Optimum timing of insecticide applications against diamondback moth *Plutella xylostella* in cole crops using threshold catches in sex pheromone traps

Gadi Venkata Prasad Reddy and Angel Guerrero*
Department of Biological Organic Chemistry, IIQAB (CSIC), Jordi Girona 18–26, 08034-Barcelona, Spain

Abstract: Field trials were conducted in cabbage (*Brassica oleracea* var *capitata*), cauliflower (*B oleracea* var *botrytis*) and knol khol (*B oleracea gongylodes*) crops at two different locations in Karnataka State (India) to optimize the timing of insecticide applications to control the diamondback moth, *Plutella xylostella*, using sex pheromone traps. Our results indicate that applications of cartap hydrochloride as insecticide during a 12–24 h period after the pheromone traps had caught on average 8, 12 and 16 males per trap per night in cabbage, cauliflower and knol khol, respectively, were significantly more effective than regular insecticide sprays at 7, 9, 12 or 15 days after transplantation. This was demonstrated by estimation of the mean number of eggs and larvae per plant, the percentage of holes produced, as well as the marketable yield of the three crops at each location. A good correlation between the immature stages, infestation level, the estimated crop yield and the number of moths caught in pheromone traps was also found, indicating the usefulness of pheromone-based monitoring traps to predict population densities of the pest.

Keywords: *Plutella xylostella*; threshold catches; insecticide application; cole crops; sex pheromone; Lepidoptera: Yponomeutidae

1 INTRODUCTION

The diamondback moth *Plutella xylostella* (L) (Lepidoptera: Yponomeutidae) is among the most serious pests of cruciferous oil-seed and vegetable crops in the world. It is highly mobile and distributed worldwide, its major hosts comprising most *Brassica* plants. In many regions, such as India and South East Asia, *P xylostella* is present throughout the year but in those locations where the larvae are unable to survive during the winter, as in Canada, the insect reinvades the original region.[1] The insect is extremely difficult to control, due to the high resistance to insecticides observed in many populations, particularly in SE Asia,[2] Taiwan[3] and N America.[4]

The major components of the diamondback moth pheromone were identified as (*Z*)-11-hexadecenal (*Z*11–16:Ald) and (*Z*)-11-hexadecenyl acetate (*Z*11–16:Ac) by Tamaki *et al*[5] and Chow *et al*.[6] A 8:2 to 4:6 mixture of *Z*11–16:Ald and *Z*11–16:Ac was found to be highly attractive to males in the field, 1 μg of a 1:1 mixture being equivalent in attractiveness to five virgin females.[7] Later, Koshihara and Yamada[8] established that addition of only 1% of (*Z*)-11-hexadecenol (*Z*11–16:OH) to a 70:30 mixture of *Z*11–16:Ald and *Z*11–16:Ac significantly increased males captures, while Chisholm *et al*[9] improved lure specificity by adding 10% of (*Z*)-9-tetradecenol (*Z*9–14:OH) to the natural pheromone. Population monitoring of the diamondback moth by using a 1:1:0.01 mixture of *Z*11–16:Ac, *Z*11–16:Ald and *Z*11–16:OH has been described by Môttus *et al*.[10] These authors reported recommended pheromone release rates of 8–17 ng h^{-1} to get optimum trap catches, and reported that decomposition products of *Z*11–16:Ald inhibited the activity of the attractant when more than 50% of the aldehyde had decomposed. Reddy and Urs[11,12] carried out field studies aimed at establishing the optimum parameters (type of trap, trap height, duration of pheromone activity, diurnal pattern of attraction, etc) to catch *P xylostella* males, as well as the efficiency of the pheromone in comparison to virgin females. The authors later performed mass trapping experiments to reduce the pest population in cabbage fields in India.[13] By monitoring the phenology of the diamondback moth by pheromone traps, we may be able to predict better the timing of insecticide applications, leading to a more rational and ecological application to control the pest. We report here studies using trapping systems

* Correspondence to: Angel Guerrero, Department of Biological Organic Chemistry, IIQAB (CSIC), Jordi Girona 18–26, 08034-Barcelona, Spain
E-mail: agpqob@iiqab.csic.es
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described in previous publications[11,12] and directed at establishing the optimum timing of insecticide application using threshold catches of *P xylostella* with pheromone-baited traps.

2 EXPERIMENTAL METHODS

Pheromone-impregnated rubber septa for *P xylostella* were obtained from the Shin-Etsu Chemical Company (Japan) and kept in a freezer until use. The lures contained *Z*11-16:Ald (50 µg), *Z*11-16:Ac (50 µg) and *Z*11-16:OH (1 µg) as pheromone components, together with BHT (5 µg) as antioxidant. Delta sticky traps (18 cm × 10 cm) were obtained from Pest Control Ltd (Bombay), and changed fortnightly. The experiments were carried out at Hebbal and Devanahally (Karnataka State, India), from August to October 1994 and January to March 1995 in cabbage (*Brassica oleracea capitata* L), cauliflower (*B oleracea botrytis* L) and knol khol (*B oleracea gongylodes* L) fields.

The treatment field for each crop was divided into two equal plots of 33 m × 18.5 m separated by 15 m to avoid trap effects.[11,12] Every plot comprised 20 sub-plots of 6 m × 4 m (24 m^2 per replicate) which were separated from each other by 0.5 m to avoid spray drift. Each sub-plot contained 10 rows of 13 plants per row. One of the plots included insecticide treatments (T1–T5, four replicates) based on pheromone catches, while the other embodied only treatments (T6–T9, four replicates) based on regular insecticide application. No insecticide spray was applied in T10 (control, four replicates). The inter-crop distance was 20 m.

Thirty-day-old seedlings of cabbage, cauliflower and knol khol were planted, and the recommended cultivation practices were followed for tillage, seed rate, fertilizer application and irrigation.[14] One spray of dimethoate 300 g litre^{-1} EC (Rogor 30; 500 ml ha^{-1}) was applied 1 week after transplantation to control sucking pests, mainly aphids. Although this insecticide may also affect the diamondback moth, the pest is very scarce up to 3 weeks after transplantation.

Four delta traps baited with pheromone septa as dispensers were set up at random in the T1–T5 plot at a height of 30 m above the crop canopy.[12] The dispensers were changed every 30 days, the number of males captured daily recorded and then discarded. For insecticide applications based on trap catches, treatments (spray with cartap hydrochloride at 1.0 g litre^{-1}) were applied within a period of 12–24 h when the mean number of catches during the previous night reached the following levels: first treatment (T1) at four or more, second treatment (T2) at eight or more, third treatment (T3) at 12 or more, fourth treatment (T4) at 16 or more, and fifth treatment (T5) at 20 or more males per trap per night. For the regular insecticide sprays (cartap hydrochloride at 1.0 g litre^{-1}), we used the same timing of application as that usually performed by farmers—ie a regular spray schedule (RSS) was applied every 7 days after transplantation (treatment T6), every 9 days (treatment T7), every 12 days (treatment T8) and every 15 days (treatment T9). The days of insecticide applications in each treatment and crop are shown in Table 1. Insecticide sprays were applied using a knapsack sprayer with a Duro mist spray nozzle (Aspee, Bombay). The total amount of spray fluid per treatment was 250 litre ha^{-1}.

The mean number of eggs laid, the number of larvae present in five randomly selected plants per replicate area and the mean percentage of holes produced were counted every week. The temperature and wind velocity were also recorded during the experimental period. Finally, at the end of the season, the crop was harvested, weighed and the marketable yield of each crop estimated and expressed as tonnes ha^{-1}. Data concerning population and damage were analyzed for significance at the 5% level using ANOVA, while those of marketable yield were analyzed using Duncan's multiple range test (DMRT).

Table 1. Number of days after transplantation (DAT) at which an insecticide[a] was applied after reaching the estimated threshold level of pheromone catches of *Plutella xylostella* in comparison to a regular spray schedule (RSS) in cole crops

	Hebbal			*Devanahally*		
Treatment	*Cabbage*	*Cauliflower*	*Knol khol*	*Cabbage*	*Cauliflower*	*Knol khol*
T1 (4 males/trap/night)	15, 25, 37, 46, 54, 65, 74, 85	16, 29, 40, 52, 67, 76	15, 30, 42, 48, 58	13, 22, 30, 38, 47, 54, 60, 68, 79, 88	13, 25, 37, 49, 56, 65, 72, 82	18, 28, 42, 54, 66, 79
T2 (8 males/trap/night)	25, 37, 46, 54, 65, 74	29, 40, 52, 67, 76	30, 42, 48, 58	30, 38, 47, 54, 60, 68, 79, 88	37, 49, 56, 65, 72, 82	28, 42, 54, 66, 79
T3 (12 males/trap/night)	37, 46, 54, 65, 74	29, 40, 52, 67	30, 42, 48, 58	47, 54, 60, 68, 79, 88	49, 56, 65, 72, 82	28, 42, 54, 66, 79
T4: (16 males/trap/night)	46, 54, 65, 74	40, 52, 67, 76	42, 48, 58	47, 54, 60, 68, 79, 88	49, 56, 65, 82, 88	54, 66, 79
T5 (20 males/trap/night)	54, 65, 74	52, 67, 76	42, 58, 65	60, 68, 75, 88	56, 65, 82	54, 66
T6 (RSS, 7 DAT)[b]	7, 14, 21, 28, 35, 42, 49, 56, 63, 70	7, 14, 21, 28, 35, 42, 49, 56, 63, 70	7, 14, 21, 28, 35, 42, 49, 56, 63	7, 14, 21, 28, 35, 42, 49, 56, 63, 70	7, 14, 21, 28, 35, 42, 49, 56, 63, 70	7, 14, 21, 28, 35, 42, 49, 56, 63
T7 (RSS, 9 DAT)[b]	9, 18, 27, 36, 45, 54, 63, 72	9, 18, 27, 36, 45, 54, 63, 72	9, 18, 27, 36, 45, 54, 63	9, 18, 27, 36, 45, 54, 63, 72	9, 18, 27, 36, 45, 54, 63, 72	9, 18, 27, 36, 45, 54, 63
T8 (RSS, 12 DAT)[b]	12, 24, 36, 48, 60, 72	12, 24, 36, 48, 60, 72	12, 24, 36, 48, 60	12, 24, 36, 48, 60, 72	12, 24, 36, 48, 60, 72	12, 24, 36, 48, 60
T9 (RSS, 15 DAT)[b]	15, 30, 45, 60	15, 30, 45, 60	15, 30, 45	15, 30, 45, 60	15, 30, 45, 60	15, 30, 45
T10 (control)	—	—	—	—	—	—

[a] Cartap hydrochloride (1.0 g litre^{-1}) was sprayed within 12–24 h.
[b] DAT = days after transplantation.

Table 2. Mean number of eggs laid and larvae per plant, and percentage of holes caused by *Plutella xylostella* in cole crops after different treatments at Hebbal

	Cabbage			Cauliflower			Knol khol		
Treatments	Eggs	Larvae	Holes	Eggs	Larvae	Holes	Eggs	Larvae	Holes
T1 (4 males/trap/night)	4.4*	0.9*	8.5*	1.4*	0.6*	3.5*	0.9*	0.2*	3.0*
T2 (8 males/trap/night)	9.6*	2.6*	11.5*	4.9*	2.3*	8.0*	2.3*	0.9*	6.5*
T3 (12 males/trap/night)	28.5*	9.5*	20.5	11.3*	4.2*	15.5*	7.7*	1.2*	10.2*
T4 (16 males/trap/night)	39.6	13.2	36.0	31.9	10.3	22.0	12.6*	3.2*	16.5
T5 (20 males/trap/night)	62.8	26.3	41.0	53.2	20.4	34.5	48.6	18.2	29.3
T6 (RSS, 7 DAT)[a]	47.3	15.8	29.5	39.6	13.2	25.5	35.2	11.4	22.0
T7 (RSS, 9 DAT)[a]	48.1	16.2	29.8	43.2	14.4	26.0	36.6	12.2	22.2
T8 (RSS, 12 DAT)[a]	51.4	17.0	30.0	45.6	15.2	26.5	38.4	12.8	23.1
T9 (RSS, 15 DAT)[a]	53.7	17.5	30.5	47.4	15.8	27.2	39.2	13.4	23.5
T10 (control)	122.3	32.5	85.0	108.6	29.2	81.4	72.3	24.1	76.5

* = Significantly different values (ANOVA, $P \leq 0.05$) in comparison with each regular spray schedule (RSS).
[a] RSS = regular spray schedule. DAT = days after transplantation.

3 RESULTS AND DISCUSSION

As shown in Tables 2 and 3, the mean number of eggs and larvae of the diamondback moth on the three crops and at both locations increased when the threshold catch for spray application was exceeded. This is demonstrated by comparing the population levels found on a specific crop when the same number of applications was applied, for instance, in Hebbal and for cauliflower, T3 (four treatments) resulted in 11.3 eggs per plant and 4.2 larvae per plant, while T4 (four treatments) resulted in 31.9 and 10.3, respectively. In knol khol a higher level of damage was noticed after T3 than after T2 (four applications each) and after T5 in comparison to T4 (three applications each). In Devanahally the same trend was observed, for instance by comparison of T4 with T3 in cabbage (six treatments) and cauliflower (five treatments), and T3 with T2 in knol khol (five treatments). A similar trend was noticed when the numbers of holes produced after the different treatments were considered, the figures being higher when the number of males caught was higher (see Tables 2 and 3).

When we compared treatments based on pheromone catches with the regular spray schedule after the same number of applications, the pheromone-based treatments were generally more effective than the applications based on regular timing. This is true not only for the number of eggs and larvae found in the plants but also for the number of holes. Thus, for instance, at Hebbal and for cabbage, T1 was better than T7 and T2 than T8, although T4 was inferior to T9; for cauliflower all pheromone-based treatments were more efficient (T1 > T8, T3 > T9, T4 > T9) and for knol khol the same trend was noticed (T1 > T8, T4 > T9) except T5 which was less effective than T9.

At Devanahally, similar results were obtained in all crops, that is, in cabbage T2 > T7, T3 > T8, in cauliflower T1 > T7, T2 > T8 and in knol khol T2 > T8, T3 > T8 and T4 > T9. The only exceptions were found in cabbage when T4 and T5 were compared with T8 and T9, respectively. Therefore, when dealing with considerably higher levels of adult population (16–20 males per trap per night), pheromone-based treatments may not be more effective than the regular timing of applications. As we expected, control plots (T10) showed a very high population density and infestation at both locations, ranging from 72.3 to 138.2 eggs per plant, 24.1 to 36.4 larvae per plant and 75.6 to 88.5% of holes for the three crops.

At the end of the season, the marketable yield of the crops at both locations was estimated and the values

Table 3. Mean number of eggs laid and larvae per plant, and percentage of holes caused by *Plutella xylostella* in cole crops after different treatments at Devanahally

	Cabbage			Cauliflower			Knol khol		
Treatments	Eggs	Larvae	Holes	Eggs	Larvae	Holes	Eggs	Larvae	Holes
T1 (4 males/trap/night)	6.6*	1.2*	10.5*	2.1*	0.7*	5.0*	1.7*	0.4*	3.5*
T2 (8 males/trap/night)	10.3*	3.1*	15.0*	5.4*	1.8*	8.5*	3.8*	0.9*	7.0*
T3 (12 males/trap/night)	32.5*	10.8	22.5	9.3*	3.1*	13.5*	7.9*	1.6*	10.5*
T4 (16 males/trap/night)	45.4	14.2	38.0	41.3	11.8	22.5	11.2*	4.4*	17.0
T5 (20 males/trap/night)	69.2	28.4	43.5	67.8	24.4	36.0	54.4	21.2	30.3
T6 (RSS, 7 DAT)[a]	56.9	18.8	30.0	54.3	16.2	26.5	42.1	14.0	21.1
T7 (RSS, 9 DAT)[a]	57.0	19.0	31.0	54.5	17.5	27.5	44.8	14.2	21.7
T8 (RSS, 12 DAT)[a]	59.1	19.7	32.0	55.8	18.0	27.8	44.0	15.3	22.2
T9 (RSS, 15 DAT)[a]	60.6	20.2	32.0	56.2	18.4	28.0	45.5	15.8	22.5
T10 (control)	138.2	36.4	88.5	117.8	32.0	82.0	91.4	28.4	75.6

* = significantly different values (ANOVA, $P \leq 0.05$) in comparison with each regular spray schedule (RSS).
[a] RSS = regular spray schedule. DAT = days after transplantation.

Table 4. Marketable yield (tonnes ha^{-1}) of cole crops after insecticide applications at Hebbal and Devanahally

	Hebbal[a]			*Devanahally*[a]		
Treatments	*Cabbage*	*Cauliflower*	*Knol khol*	*Cabbage*	*Cauliflower*	*Knol khol*
T1 (4 males/trap/night)	19.3a	15.5a	17.5a	18.5a	14.0a	16.5a
T2 (8 males/trap/night)	16.5a	14.0a	16.2a	16.0a	12.5a	16.0a
T3 (12 males/trap/night)	14.5b	12.0a	15.4a	14.0b	10.0a	14.5a
T4 (16 males/trap/night)	8.0d	7.5c	16.5a	8.5d	7.0c	14.5a
T5 (20 males/trap/night)	4.9e	4.8d	9.2c	5.4e	3.9d	8.8c
T6 (RSS, 7 DAT)[b]	12.5c	8.5b	13.0b	10.8c	8.5b	12.4b
T7 (RSS, 9 DAT)[b]	13.0c	8.3b	12.7b	10.5c	9.0b	12.2b
T8 (RSS, 12 DAT)[b]	12.8c	8.7b	12.8b	10.7c	8.4b	12.4b
T9 (RSS, 15 DAT)[b]	12.5c	8.5b	12.5b	10.5c	8.6b	12.0b
T10 (control)	3.6f	2.2e	4.2d	2.2f	1.8e	3.8d

[a] Means within a column followed by the same letter are not significantly different (DMRT, $P \leq 0.05$).
[b] RSS = regular spray schedule. DAT = days after transplantation.

are presented in Table 4. This important parameter also followed a similar trend to that found with the number of eggs, larvae and holes, that is, pheromone-based triggering of sprays was generally more efficient than fixed schedule treatments for the same number of applications. Thus, at Hebbal for cabbage T1 was better than T7, T2 than T8 but T4 was inferior to T9; for cauliflower T1 was superior to T8, T3 to T9 and for knol khol both T3 and T4 were better than T9. At Devanahally similar results were obtained: for cabbage T1 > T6, T2 > T7, T3 > T8, for cauliflower T1 > T7, T2 > T8 and for knol khol T2 > T8 and T3 > T8. Again, in cases when the number of males caught was 16 or more per trap per night, pheromone-based triggering of insecticide application was no better than the regular sprays. This was observed at Hebbal for the three crops for which T4 and T5 were inferior to T9, and at Devanahally for cabbage (T4 < T8 and T5 < T9). The untreated plots furnished considerably lower marketable yields (2.2–4.23 tonnes ha^{-1} as an average range for the three crops). Through the season, the average wind velocity and temperature at Hebbal were 6.22 m s^{-1} and 32.8 °C, and 4.47 m s^{-1} and 29.8 °C at Devanahally, respectively.

Infestation monitoring by sex pheromones in integrated pest management programs is well established.[15] The timing of control measures very often depends on the assessment of a reliable threshold catch.[16] Use of pheromone traps to determine threshold level has been reported for several insects. For instance, Neumark *et al*[17] reported that a capture threshold of five moths per trap per night in gossyplure traps at the end of July, and eight moths per trap per night later, was completely satisfactory in diminishing *Pectinophora gossypiella* (Saunders) infestation in Israel. In California, when the number of *P gossypiella* males captured in hexalure-baited traps averaged 3.5–4, application of insecticide sprays within 24 h resulted in significantly fewer applications being required for control than when sprays were applied on a fixed schedule every 5–7 days.[18] Likewise, Taneja and Jayaswal[19] found that application of insecticide when the number of moths averaged 4–8 per trap per night was superior to a regular spray schedule at intervals of 13–14 days in reducing *P gossypiella* damage on cotton seed. Against *Laspeyresia nigricana* (Stephens), insecticide spray was only necessary when the threshold catch was over 10 moths per trap during two consecutive alternate-day periods.[20] Other insects for which timing of insecticide sprays has been established include the codling moth *Laspeyresia pomonella* (L)[21] and the summer fruit tortrix moth *Adoxophyes orana* FvR.[22]

In *P xylostella* there have been no reports so far on the optimum trap catch threshold to optimize the timing of insecticide sprays, although Srinivasan and Veeresh[23] reported that visual damage of up to 1.0 hole per leaf could be effectively controlled by weekly or fortnightly insecticide treatments. Our results show that when the adult populations are 8, 12 and 16 males per trap per night in cabbage, cauliflower and knol khol, respectively, the pheromone-based treatments allow the establishment of an optimum period of insecticide application rather than a regular 7- to 15-day spray schedule. We have also found a good correlation between the immature stages, infestation level and crop yield with the number of trap catches, which makes pheromone-mediated monitoring a useful tool to predict population densities of the diamondback moth, thus replacing more costly and cumbersome sampling techniques. The relationship between moth catches and the actual population of adults, immature stages in the field or damage has been reported for other insects. For instance, in South Carolina, a good correlation was found between the number of *Heliothis virescens* F moths caught in pheromone traps and the number of eggs laid in a cotton field,[24] or between catches of the spruce budworm *Choristoneura fumiferana* Clem and density of second-instar larvae of the next generation.[25]

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