]

[A] Queensland Department of Primary Industries, PO Box 102, Toowoomba, Qld 4350, Australia; e-mail: scholzb@dpi.qld.gov.au
[B] CRC for Tropical Pest Management and Department of Entomology, University of Queensland, Brisbane, Qld 4072, Australia.
[C] Present address: Bowen Crop Monitoring Services, PO Box 4, Bowen, Qld 4805, Australia.

Summary. *Helicoverpa armigera* is a serious insect pest of sweet corn in Australia and is becoming increasingly difficult to manage with conventional chemical insecticides due to resistance problems. A number of alternative *H. armigera* control options were evaluated in sweet corn and compared with deltamethrin and no action (control). The alternative tactics evaluated were: heliothis nuclear polyhedrosis virus plus *Trichogramma* nr. *brassicae* releases; *Bacillus thuringiensis*; and *Trichogramma* alone. The *H. zea* nuclear polyhedrosis virus + *Trichogramma* plots had the lowest cob damage (6.0%), followed by the *B. thuringiensis* plots (12.0%), *Trichogramma* alone plots (20.2%), control plots (23.2%) and deltamethrin plots (53.5%). There was no evidence to suggest that the *Trichogramma* nr. *brassicae* releases had any impact on *H. armigera* egg mortality. However, there was a large natural population of *Trichogramma pretiosum* in all plots. The application of deltamethrin reduced the action of these wasps and predators, resulting in higher larval infestation and significantly more cob damage. The findings indicate that the pathogens heliothis nuclear polyhedrosis virus and *B. thuringiensis* can effectively control *H. armigera* when their action complements high natural levels of egg parasitism, and that they have potential for use in integrated pest management programs in sweet corn.

Additional keywords: *Trichogramma*, nuclear polyhedrosis virus, *Bacillus thuringiensis*, integrated pest management, *Zea mays*.

Introduction

The corn earworm or heliothis caterpillar, *Helicoverpa armigera* (Hübner), is a serious pest of maize and sweet corn, *Zea mays* L., in Australia (Zalucki *et al*. 1986; White *et al*. 1995). The annual cost of *H. armigera* to Australia's primary producers is estimated at $A220 million, including $6 million for corn and maize (Adamson *et al*. 1997).

In sweet corn, *H. armigera* moths lay eggs on leaves, tassels and emerging silks. Larvae that feed on silks eventually tunnel into the tops of cobs, causing obvious feeding damage, and rendering the cobs unsuitable for sale as fresh produce. Consumers demand damage-free and caterpillar-free produce. To achieve this, *H. armigera* must be killed at the egg or young larval stage. Once larvae shelter in silks, or burrow into cobs, they are difficult to contact and manage with insecticides.

To date, chemical insecticides are the most widespread commercially used means of controlling *H. armigera* on sweet corn in Australia. However, they are becoming increasingly difficult to manage with conventional chemical insecticides due to resistance problems (Forrester 1994), and alternative tactics need to be developed.

Here we evaluate *H. armigera* control options that display promise for inclusion in integrated pest management strategies in sweet corn. Emphasis was placed on evaluating control options that have minimal impact on naturally occurring populations of parasitoids and predators. Biological control involving inundative releases of *Trichogramma* egg parasitoids and applications of selective pathogenic insecticides were evaluated.

Trichogramma spp. (Hymenoptera : Trichogrammatidae) and their relatives are egg parasitoids; they attack insect eggs, and have attracted worldwide interest because they kill pest insects before they hatch and cause damage. *Trichogramma* are used as inundative biocontrol agents of lepidopteran pests throughout the world (Stinner 1977; Li 1994). Experimental work evaluating *Trichogramma* against *H. armigera* in sweet corn has given mixed results. Some researchers have found that the pest cannot be managed by inundative releases of *Trichogramma* (Fletcher 1933; Larrimer 1935; Neil and Specht 1990). Nevertheless, research interest persists because natural populations of *Trichogramma* can have an impact on *Helicoverpa* spp. in unsprayed crops (Oatman 1966), and they have been successfully used against other insect pests (see Li 1994).

 10.1071/EA98050

Trichogramma are currently commercially available in Australia, and were evaluated against *H. armigera* for this paper.

A type of nuclear polyhedrosis virus (NPV) infects heliothis larvae. This NPV was derived from the North American species *Helicoverpa zea* (Boddie) and only infects the *Heliothis–Helicoverpa* complex of caterpillars (Teakle 1986). The *H. zea* NPV (HzNPV) was found to be infective for *H. armigera* (Teakle *et al.* 1985), and previous research demonstrated control potential against *H. armigera* (Teakle *et al.* 1983, 1985; Rogers *et a*l. 1985). Nuclear polyhedrosis viruses do not affect beneficial invertebrates or vertebrates (including humans), and do not leave toxic residues (Gröner 1996). To date, there have been no records of resistance developing to NPVs (Jones 1994). A new HzNPV product called GemStar has recently become available and is being evaluated against *Helicoverpa* spp. in cotton, sorghum and chickpea (Teakle 1994; Murray *et al.* 1996), and was evaluated against *H. armigera* in sweet corn here.

Effective commercial formulations of the bacterium *Bacillus thuringiensis* var. *kurstaki* (Berliner) for the control of lepidoptera, including *Helicoverpa* spp., have been available for over 20 years. The use of *B. thuringiensis* for *H. armigera* control in sweet corn in Australia has been limited. Results have generally been poor or inconsistent, resulting in a lack of confidence in the product compared with chemical insecticides. Recent research has demonstrated that *B. thuringiensis* can provide effective control of *H. armigera* in pretasselling and silking sweet corn (C. J. Monsour unpublished data), so it was included in this trial.

The above control tactics (*Trichogramma* releases, HzNPV and *B. thuringiensis*) were compared with a non-treated control and a treatment where synthetic pyrethroid applications were used to disrupt the action of naturally occurring predators and parasitoids. The affects of these treatments on the proportion of corn cobs damaged at harvest, and the impact of the treatments on the levels of *H. armigera* egg parasitism were assessed.

Materials and methods

Sweet corn was planted at the Queensland Department of Primary Industries Gatton Research Station (27º33'S, 152º20'E). Four bays of H5 sweet corn (12 rows wide) were separated by 3 bays of Hycorn 83 maize (16 rows wide). The rows were 180 m long and 70 cm apart, and there were about 6 corn plants per metre of row. Four rows of maize buffer were grown on both edges of the study site. The treatment plots were 25 m long and 12 rows wide, arranged as a randomised complete block design, and separated by buffers 15 m long and 12 rows wide. The trial was sown on 24 February 1997 and the first silks appeared 54 days after sowing (DAS). Five different *H. armigera* control options were evaluated, with each replicated 4 times.

Treatments

Deltamethrin. Deltamethrin (Decis) was applied 56, 60, 63 and 67 DAS at a rate of 12.5 g a.i./ha in a spray volume of 50 L/ha using a Stihl SR400 mistblower. Deltamethrin was used to disrupt the action of natural enemies, and was not representative of a standard commercial pest management tactic.

HzNPV + Trichogramma. *Trichogramma* nr. *brassicae* Bezdenko was released inundatively 48, 50 and 57 DAS at rates of 307 000, 584 000 and 235 000 females/ha respectively. These plots were also sprayed with HzNPV (GemStar) 58 and 64 DAS at a rate of 1.5×10^{12} polyhedral inclusion bodies/ha in a spray volume of 52 L/ha using a knapsack sprayer (Hardi RY-2).

The *Trichogramma* were obtained from a commercial supplier and released as pupae in parasitised *Sitotroga cerealella* (Olivier) eggs by one of 2 methods: (i) suspended in a thickened water solution, using AquaKeep, and sprayed onto corn leaves with a hand-held atomiser; or (ii) stuck onto paper cards (1.5 by 7 cm) and placed on corn plants at silk height every 6 m in every second row (i.e. 20 cards/plot). The first 2 *Trichogramma* releases (48 and 50 DAS) were in liquid suspension, and the third release (57 DAS) was with egg cards.

The emergence of released *Trichogramma* was assessed by placing 50 parasitised *Sitotroga* eggs (taken from the material to be released in the field) individually into the wells of a microtitre tray using a fine paint brush dipped in water. The tray was covered with sticky tape to contain the emerged wasps, tied to a plant at silk height in the field, and checked daily to record the wells containing emerged wasps.

Bacillus thuringiensis. In these plots *B. thuringiensis* (Dipel Forte) was applied 58 and 64 DAS at a rate of 1.36×10^{10} IU/ha in a spray volume of 52 L/ha using a knapsack sprayer (Hardi RY-2).

Trichogramma *alone*. *Trichogramma* nr. *brassicae* was released in these plots and no other management tactics were used. The releases were carried out in the same manner and on the same days as outlined in the HzNPV + *Trichogramma* treatment above.

Control. No action was taken in these plots.

Insect assessments

The numbers of *H. armigera* eggs and larvae were counted twice weekly on each of 3 consecutive plants at 4 randomly selected locations per plot. The eggs were recorded according to colour: white (freshly laid), brown (1–2 days old), or black (parasitised). Visual counts of the most common predators on the same plants were also recorded. These data were averaged to obtain the mean numbers per plant.

Egg parasitoid action was assessed by monitoring eggs in the field and collecting eggs from corn silks. Naturally laid *H. armigera* eggs were 'tagged' by marking plants with coloured plastic tape and using a felt-tipped marker pen to circle and number 206 freshly laid eggs on leaves 1 week before silking commenced. These eggs were examined daily for 6 days and their fate recorded as either predated, collapsed, parasitised or hatched. Eggs that disappeared 1–3 days after tagging were assumed to be eaten by chewing predators (egg remains were sometimes noticed). Eggs that were shrunken or discoloured, but had not hatched, were recorded as collapsed. Eggs that disappeared 4–5 days after tagging were assumed to have hatched under the field temperatures experienced in the trial. Parasitised eggs turned black 4–5 days after tagging. There were 5.2 ± 0.6 (mean ± s.e.) eggs tagged per plant.

Twelve brown corn silks were collected from each plot and individually placed into labelled brown paper bags 13 days after silking commenced. The bags were taken back to the laboratory, and the number of *H. armigera* eggs per silk was counted and their colour recorded. The eggs were individually placed into the wells of microtitre trays and covered with clear plastic film. The trays were held in a constant temperature room at 25 ± 1°C, 70 ± 10% relative humidity and 14/10 h (light/dark) photoperiod until the eggs hatched or showed signs of parasitism. Parasitised eggs were held until wasps emerged, and the wasps were counted, sexed and identified to species where possible.

Helicoverpa armigera larvae were randomly collected to assess the levels of HzNPV infection. Field-collected larvae were individually held in 28 mL plastic cups containing a small amount of navy bean diet (after Teakle and Jensen 1985). Individual records of larvae were kept by inspecting them daily and recording their fate as NPV death, other death or healthy.

A damage assessment of ripe cobs was completed 85 DAS by inspecting 100 cobs from each plot at random. Each cob was checked for feeding damage by *H. armigera*, including silk damage, and for the presence of larvae.

Statistical analyses

The data were analysed by analysis of variance, and means were compared using Fisher's least significant difference technique with the statistical software packages StatView or Microsoft Excel. All percentage data were arcsine transformed for analyses.

Results

Helicoverpa armigera egg laying peaked about 1 week before silking started (Fig. 1). Deltamethrin applications commenced 2 days after silking started, and applications of the pathogens (HzNPV and *B. thuringiensis*) commenced 4 days after silking started.

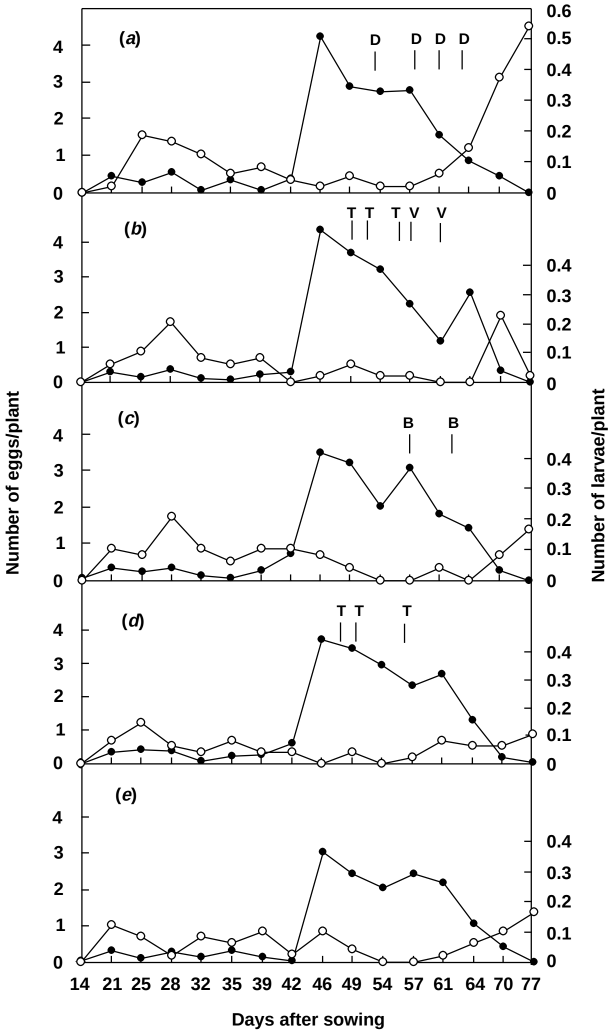

Figure 1. Mean number of *H. armigera* eggs (●) and larvae (○) per plant on sweet corn under various management regimes: (*a*) deltamethrin; (*b*) HzNPV + *Trichogramma*; (*c*) *Bacillus thuringiensis*; (*d*) *Trichogramma*; and (*e*) control. Mean egg counts are for white and brown eggs. Silking commenced 54 days after sowing. The lettered lines indicate when management tactics were applied: B, *B. thuringiensis*; D, deltamethrin; T, *Trichogramma*; V, HzNPV.

The 4 sprays of deltamethrin failed to manage larvae and led to an infestation of 0.54 larvae/plant when sampling ceased 77 DAS. The HzNPV + *Trichogramma* treatment had the lowest larval infestation at this time, 0.02 larvae/plant (Fig. 1). Larval infestations in the other treatments ranged from 0.1–0.2 larvae/plant.

Cob damage was greatest in deltamethrin-treated plots (53.5%), and lowest in the HzNPV + *Trichogramma* plots (6.0%). Larval infestation of cobs was also greatest

Table 1. Proportion of cobs undamaged and infested with heliothis larvae at harvest under different heliothis management regimes

Data are the mean (± s.e.) of four replicates inspected 85 days after sowing
Column means followed by the same letter are not significantly different at $P = 0.05$ (ANOVA, Fisher's l.s.d. technique)

Treatment	Nil damage (%)	Corn cobs with larvae (%)
Control	76.8 (± 2.4)c	11.3 (± 2.2)b
Deltamethrin	46.5 (± 3.1)d	33.8 (± 6.4)a
HzNPV + *Trichogramma*	94.0 (± 1.9)a	1.8 (± 0.6)d
Bacillus thuringiensis	88.0 (± 1.8)ab	4.0 (± 1.5)cd
Trichogramma only	79.8 (± 4.5)bc	7.8 (± 1.8)bc

in the deltamethrin plots (33.8%) and lowest in the HzNPV + *Trichogramma* plots (1.8%) (Table 1). Larvae were difficult to find in the non-chemically treated plots. However, larval mortality due to HzNPV was high in the plots sprayed with HzNPV and negligible in the other treatments (Table 2), indicating that the HzNPV mortality was due to the application of GemStar and not a natural epizootic.

Pirate bugs (*Orius* sp.), ladybirds (larvae and adults) and spiders were the most abundant predators present (Fig. 2). Two species of ladybirds were recorded: the transverse ladybird, *Coccinella transversalis* Fabricius; and the 3-banded ladybird, *Harmonia octomaculata* (Fabricius). No attempt was made to identify spiders. The number of predators in the chemically treated plots fell to almost zero after spraying with deltamethrin commenced. Predator numbers were similar in all other treatments, commonly ranging between 2 and 3 predators/plant (Fig. 2).

Table 2. Mortality of heliothis larvae due to HzNPV under different heliothis management regimes

GemStar was applied on 5 and 11 April 1997
n represents the number of larvae collected from each treatment; larvae in non-chemically treated plots were difficult to find
The *Trichogramma* alone plots were not sampled due to time constraints
There were insufficient data for statistical analyses

Sample	Treatment	NPV mortality (%)	*n*
Pre-spray I	Control	0	12
5 April 1997	HzNPV + *Trichogramma*	0	12
	Bacillus thuringiensis	0	12
	Deltamethrin	0	12
3 Days post-spray I	Control	0	12
8 April 1997	HzNPV + *Trichogramma*	83.3	12
	Bacillus thuringiensis	8.3	12
	Deltamethrin	0	12
Pre-spray II	Control	0	11
11 April 1997	HzNPV + *Trichogramma*	100	6
	Bacillus thuringiensis	12.5	8
	Deltamethrin	0	12
4 Days post-spray II	Control	14.3	7
15 April 1997	HzNPV + *Trichogramma*	88.9	9
	Bacillus thuringiensis	0	8
	Deltamethrin	0	12

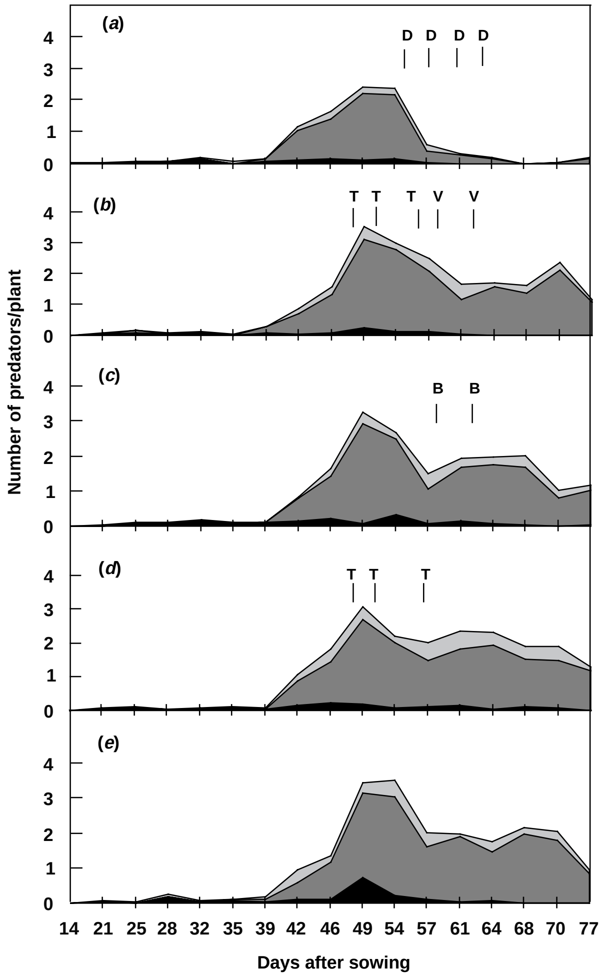

Figure 2. Mean number of Coccinellidae (black shading), *Orius* sp. (medium stipple) and spiders (light stipple) per plant on sweet corn under various management regimes: (*a*) deltamethrin; (*b*) HzNPV + *Trichogramma*; (*c*) *Bacillus thuringiensis*; (*d*) *Trichogramma*; and (*e*) control. Silking commenced 54 days after sowing. The lettered lines indicate when management tactics were applied: B, *B. thuringiensis*; D, deltamethrin; T, *Trichogramma*; V, HzNPV.

Egg parasitism was recorded in all treatments, including moderate levels of egg parasitism in the deltamethrin plots (Table 3). Of the 206 white *H. armigera* eggs tagged on vegetative plants: 46.6% were parasitised, 24.7% collapsed, 23.8% were missing (presumed eaten), and 4.9% hatched. *Trichogramma pretiosum* Riley was the most abundant species found throughout the study site, accounting for 91.3% of all parasitoids collected (Table 4). Naturally occurring

Table 3. Levels of brown egg infestation and parasitism recorded for eggs collected from brown silks on 14 April 1997 (13 days after silking commenced)

Deltamethrin was applied on 10 April 1997
Data are the mean (± s.e.) of four replicates (12 silks per replicate)
Column means followed by the same letter are not significantly different at $P = 0.05$ (ANOVA, Fisher's l.s.d. technique)
Absence of letters denotes non-significance

Treatment	No. of brown eggs per silk	Brown egg parasitism (%)
Control	0.67 (± 0.15)	85.7 (± 10.1)a
Deltamethrin	1.13 (± 0.31)	27.7 (± 12.2)b
HzNPV + *Trichogramma*	1.00 (± 0.08)	88.0 (± 7.0)a
Bacillus thuringiensis	1.63 (± 0.52)	95.1 (± 1.8)a
Trichogramma only	0.95 (± 0.44)	97.5 (± 2.5)a

Trichogrammatoidea bactrae Nagaraja were also collected (6.7% of total), but very few of the released *T.* nr. *brassicae* were recovered (Table 4). The emergence of inundatively released *T.* nr. *brassicae* was generally poor: 62, 32 and 58% emergence for each release respectively. In addition, emergence did not peak until at least 3 days after release (Table 5).

Discussion

HzNPV and *B. thuringiensis* have potential for use against *H. armigera* in sweet corn. The obvious advantage in using these products is the added benefit of conserving natural enemies. The combination of these selective insecticides and natural populations of egg parasitoids and predators produced significantly more undamaged cobs than most other management tactics investigated.

The deltamethrin-treated plots suffered significantly more cob damage and larval infestation than all of the other treatments because the abundance and action of naturally occurring egg parasitoids and predators were reduced. Almost 77% of cobs in the control plots were undamaged, illustrating the importance that these natural enemies had on managing *H. armigera*. The high level of egg parasitism (47%) recorded during the vegetative stage (1 week before silking) apparently acted as a foundation for subsequent generations of *Trichogramma* that caused very high levels of egg parasitism during silking. There was no evidence to suggest that the inundative releases of *T.* nr. *brassicae* had any impact on *H. armigera* egg mortality, despite the high rates of release (up to 584 000 females/ha). Only 2% of all parasitoids collected were *T.* nr. *brassicae*. The poor overall emergence of released *T.* nr. *brassicae* (32–62%), and the delayed emergence patterns, are issues that need to be addressed by the commercial suppliers of *Trichogramma*. *Helicoverpa armigera* eggs laid just before, or on, the day of parasitoid release would have hatched or been unsuitable for parasitisation. Rapid wasp emergence is crucial for successful inundative releases of *Trichogramma* against *Helicoverpa* spp. *Helicoverpa armigera* eggs can hatch in 2–3 days during summer (Kay 1981). Consequently, delayed emergence of 3 or more days may be ineffective against some egg lays. Delayed emergence may also expose parasitoids to adverse environmental conditions, or increase the likelihood that parasitoid pupae may be eaten by predators.

The high levels of egg parasitism recorded in the non-deltamethrin plots were due to naturally occurring *T. pretiosum* that may have migrated from an adjacent unsprayed 2 ha planting of sorghum. Egg parasitism due to *T. pretiosum* was recorded in all treatments, including moderate levels in the deltamethrin-sprayed plots. *Trichogramma pretiosum* seemed to rapidly re-invade these plots, probably because they represented only 6% of the total study site. Despite this, the deltamethrin disrupted *Trichogramma* activity enough to allow sufficient larvae to hatch and cause significantly more cob damage than all other treatments investigated.

The application of HzNPV or *B. thuringiensis* significantly increased the proportion of undamaged cobs by 17 and 11%, respectively, to that of the control, thereby enhancing the level of control achieved due to natural enemies alone. Only 2 applications of HzNPV

Table 4. Species (*Trichogramma pretiosum*, *Trichogramma* nr. *brassicae*, *Trichogrammatoidea bactrae* or *Telenomus* sp.) of egg parasitoids recovered from *H. armigera* eggs on sweet corn (pooled data for all treatments)

Data are the number of parasitised eggs that produced a given species of parasitoid

Date	*T. pretiosum*	*T.* nr. *brassicae*	*T. bactrae*	*Telenomus* sp.
25.iii.97	138	13	15	1
02.iv.97	124	2	10	0
09.iv.97	128	1	3	0
11.iv.97	327	4	15	0
14.iv.97	1332	27	102	0
16.iv.97	233	4	21	0
23.iv.97	6	0	1	0
Total no.	2288	51	167	1
Total %	91.3	2.0	6.7	0

Table 5. Emergence (%) of *T.* nr. *brassicae* on each day after release (DAR) in sweet corn where DAR 0 is day of release

DAR	Release no. 1	Release no. 2	Release no. 3
0	0	0	0
1	0	6	0
2	6	0	0
3	32	8	2
4	18	4	22
5+	6	14	34
Total emergence	62	32	58

and *B. thuringiensis* were made during the trial, with the first spray applied shortly after the crop commenced silking. The timing of sprays is critical, as it is essential to target neonate larvae before they seek shelter and are difficult to contact with sprays. HzNPV can be self-perpetuating in the environment, with dead infected larvae releasing virus into the surrounding environment (Jones 1994). Therefore, early sprays and infections could lead to subsequent secondary spread of the virus.

The results suggest that *B. thuringiensis* can contribute to *H. armigera* management in sweet corn, especially in crops that contain high natural populations of foraging egg parasitoids and predators. Farmers apparently prefer using chemicals instead of *B. thuringiensis* because they lack confidence in the efficacy of the product. However, these research findings indicate that *B. thuringiensis* has potential for *H. armigera* management, particularly in integrated pest management programs where it can complement natural mortality.

Predation also impacted on egg mortality. Only 4.9% of eggs tagged 1 week before silking hatched, 23.8% were presumed eaten by chewing predators, because they were missing, and 24.7% of eggs were collapsed. A proportion of the collapsed eggs were probably eaten by sucking predators, for example *Orius* sp. It is therefore likely that ≥40% of eggs were predated. The application of deltamethrin reduced the numbers of predators dramatically. Further research is necessary to determine the numbers and species of predators necessary to manage various *H. armigera* infestations.

The results of this study illustrate that natural populations of *Trichogramma* and selective insecticides can contribute to heliothis management. The key to successfully utilising natural populations of *Trichogramma* is: (i) recognising that they may be present and active in a crop; and (ii) adopting pest management practices that do not disrupt their action, i.e. avoiding the use of broad spectrum chemical insecticides.

The use of selective insecticides, such as NPV or *B. thuringiensis*, are ideal for inclusion in integrated pest management programs. These products do not disrupt parasitoids and predators, and they can impose additional mortality to that achieved by natural enemies alone. *Helicoverpa armigera* presence in sweet corn is acceptable if natural enemies are also present in sufficient numbers to maintain crop damage at acceptable levels. The research presented in this paper demonstrates that selective insecticides have potential to control *H. armigera* in sweet corn crops that contain large populations of egg parasitoids and predators.

Acknowledgments

We thank Andrea Gerrard, Kristin Latimer and Sue Maclean for technical support; and Dave Schofield and the farm hands at Queensland Department of Primary Industries Gatton Research Station for planting and maintaining the study site. This research was funded by the Horticultural Research and Development Corporation.

References

Adamson, D., Thomas, G., and Davis, E. (1997). An economic estimate of *Helicoverpa's* effect on Australian agricultural production. Report for the Cooperative Research Centre for Tropical Pest Management, Brisbane. 108 pp.

Fletcher, R. K. (1933). Experiments in the control of the corn earworm, *Heliothis obsoleta* (Fabr.), with *Trichogramma minutum* Riley. *Journal of Economic Entomology* **26**, 978–82.

Forrester, N. W. (1994). Management of resistance in *Helicoverpa armigera* in Australia. *In* 'Proceedings of the Seventh Australian Cotton Conference'. Broadbeach, Queensland, 10–12 August 1994. pp. 7–15. (Australian Cotton Growers Research Association: Broadbeach.)

Gröner, A. (1996). Specificity and safety of baculoviruses. *In* 'The Biology of Baculoviruses'. Vol. I. (Eds R. R. Granados and B. A. Federici.) pp. 177–203. (CRC Press: Boca Raton, FL.)

Jones, K. A. (1994). Use of baculoviruses for cotton pest control. *In* 'Insect Pests of Cotton'. Vol. 25. (Eds G. A. Matthews and J. P. Tunstall.) pp. 477–504. (CAB International: Wallingford, UK.)

Kay, I. R. (1981). The effect of constant temperatures on the development time of eggs of *Heliothis armiger* (Hübner) (Lepidoptera : Noctuidae). *Journal of the Australian Entomological Society* **20**, 155–6.

Larrimer, W. H. (1935). Corn earworm not controlled in sweet corn by release of *Trichogramma*. *Journal of Economic Entomology* **28**, 815–16.

Li, Li-Ying (1994). Worldwide use of *Trichogramma* for biological control on different crops: a survey. *In* 'Biological Control with Egg Parasitoids'. Vol. 2. (Eds E. Wajnberg and S. A. Hassan.) pp. 37–53. (CAB International: Wallingford, UK.)

Murray, D., Teakle, B., Lloyd, R., Rynne, K., and Ingram, B. (1996). The utility of nuclear polyhedrosis for heliothis management in cotton IPM programs. *In* 'Proceedings of the Eighth Australian Cotton Conference'. Broadbeach, Queensland, 14–16 August 1996. pp. 341–6. (Australian Cotton Growers Research Association: Broadbeach.)

Neil, K. A., and Specht, H. B. (1990). Field releases of *Trichogramma pretiosum* Riley (Hymenoptera: Trichogrammatidae) for suppression of corn earworm, *Heliothis zea* (Boddie) (Lepidoptera: Noctuidae), egg populations on sweet corn in Nova Scotia. *Canadian Entomologist* **122**, 1259–66.

Oatman, E. R. (1966). Parasitization of corn earworm eggs on sweet corn silk in southern California, with notes on larval infestations and predators. *Journal of Economic Entomology* **59**, 830–5.

Rogers, D. J., Teakle, R. E., and Brier, H. B. (1983). Evaluation of *Heliothis* nuclear polyhedrosis virus for control of *Heliothis armiger* on navy beans in Queensland, Australia. *General and Applied Entomology* **15**, 31–4.

Stinner, R. E. (1977). Efficacy of inundative releases. *Annual Review of Entomology* **22**, 515–31.

Teakle, R. E. (1986). Studies on a nuclear polyhedrosis virus in relation to the control of *Heliothis armigera* (Hübner) and *Heliothis punctigera* Wallengren. PhD Thesis, University of Queensland. 271 pp.

Teakle, R. E. (1994). Virus control of heliothis and other key pests: potential and use, and the local scene. *In* 'Proceedings of the 1st Brisbane Symposium. Biopesticides: Opportunities for Australian Industry'. (Eds C. J. Monsour, S. R. Reid and R. E. Teakle.) pp. 51–6. (Department of Chemical Engineering, University of Queensland, and the Cooperative Centre for Tropical Pest Management: Brisbane.)

Teakle, R. E., and Jensen, J. M. (1985). *Heliothis punctiger*. *In* 'Handbook of Insect Rearing'. Vol. 2. (Eds P. Singh and R. F. Moore.) pp. 313–22. (Elsevier Science Publishers: Amsterdam.)

Teakle, R. E., Jensen, J. M., and Mulder, J. C. (1985). Susceptibility of *Heliothis armiger* (Lepidoptera: Noctuidae) on sorghum to nuclear polyhedrosis virus. *Journal of Economic Entomology* **78**, 1373–8.

Teakle, R. E., Page, F. D., Sabine, B. N. E., and Giles, J. E. (1983). Evaluation of *Heliothis* nuclear polyhedrosis virus for control of *Heliothis armiger* on sorghum in Queensland, Australia. *General and Applied Entomology* **15**, 11–18.

White, G. G., Murray, D. A. H., and Walton, M. P. (1995). Heliothis management in Australia. Cooperative Research Centre for Tropical Pest Management Workshop Report, Brisbane. 100 pp.

Zalucki, M. P., Daglish, G., Firempong, S., and Twine, P. T. (1986). The biology and ecology of *Heliothis armigera* (Hübner) and *H. punctigera* Wallengren (Lepidoptera: Noctuidae) in Australia: what do we know? *Australian Journal of Zoology* **34**, 779–814.

Received 5 March 1998, accepted 28 July 1998