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Pheromonal Control of Diamondback Moth in the Management of Crucifer Pests

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Abstract

The effect of delayed mating on the reproductive potential of the diamondback moth, *Plutella xylostella* (L.), population was evaluated in the laboratory. The insecticide-resistant diamondback moth could be controlled by synthetic sex pheromones which are not harmful to beneficial species. However, the pheromones had no effect on other pests like aphids and common cabbageworm. Predators crawling on the ground, like lycosid spiders, played an important role as a biotic mortality agent of immature stages of diamondback moth. The chitin synthesis inhibitors that are selective insecticides were very effective on caterpillars like the common cabbageworm. Pheromone and chitin synthesis inhibitors which are harmless to beneficial arthropods are regarded as main chemicals acceptable in management of crucifer pests.

Introduction

The main drawbacks in insecticidal control of diamondback moth (DBM), *Plutella xylostella* (L.) (Lepidoptera: Yponomeutidae), are: (1) development of insecticide resistance; (2) resurgence of the insect after applications of insecticide; (3) nonselective killing of harmless and beneficial species (Nemoto 1986).

Synthetic sex pheromones have been utilized to suppress insect pest populations through either disruption of communication between the sexes or mass trapping of adult males. The efficacy of the pheromone is frequently measured by making comparisons between the percentage of tethered virgin females that mate in treated and control plots (Nemoto et al. 1985). In this paper, we present a converted Kiritani and Kanoh's equation (ER) and attempt to evaluate the effect of delayed mating on the reproductive potential of the DBM population by laboratory experiment. A disruption experiment was conducted in a commercial grower's field to evaluate efficacy of synthetic sex pheromones in controlling DBM.

Nemoto (1986) reported that according to immunological tests lycosid spiders are important as biotic mortality agents of DBM. The role of predator or parasite in this experiment was evaluated by artificially excluding them from the estimation of DBM mortality.

The control of only one species of pest is meaningless for crucifers that require simultaneous protection from other pests. The effect of insecticides on these pests was evaluated.

Evaluation of delayed mating DBM population

The possible role of a pheromone-induced delay in mating on the reproduction of the oriental tea tortrix, *Homona magnanima* Diakonoff, has been examined by Kiritani and Kanoh (1984), who considered that the delayed mating or fertilization on the part of females might reduce their fecundity through shortening their reproductive period and aging. They proposed an equation for the expected reproduction (ER) of a t-day-old female.

A high percentage of mating inhibition, for example 90%/night, however, does not result in the same degree of suppression of the target population if the mean longevity of the adults exceeds 1 day. If the virgin females lived for only 1 day, a 90% mating inhibition/night would result in 10% of the females being mated, while up to 65% ($1 - 0.9^{10} = 0.65$) of the females would eventually be fertilized if they lived for 10 days. On the other hand, the delay in mating reduces total fecundity through shortening the female reproductive period. Yamada (1979) observed that most of the newly emerged females mated on the first night of their emergence and began to lay eggs on the following night. Unmated females lay a few eggs. The effect of delayed mating on various reproductive traits is presented in Table 1. Fecundity, viability of eggs and oviposition period all decreased with an increase in number of days elapsing before pairing after emergence.

Table 1. Effect of delayed mating on the reproductive traits of DBM.

Days after emergence and before pairing	No. of pairs	No. (and %) of pairs mated	No. of eggs laid/ovipositing female	No. of fertilized eggs/ovipositing female	Expected reproduction (RER)
0	20	17(85)	108.1±8.8a	102.9±28.9e	87(95)
2	19	18(95)	100.9±10.9ab	97.1±10.9e	92(100)
4	20	14(70)	79.6±10.0bc	77.9±10.1ef	41(44)
6	15	10(67)	71.8±11.8c	60.3±13.9f	21(23)
8	11	8(73)	61.8±15.3c	51.1±15.6f	15(16)
11	14	8(57)	73.9±15.0bc	52.4±16.8f	14(15)
Unmated control	28	–	13.6 ± 24.3 d	–	0(0)

The expected reproduction (the total number of viable eggs that could be laid during the female lifespan) of a t-day-old female which mated first on the tth day after emergence can be expressed by the following equation (Kiritani and Kanoh 1984):

$$\text{Expected reproduction of a } t\text{-day-old female (ER)} = \text{Percentage successful mating} \times \text{Survival rate until } t\text{th-day} \times \text{Total no. of viable eggs deposited}$$

This may be converted to the following equation:

$$\text{ER} = \text{Percentage successful mating} \times \Sigma\ \text{the age-specific survival rate of female adults} \times \text{age-specific fecundity}$$

Successful mating refers to mated females that lay fertilized eggs. All mated females laid fertilized eggs in the present experiment. The relative expected reproduction (RER) of the female mated t days after emergence is then calculated (Table 1). The effect of delayed mating on ER becomes highly significant when the delay exceeds 6 days. This effect would be intensified under natural conditions, where adult survival would be influenced by weather, predators and other factors.

Utilization of synthetic sex pheromones for DBM control aims to reduce the number of fertilized females in a given area. The effect of pheromone on the pest population therefore depends on the extent to which the pheromone application inhibits mating of virgin females. The realized RER (see the 4th column in Table 2) of the treated population at various levels of inhibition was calculated to evaluate the effect of this inhibition on the reproduction of the DBM population.

The cumulative percentage of mated females and the realized RER of populations subjected to various levels of mating inhibition are shown in Table 3. If it is assumed that the life span of females is invariably 12 days, then mating inhibition as high as 72% will have little influence on the population size of the following generation. Ninety percent inhibition is expected to reduce the target population to 41% of the untreated population, assuming no immigration from outside of the plot. A similar conclusion has been reached by Kiritani and Kanoh (1984) for *H. magnanima* and Nakasuji and Fujita (1980) for *Spodoptera litura* (F.) populations by means of computer simulations.

Comparison between the cumulative mating percentage and the realized RER shows that the initial reduction of RER occurs at a lower level of daily mating inhibition than the cumulative mating percentage (Table 3). This is because realized RER involves the effect of delayed mating on reproduction. Delayed mating also leads to a delay in oviposition or lengthening of the preoviposition period. Although this factor has not been considered in the present discussion, it may play an important role in slowing down the population growth of insects under certain conditions. From the practical point of view, the optimum level of mating inhibition will depend on the cost: benefit aspects of the relationship between the number of pheromone sources required and the necessary level of mating inhibition. The latter is also a function of pest density and the reproductive traits of the species.

It can be concluded that the effect of sex pheromone on the target DBM population depends not only on the direct effect of mating inhibition, but also on the indirect effects of delayed mating which reduces ER. A high level of mating inhibition (more than 90%) and/or other mortality agents would be required for a substantial reduction of DBM populations.

Table 2. Cumulative percentage of mating females and the realized relative expected reproduction (RER) for the population when mating of females is inhibited.

Pivotal age of female	RER (A)	Daily rate of virgin females (B)	Realized RER (C) = (A).(B)
0.5	95	0.10	9.5
1.5	98	0.09	8.8
2.5	100	0.08	8.1
3.5	79	0.07	5.8
4.5	44	0.07	2.9
5.5	30	0.06	1.8
6.5	23	0.05	1.2
7.5	18	0.05	0.9
8.5	16	0.04	0.7
9.5	16	0.04	0.6
10.5	15	0.03	0.5
11.5	15	0.03	0.5

Lonegvity of females and the level of daily mating inhibition are assumed to be 12 days and 90%, respectively.

Table 3. Cumulative percentage of mated females and the realized RER in a hypothetical population where all females live for 12 days under various levels of mating inhibition.

Daily level of inhibition (%)	99	98	97	96	95	94	90	80	70	60	40	20	0
Cumulative % of mated females	11[a]	22	31	39	46	52	72	93	99	100	100	100	100
Realized RER of the population	5	10	17	19	24	28	41	65	79	87	94	95	100

[a] $1-(0.99)^{12} = 0.11$.

Pheromonal Control of DBM in the Field

A disruption experiment was conducted in a 5-ha field in Kawagoe, Saitama Prefecture, in 1989. Brassica greens (pakchoy), radish, taro and other vegetables were cultivated. In this area DBM has developed resistance to synthetic pyrethroids and other chemicals. Brassica greens were covered with netting to prevent physical invasion by flying adult pests. Twenty meters per 0.1 ha of KONAGA-CON (a rope-type dispenser containing synthesized sex pheromone for DBM in a 1:1 mixture of Z11-16Ald and Z11-16Ac (25 g AI/100m), and made by Shin-Etsu Chemical Co. Ltd.) were extended on the poles 40 cm high in the radish fields and on the netting tunnels in the brassica greens fields. The rope-type dispensers were arranged in a mosaic pattern in the 5-ha experimental fields. Throughout the season (June to October), the number of DBM males captured in the yellow sticky traps which were set as monitors in both the pheromone and pheromone+chemical (EPN) treatment fields was always lower than the traps in the control or only chemical (pyrethroid) treatment fields. The reduction of DBM larval density on radish leaves in both the pheromone and pheromone+chemical treatment fields was also apparent when compared with the density in the control or chemical (pyrethroids) treatment field (Fig. 1). The daily percentage mating inhibition using tethered virgin DBM females in the pheromone-treated field ranged from 50 to 100% (average 70%). Seventy percent inhibition is expected to reduce the target population to only 79% of the untreated population (see Table 3).

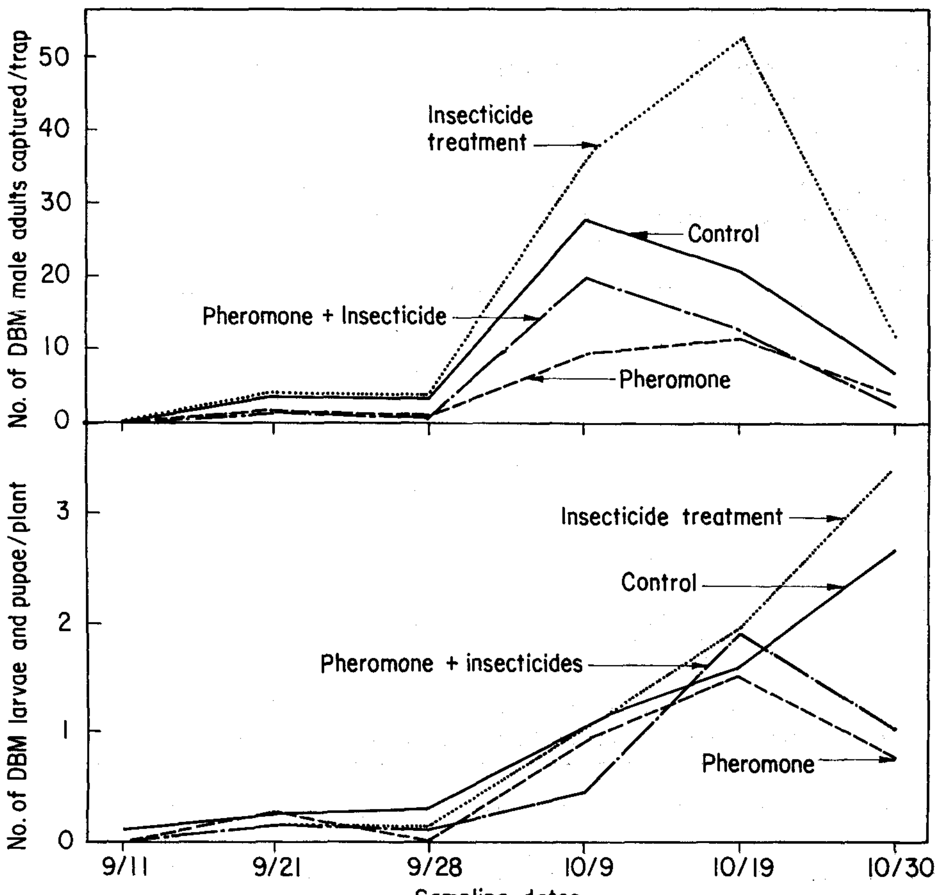

Fig. 1. Effects of pheromone treatments on the DBM populations in radish fields in 1989 at Kawagoe, Saitama, Japan.

But DBM could be controlled in the radish and brassica greens fields through the application of the synthetic sex pheromone which was harmless to beneficial arthropods. In this experiment, the pheromone treatment, however, had the most effect on DBM. We, therefore, thought that natural enemies played a more important role in the control of DBM in pheromone-treated fields.

Evaluation of Natural Enemies

The role of predator and parasite was evaluated by artificially excluding them from the estimation of DBM mortality. The brassica greens on which DBM eggs were laid in the laboratory within 24 hours were planted in cages in the cabbage field at Saitama Horticultural Experiment Station (SHES) during 1989-90. Cages (90 × 90 × 90 cm) were covered with mesh netting (0.2, 1.0, 1.4, 6.0 and 13.0 mm). Another cage (90 × 90 × 30 cm) was covered with vinyl film except the top and treated with a sticky substance on the upper edges of the vinyl film to exclude ground-crawling predators but to allow flying predators to invade the cage. The 0.2-mm-mesh cage excluded all predators and parasites. The 1.0- and 1.4-mm-mesh cages excluded predators but no parasites. The 6- and 13-mm-mesh cages excluded birds and/or predatory wasps but not ground-crawling predators. The larvae within the cages covered with 6 and 13 mm mesh and in the control plots decreased more rapidly than in the other cages (Fig. 2). This showed the importance of all natural enemies in reducing DBM population.

Nemoto (1986) reported the lycosid spiders were reduced through the application of methomyl, and were important biotic mortality agents of DBM based on immunological tests. These results suggest that ground-crawling predators like lycosid spiders play an important role as biotic mortality agents of immature stages of DBM.

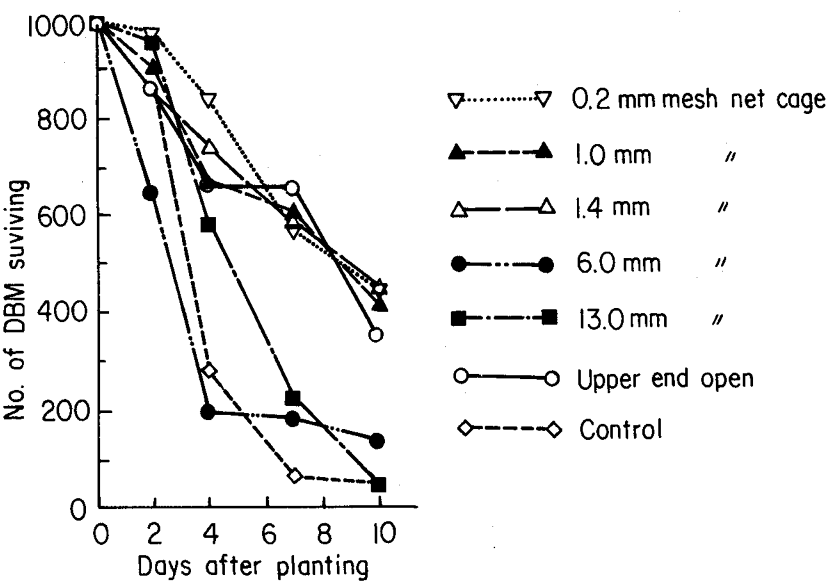

Fig. 2. Survivorship curves of immature stages of DBM (out of a thousand originally born) within the different mesh cage.

Effectiveness of different chemicals

The major pests of crucifers in Japan are DBM, common cabbageworm, *Pieris rapae crucivora* Boisduval, beet semi-looper, *Autographa nigrisigna* Walker, green peach aphid, *Myzus* *persicae* Sulzer, and cabbage aphid, *Brevicoryne brassicae* L. The control of only one species of pest is meaningless for crucifers that also require simultaneous protection from other pests. The pheromone was able to control DBM, but didn't control other pests. If chemical insecticides were not sprayed, crucifer production was seriously affected by the common cabbageworm and cabbage aphid.

The effects of the chemicals with different modes of action on pests of crucifer vegetables are shown in Fig. 3. Thiocyclam was effective on caterpillars and aphids. This insecticide had good initial action against the pests, but its residual effect was weak. DBM and aphid populations increased again 20 days after spraying. Cypermethrin was effective against aphids and caterpillars, but not DBM. Chlorfluazuron and other chitin synthesis inhibitors, which are selective insecticides and are harmless to beneficial arthropods, performed well against caterpillars, but were ineffective for aphids.

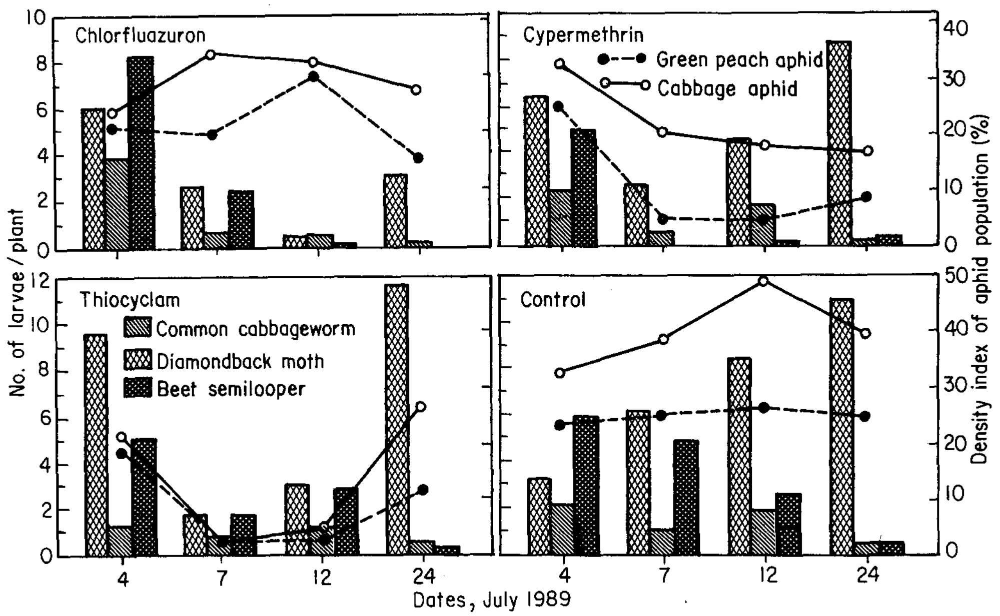

Fig. 3. Insect population densities after application of chemical at SHES in 1989.

Discussion

Insecticide resistance is most acute in DBM. The frequency of resistance in pest population is in large part a result of selection pressure from pesticide use (Georghiou 1980). Insect pests which were resistant to insecticides could be controlled by pheromones. The pheromone reduced the frequency of application of insecticides to control DBM, but the pheromones cannot control other pests. It is difficult for farmers not to spray chemical insecticides, because of the lack of economical alternative pest control methods for the other pests, except *S. litura*. Mass trapping of *S. litura* by synthetic sex pheromones was demonstrated successfully in 1978 in the area where the disruption experiment for DBM control was conducted (Nemoto et al. 1980). *Sl*NPV also shows potential in the control *S. litura* (Nemoto and Okada 1990). These are alternative pest control measures for *S. litura*.

However, we do not have nonchemical control methods for aphids and common cabbageworm. Ground-crawling predators such as lycosid spiders played an important role as a biotic mortality agent of immature stages of DBM. Pest management in crucifers requires the nonchemical control method and application of selective insecticides. The chitin synthesis inhibitors, which are selective, were highly effective on caterpillars like common cabbageworm.

Pheromone and chitin synthesis inhibitors are regarded to be the best means of pest management in crucifers.

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