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Changes in Insecticide Susceptibility of the Diamondback Moth in Wakayama, Japan

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Abstract

Susceptibility to some pesticides of the diamondback moth, Plutella xylostella L., collected from Wakayama Prefecture, Japan was examined with the third instar larvae by the leaf-dip method. Most populations under test showed remarkably reduced susceptibility to organophosphates and carbamates. Cartap was relatively effective except in some locations. Pyrethroid resistance was first identified in Wakayama, Gobo and Inami, where cruciferous crops were extensively grown, and the resistant moths spread over Wakayama Pref. with time. Most of the populations showed no resistance to Bacillus thuringiensis (BT). The Gobo population however developed resistance to BT, reaching approximately 60 of resistance ratio in 1986 and 1987 under the frequent applications of BT. No resistant populations for chitin synthesis inhibitors have been observed so far.

Discipline: Insect pest
Additional key words: Bacillus thuringiensis, chitin synthesis inhibitor, organophosphate, pyrethroid

Introduction

Incidences of damage caused by the diamondback moth, *Plutella xylostella* L., have gradually increased in Japan in accordance with the expansion of the areas grown to cruciferous crops all the year round[1]. Organophosphates and carbamates were intensively applied for controlling the diamondback moth since the late 1980s in Wakayama Pref. It was however confirmed that high resistance to dichlorvos and salithion appeared out by the late 1970s and to methomyl and acephate by the early 1980s. In controlling such insecticide-resistant moths, pyrethroids were highly effective at the initial period of their use. However, the diamondback moth resistant to the pyrethroids were observed in Wakayama, Gobo, Inami districts in 1985[4]. Insecticides available for effective control of those resistant moths are limited at present.

This paper reviews the present status of insecticide resistance of the diamondback moth and its control in Wakayama Pref. located in the southwest of Japan.

Cruciferous cropping pattern

Major cruciferous crops in Wakayama Pref. were cabbage (*Brassica oleracae*; 631 ha), Chinese cabbage (*B. campestris*; 202 ha), Japanese radish (*Raphanus sativus*; 391 ha), broccoli (*Brassica oleracae*; 309 ha) and common stock (*Matthiola incana*; 36 ha), as of 1989.

Fig. 1 shows seasonal changes in occurrence of the diamondback moth, cruciferous cropping patterns and application frequencies of insecticides per growing season for controlling the diamondback moth in Wakayama district. The moth adults trapped with pheromone increased from spring, reaching the first peak in May/June and the second, lower peak in Nov./Dec. As indicated in Fig. 1, there are various types of cropping patterns of crucifers. Reflecting those patterns, insecticides for controlling the diamondback moth are applied more frequently in the warm season, i.e. April to September, because the moth population grows with a high rate. No insecticides are applied to Chinese cabbage, which is cultivated in the period from February to April.

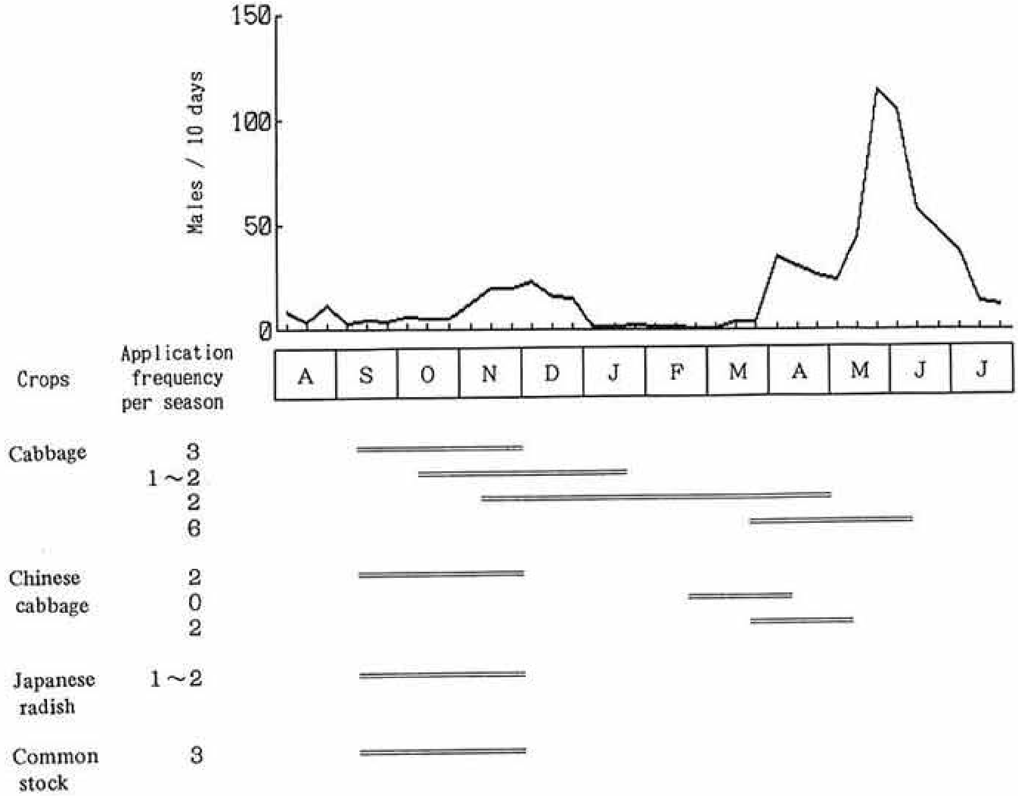

Fig. 1. Seasonal changes in occurrence of the diamondback moth expressed by pheromone trap catches (mean value for 1981–1990), planting patterns of crucifers, and application frequencies of pesticides per growing season (═) in Wakayama district

Susceptibility to insecticides

1) Bioassay

Larvae and pupae were collected from farmers' fields and reared on radish seedlings in the laboratory. Laboratory assays were conducted with the third instar larvae of the first or second generation. The insects were released on cabbage leaves dipped in concentrations of various insecticides and kept at 25°C. Mortality was recorded after 72 hr for *Bacillus thuringiensis* (BT) and 48 hr for the other insecticides.

2) Organophosphates, carbamates and tertiary amines

Table 1 shows the susceptibility to several insecticides presented by the diamondback moths collected from various commercial fields in Wakayama Pref. Methomyl and acephate were less effective in all the populations examined. Prothiofos and phenthoate seemed to be less effective except in several locations. The diamondback moths have developed high resistance to organophosphates and carbamates. Methomyl and acephate, however, are still applied in the fields, since the incidences of other pests, such as aphids, cabbage worm (*Pieres rapae*) and cabbage armyworm (*Mamestra brassicae*), are effectively controlled with them.

Among the organophosphates tested only dimethylvinphos was relatively effective (LC_{50}; 67 ppm). Carbosulfan and benfuracarb (carbamate) were also effective with a pricking-in hole treatment or a plant root treatment at the planting stage. Cartap (tertiary amines) was relatively effective except in some locations such as Gobo, Minabe and Hashimoto (Table 1).

Table 1. Susceptibility to insecticides of the diamondback moth collected from different locations in Wakayama Pref., Japan

Location	Year	LC50 (ppm)						
		Methomyl 45% WP	Acephate 50% WP	Prothiofos 45% EC	Phenthoate 50% EC	Fenval. 10% + mala. 30% WP[a]	Cartap 50% SP	*B. thuringiensis* (Toarrow) 7% WP
Hashimoto	1987	1,800<	2,000<	1,030	-	56	272	-
	1988	-	2,000<	-	217	119	23.9	0.92
Katsuragi	1987	1,800<	1,680	170	-	17	25	0.32
Uchita	1988	-	2,000<	-	1,360	800<	32.6	2.1
Iwade	1985	1,800<	2,000<	520	-	84	-	0.22
Wakayama	1985	1,800<	1,240	1,800<	-	1,600<	-	-
	1988	-	1,690	1,800<	-	1,600<	-	-
Gobo	1985	1,800<	2,000<	560	-	1,600<	340	3.9
	1988	-	1,630	-	2,000<	1,600<	403	3.0
Inami	1985	1,800<	2,000<	1,360	-	1,600<	49	0.34
	1988	-	2,000<	-	1,900	1,600<	51.3	0.62
Minabe	1988	-	640	-	1,620	1,600<	288	1.2
Kushimoto	1985	1,650	900	200	-	38	55	0.90
Kozagawa	1985	1,800<	500	230	-	64	102	0.5>

a): Fenvalerate + malathion.

3) Pyrethroids

Regarding the pyrethroids, fenvalerate was first introduced to Wakayama Pref. in 1983. However, high resistance to this insecticide was found in Wakayama, Gobo, and Inami districts before 1985 (Table 1). In these areas, the pyrethroids had been used more than 10–20 times for two years before the pyrethroid resistance developed in the moth populations. The diamondback moth resistant to the pyrethroids has rapidly spread over Wakayama Pref. with time. Such a rapid development of pyrethroid resistance in Wakayama Pref. was similar to that in other prefectures[2,3].

The Gobo population showed high resistance to the other pyrethroids, i.e. permethrin, cypermethrin and flucythrinate, which had never been used before the present survey. This result suggested cross-resistance of the diamondback moth to various pyrethroids.

4) Bacillus thuringiensis toxins

Although no resistance to BT toxin (Toarrow-CT) was found in all the populations under test, the LC_{50} value against BT was higher in the Gobo population than the other populations (Table 1). Since 1985, the susceptibility of moths to BT (Toarrow-CT) has been monitored in the same field in Gobo district. The LC_{50} values against BT increased with time, reaching the maximum level of ca. 20 ppm (resistance ratio; 60) in autumn, 1986 and 1987. Thereafter, they decreased to 2.3 ppm in 1988 and 0.22 ppm in 1989 (Figs. 2 and 3). In 1985 and 1986, BT (Toarrow-CT or Thuricide) was intensively used in this area. However, this insecticide has not been

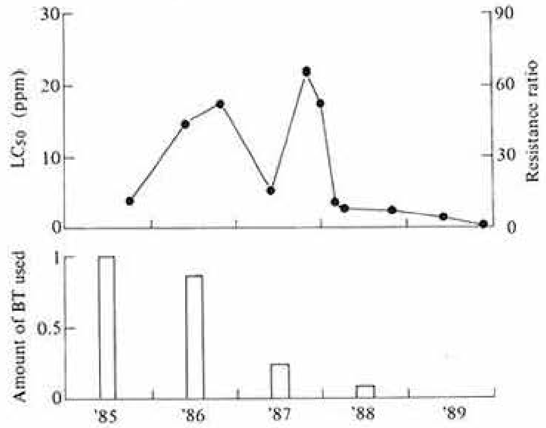

Fig. 2. Changes in susceptibility of the diamondback moth to *B. thuringiensis*
The amount of *B. thuringiensis* formulation used is calculated on the basis of 1 in 1985 in Nada, Gobo district.
Resistance ratio indicates a ratio of LC_{50} value of the population against that in a susceptible strain (Nihon Noyaku Co.).

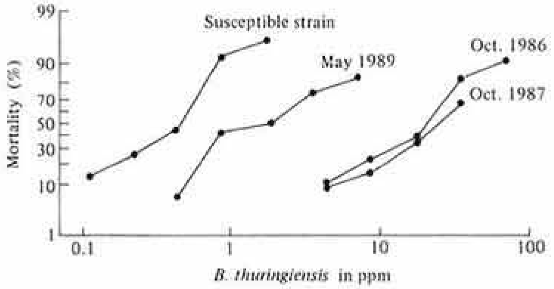

Fig. 3. Concentration–mortality relationships of the diamondback moth collected from Gobo and a strain susceptible to *B. thuringiensis*

Table 2. Comparison for susceptibility of the diamondback moth (Gobo population) to chlorfluazuron under different stages

Stage	LC_{50} (ppm, 95% C.I.)
2 days after the treatment	0.467 (0.267–0.816)
3 days after the treatment	0.164 (0.100–0.267)
11 days after the treatment (adult emergence)	0.058 (0.032–0.106)

Table 3. Comparison for susceptibility to insecticides between the diamondback moth in a cabbage field and that in a field of noncultivated plant (wild radish) in Gobo district

Insecticide	LC_{50} (ppm)	
	Cabbage	Wild radish
Fenvalerate 10% + malathion 30% WP	1,600<	1,600<
Cartap 50% SP	1,031	279
B. thuringiensis (Toarrow 7% WP)	3.2	2.7

used so extensively since 1987, because the growers were concerned about the development of the diamondback moth population resistant to it. This indicates that the susceptibility to BT has significantly declined in accordance with the decrease in its application frequencies. Tabashnik et al.[7] and Tanaka and Kimura[8] have recently reported that high resistance to BT was acquired by the moth on watercress, *Roripa nasturtium-aquaticum*, under its heavy applications.

5) Chitin synthesis inhibitor

To examine the susceptibility of the diamondback moth to chitin synthesis inhibitor (IGR), larvae were fed for 2 days with cabbage leaves that were dipped in concentrations of IGR, and thereafter with new leaves without insecticides and emergence of the adults in 10–12 days after the treatment at 25°C was surveyed as the criterion for estimating the effectiveness of IGR (Table 2). As well known, IGR prevents molting of insects by interfering with their formation of a new cuticle. In the present study, cabbage leaves were used for bioassay, while Perng and Sun[6] used mustard seedlings.

No resistant population for chitin synthesis inhibitors was identified in Wakayama Pref. The LC_{50} values for Wakayama population of chlorfluazuron, teflubenzuron, and flufenoxuron were 0.14, 0.07, and 0.05 ppm, respectively. However, a control failure for the diamondback moth with chlorfluazuron was experienced in Kagoshima Pref., southern Japan (Horikiri, personal communication).

Table 3 shows the susceptibility of the diamondback moths collected from the cabbage field and the non-cultivated crucifer (wild radish) field, which are 1.7 km off each other in Gobo district. No differences in the LC_{50} values to the 3 insecticides were observed between cabbage and wild radish. This suggests that non-cultivated plants cannot maintain the susceptible population because of their relatively small capacity of growing the moth population as well as of the invasion of a large number of insecticide-resistant immigrants from the cultivated plants.

Countermeasures

In spite of high resistance of the diamondback moth to various insecticides, the result of a field experiment indicated that dimethylvinphos, BT toxin (Toarrow-CT) and chitin synthesis inhibitor (Teflubenzuron) provided rather effective control (Table 4). In addition, carbosulfan and benfuracarb were also effective with a plant root treatment at the planting stage. In order to put off or suppress the rapid development of insecticide resistance, it may be useful to take a rotational application of various kinds of insecticides.

A recommended system of the rotational application is as follows: in the warm season, when the

Table 4. Effects of the insecticides on the diamondback moth in cabbage, Kishigawa district in 1990

Insecticide	Dilution rate	No. of larvae per plant				Index of corrected infestation		
		Before application	3 DAA[a]	7 DAA	11 DAA	3 DAA	7 DAA	11 DAA
Fenvalerate 10% + malathion 30% WP	1,000	10.7	7.6	13.4	24.1	55.0	76.0	126.9
BT (Toarrow-CT)	1,000	17.4	0.8	1.1	10.0	3.9	4.0	32.6
Teflubenzuron 5% EC	2,000	10.4	2.8	0.4	0.2	20.3	2.2	1.4
Salithion 25% EC + carbaryl 85% WP	1,000	13.1	4.4	7.5	15.7	25.8	34.9	67.9
Dimethylvinphos 50% WP	1,000	15.5	2.3	3.2	11.6	11.3	12.8	42.4
Untreated		8.6	11.1	14.1	15.2	100.0	100.0	100.0

a): DAA; days after application.

diamondback moth population rapidly increases, the plant root treatment is practiced with carbosulfan or benfuracarb at the planting time followed by an application of chitin synthesis inhibitor in 20-25 days after the planting. If the diamondback moth occurs, BT or dimethylvinphos is additionally applied. For the other types of cropping patterns the same steps are taken without the plant root treatment.

It is also important to accompany other countermeasures, such as avoidance of continuous growing of cruciferous crops, row-cover treatment with materials, use of sex pheromones and natural enemies. The row-cover treatment along with 1-2 times application of insecticides provides an effective control for the diamondback moth. This would be equally effective to the conventional insecticide spray of 6-8 times in summer cabbage[5].

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