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

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Abstract

The changes in insecticide susceptibility of the diamondback moth (Plutella xylostella L.) collected from cabbage fields in Iwaoka, Hyogo Prefecture, Japan were investigated during the period 1985 to 1990. The susceptibility of the diamondback moth to acephate had been continuously low since the initiation of the experiment conducted in 1985. The susceptibility to cartap and BT was high in 1985 when they were both introduced to Iwaoka for the first time. However, since 1988, their effectiveness has gradually declined, followed by a drastic decrease since 1989. Susceptibility to phenthoate has rapidly receded due most probably to intensive sprays repeated every year. The combination of fenvalerate with malathion applied for 2 years, resulted in the rapid decline in effectiveness, starting in June 1986. However, its effectiveness slowly recovered in 3 years after its use was discontinued. It is very likely that the development of insecticide resistance in insects is heavily dependent on the spray frequencies in fields. Effectiveness of insecticides for several moth populations in Hyogo Pref. was examined. The populations in the highlands of Hidaka and Kinosaki showed high susceptibility to all the insecticides tested. On the other hand, the populations in the southern lowlands of Hyogo, such as Mihara and Hirano, possessed very low susceptibility to them at the initial stage of application. Their susceptibility level also declined year by year, however. Dimethylvinphos and chlorfluazuron are most probably recommendable for practical use in fields.

Discipline: Insect pest
Additional key words: cabbage, fluctuation, resistance, Plutella xylostella L.

Introduction

The diamondback moth, *Plutella xylostella* L., is one of the important pests for cruciferous crops, causing serious crop damages in many parts of the world, especially in Southeast Asia. In Japan, the population of this insect has expanded since 1960, and severe damage took place mainly in cabbage. It is recognized that this species easily develops insecticide resistance, as a consequence, it is now the most difficult pest to control[1,2,6]. Insecticides are applied once every week in cruciferous fields, mainly for cabbage, in Hyogo Pref.; in fact, they are generally applied 6 to 7 times, occasionally more than 10 times, in each cropping season (Table 1). Under such heavy applications, susceptibility of the diamondback moth to various insecticides has decreased year by year, and resistant colonies are now widely distributed in the prefecture[1,2,6,7].

Through the use of organophosphorus insecticides such as dichlorvos and acephate, the diamondback moth has developed its resistance to them since the latter half of the 1970s[3,4]. The resistance to carbamates, including methomyl, has developed since the 1980s[7]. The synthetic pyrethroids have been used extensively since 1983 with high effectiveness in

Table 1. Frequencies of insecticide applications

Crop	Application times per cropping (time)	Application interval (day)
Cabbage (Spring)	6.0	9.3
Cabbage (Autumn-Winter)	6.9	8.4
Chingensai	4.5	5.3

controlling the diamondback moth. However, the resistance emerged in Okinawa and Kagoshima in 1984[5], spreading in the western part of Japan, including Wakayama, in 1985[6]. In Hyogo Pref., the decrease in susceptibility to the pyrethroids was first observed in a small part of Kobe in 1984[1,8], extending to various locations in 1985 and the following years. Such a decrease took place not only with the pyrethroids but also with many other insecticides; thus, the effective insecticides presently available are extremely limited. Although IGR is now applied in practice, it is far below the satisfactory level in controlling this pest[2,6].

This paper attempts to review the susceptibility of the diamondback moth to various insecticides in Hyogo Pref. and its changes occurring in the same cabbage fields.

Materials and methods

1) Insects

More than 200 of the last instar larvae and pupae of the diamondback moth, *Plutella xylostella* L., were collected from cabbage fields in various locations of Hyogo Pref. (Fig. 1). After emergence, 50 adults were released on radish seedlings grown in a plastic container (25 × 18 × 8 cm). The eggs were laid and the hatched larvae were raised at 25°C. The third instar larvae of F_1 were used for bioassay. In Iwaoka in Kobe, the moths were collected twice a year, i.e. in spring and autumn, from the same cabbage field in the period 1985 to 1990 to examine the changes in their insecticide sensitivity. A susceptible strain was provided by Sumitomo Chemical Co., Ltd. for raising under the same procedure with the field populations.

2) Insecticides

Organophosphates: phenthoate 50% EC, acephate 50% WP, dimethylvinphos 50% WP; Pyrethroids: fenvalerate + malathion 40% WP, permethrin 20% EC; Nereistoxin derivatives: cartap 50% SP; BT: Toarrow-CT 7% WP, Bacilex 10% WP; IGR: chlorfluazuron 5% EC.

3) Bioassay

Each of the insecticides was diluted with tap water to get 4 to 6 concentrations and 0.02% spreader was added in each solution. A cabbage leaf was dipped in the solution for 1 min. After drying at the room temperature, the treated leaf was put into a plastic cup (10 cm diameter, 4.5 cm deep), in which 10 third instar larvae were released. The cup was kept at 25°C under 16 hr-light and 8 hr-dark for 2 days to examine mortality of the moths. The experiment was replicated 3 times.

Fig. 1. Locations in which diamondback moths were collected in Hyogo Pref.

4) Field test

Populations of the diamondback moth were surveyed in a cabbage field of Iwaoka.

Insecticides applied: BT (Toarrow-CT 7%) WP × 1,000, cartap 50% SP × 1,000, dimethylvinphos 50% WP × 1,000, chlorfluazuron 5% EC × 2,000, permethrin 20% EC × 1,000, permethrin 20% EC × 2,000 + acephate 50% WP × 1,000, carbaryl 50% WP × 1,000 + salithion 50% EC × 1,000.

Table 2. Changes in insecticide susceptibility of the diamondback moth

Insecticide		Oct. 1985		June 1986		Oct. 1986		May 1987		Oct. 1987		Feb. 1988	
		LC_{50}[a)]	R/S	LC_{50}	R/S	LC_{50}	R/S	LC_{50}	R/S	LC_{50}	R/S	LC_{50}	R/S
Acephate	WP	1862	38.8	–	–	677	14.2	728	15.2	1268	26.5	1202	25.1
Cartap	SP	–	–	187	2.4	328	4.2	126	1.6	447	5.8	468	6.1
Phenthoate	EC	–	–	370	24.7	219	14.6	407	27.1	1213	81.0	950	63.0
Fenvalerate + malathion	WP	<100		811	40.6	582	29.1	389	19.5	954	47.7	773	38.7
BT (Toarrow)	WP	–	–	0.7	0.3	–	–	–	–	2.6	1.1	5.5	2.3
BT (Bacilex)	WP	–	–	<0.6		2.7	1.0	1.2	0.4	–	–	5.6	1.9

Insecticide		July 1988		Oct. 1988		June 1989		Nov. 1989		June 1990		Nov. 1990	
		LC_{50}	R/S	LC_{50}	R/S	LC_{50}	R/S	LC_{50}	R/S	LC_{50}	R/S	LC_{50}	R/S
Acephate	WP	890	18.6	1825	38.2	2000<		–	–	–	–	708	13.2
Cartap	SP	359	4.7	435	5.6	518	6.9	710	9.2	–	–	1230	28.1
Phenthoate	EC	1184	78.9	1136	75.7	2000<		1529	101.9	871	58.1	909	60.6
Fenvalerate + malathion	WP	1600<		825	41.3	297	14.9	567	28.4	734	36.7	487	15.9
BT (Toarrow)	WP	–	–	19.3	8.0	43.7	19.0	–	–	–	–	96.0	41.7
BT (Bacilex)	WP	–	–	16.5	5.7	78.8	27.2	55.6	19.2	28.0	9.7	34.0	11.7

a): LC_{50}; ppm.

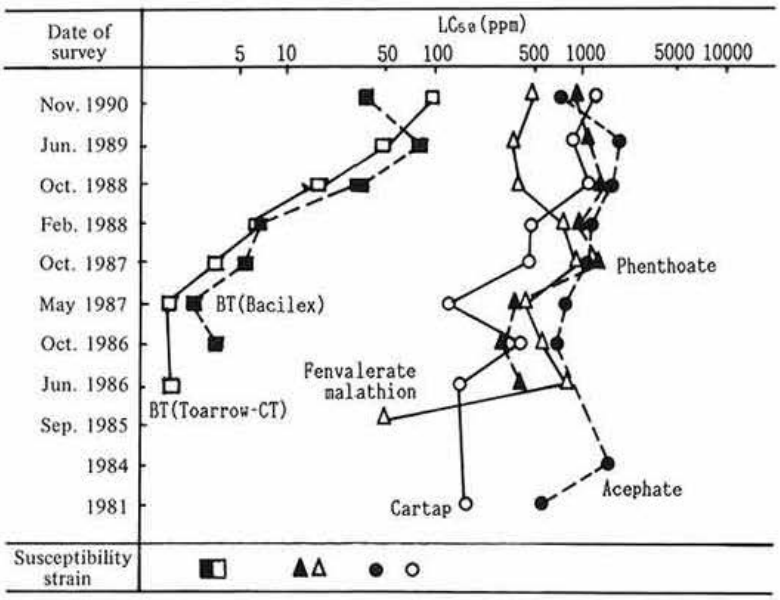

Fig. 2. Changes in insecticide susceptibility of the diamondback moth in Iwaoka, Japan

The above insecticides were sprayed with an autosprayer at a rate of 200 l/10 a. In the experiment, four surveys were made: before the spray, 3, 8, and 15 days after the spray. Numbers of survived larvae or pupae of the diamondback moth were counted on 10 cabbage hills in each area.

Results and discussion

Table 2 and Fig. 2 show the changes in susceptibility to 5 insecticides of the diamondback moth collected in Iwaoka, which is the main producing area of cabbages in Hyogo Pref. Among the insecticides applied, the susceptibility to acephate was continuously low since the first experiment was conducted in 1985. This may be the major reason why acephate had been used for several years even before 1985

Table 3. Insecticide susceptibilities of the diamondback moth in June 1988

Insecticide		LC_{50} (ppm)							Susceptible strain
		Iwaoka	Kande	Uozumi	Inami	Sumoto	Mihara	Hidaka	
Acephate	WP	891	2000<	2000<	2000<	1877	1481	293	53.5
Cartap	SP	360	187	261	349	158	164	<31	43.7
Phenthoate	EC	1184	1851	1338	1229	207	1116	65	15.0
Fenvalerate + malathion	WP	1600<	1600<	1600<	1600<	1600<	1600<	121	30.6
BT (Toarrow)	WP	<4.4	<4.4	<4.4	4.6	-	-	<4.4	3.5

Table 4. Insecticide susceptibilities of the diamondback moth in October 1989

Insecticide		LC_{50} (ppm)							
		Iwaoka	Kande	Uozumi	Inami	Hirano	Ikawadani	Mihara	Hidaka
Acephate	WP	1898	2000<	420	2000<	1624	2000<	2000<	1457
Cartap	SP	336	103	104	140	1000<	209	156	137
Phenthoate	EC	700	291	631	531	675	2000<	319	433
Fenvalerate + malathion	WP	470	1205	1600<	704	1600<	1600<	1600<	867
Permethrin	EC	144	-	800<	-	516	174	128	147
BT (Toarrow)	WP	-	0.2	0.8	0.5	17.2	0.8	0.8	<0.4
BT (Bacilex)	WP	2.0	0.3	1.3	-	9.1	0.6	3.4	-
Dimethyl-vinphos	WP	30.6	42.7	164	50.8	43.0	175	105	-
Chlorfluazuron	WP	0.056	-	-	0.023	0.08	-	0.034	-

Table 5. Insecticide susceptibilities of the diamondback moth in November 1990

Insecticide		LC_{50} (ppm)				
		Iwaoka (A)	Iwaoka (B)	Uozumi	Hirano	Ikawadani
Acephate	WP	707	2000<	2000<	2000<	2000<
Cartap	SP	1230	229	147	1470	453
Phenthoate	EC	909	442	2000<	1897	2000<
Fenvalerate + malathion	WP	487	1036	1600<	1600<	1600<
Permethrin	EC	112	148	231	529	800<
BT (Toarrow)	WP	96.0	15.2	4.3	29.9	14.2
BT (Bacilex)	WP	34.0	16.9	5.5	8.6	21.8
Dimethylvinphos	WP	-	-	179	187	142
Chlorfluazuron	WP	-	1.25	0.035	-	0.08

to control the diamondback moth. As a matter of fact, the susceptibility to this insecticide is still low at present. It should be noticed that this insecticide has been used until now to control not only the diamondback moth but also other pests such as cabbage armyworms. Cartap was highly effective in 1985 (LC_{50}: 187 ppm, R/S: 2.4). However, its effectiveness has gradually decreased since 1988; its LC_{50} value reached over 1,000 ppm (R/S: 28.1) in 1990. In fact, it was confirmed that this insecticide was not practically effective to control the diamondback moth in field in that year. Phenthoate had kept a high effectiveness until 1987, which has rapidly declined since October 1989 (Tables 3 & 4). It is very likely that the extensive use of phenthoate in 1986 and 1987 caused the rapid development of the moth resistance to insecticides in the following years. The use of wet powder of fenvalerate with malathion started in 1983 with very high effectiveness. However, in 1986, it was confirmed that the moth acquired high resistance to that insecticide (LC_{50}: 811 ppm, R/S: 40.6). This change was most probably attributed to the intensive use of fenvalerate with malathion due to the lack of effective alternatives. The application of this composition was discontinued in 1986 and 1987 with an expectation of recovery in susceptibility of the moth to it during the two-year period. The susceptibility level to the synthetic pyrethroids varied according to the frequencies of their applications, including spraying times and successive or intermittent use.

Table 6. Susceptibilities to synthetic pyrethroids in October 1989

Insecticide			LC_{50} (ppm)
Permethrin	20%	EC	454
Fluvalinate	20%	WP	800<
Flucythrinate	20%	EC	200<
Tralomethrin	1.6%	EC	60<
Ethofenprox	20%	EC	800<
Baythroid	5%	EC	200<
Fenvalerate + malathion		WP	567
Flucythrinate + phenthoate		EC	477
Flucythrinate + cartap		WP	339
Flucythrinate + methomyl		WP	1279
Phenthoate	50%	EC	1071
Cartap	50%	SP	341

The effectiveness of various kinds of insecticides was evaluated for the Iwaoka moth population in 1989 (Table 6). Permethrin and its mixtures with cartap and phenthoate showed relatively high effectiveness. Susceptibility to the pyrethroids, however, was generally low compared with the other insecticides.

Susceptibility of the moth to BT (Toarrow-CT, Bacilex) was high and stable in 1986 and 1987, but it declined gradually in 1988, though it has receded very rapidly since 1989. The pattern of changes in susceptibility to BT was similar to that to cartap. For this reason, these two insecticides were both intensively applied, so long as they did not lose their low effectiveness. Even in case where the susceptibility to BT was adversely influenced by its frequent applications, the susceptibility was recovered after its use was discontinued for a certain period. A field trial was conducted with the Iwaoka moth population in 1989, results of which are shown in Fig. 5. Although cartap and BT indicate a low effect for controlling the moth, the other insecticides tested, i.e. chlorfluazuron (IGR), dimethylvinphos, permethrin + acephate and carbaryl + salithion, were all highly effective. This result was confirmed by the laboratory biossay.

The effectiveness fluctuated from year to year, being influenced mainly by frequencies of the applications. The greatest variations were observed in, among the insecticides tested, BT, cartap and phenthoate. Seasonal changes also took place: the effectiveness was generally lower in autumn (October and November) than in spring (May and June).

For the purpose of comparing susceptibilities to insecticides among the moth populations collected from different places, several insecticides were subjected to testing. Acephate and fenvalerate + malathion showed very low effectiveness, except in the Hidaka population, in the period from June 1988 to November 1990. On the other hand, BT (Toarrow-CT, Bacilex) was highly effective in all the populations tested in 1988 and June 1989, while the susceptibility of the Iwaoka, Hirano and Mihara populations to BT declined significantly in the autumn of 1989. As a matter of fact, in 1990, the Iwaoka, Hirano and Ikawadani populations of the diamondback moth could not be satisfactorily controlled with the BT sprays in fields (Tables 3, 4, 5 and Figs. 3, 4).

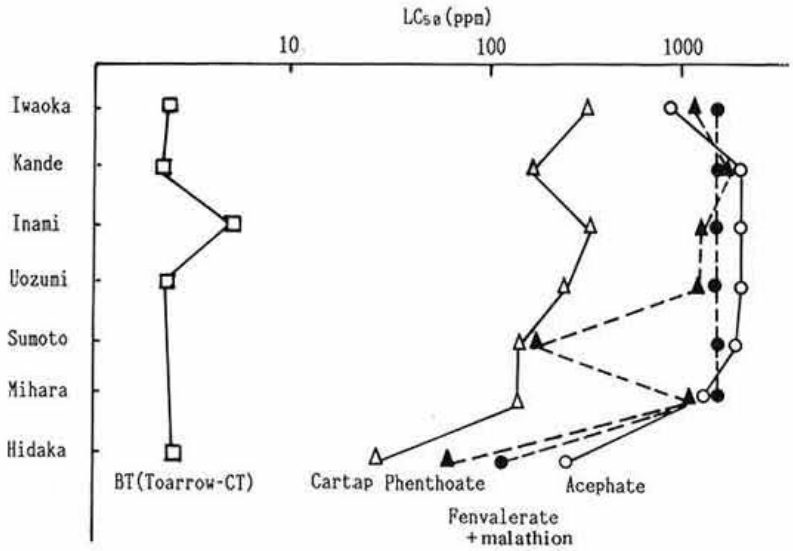

Fig. 3. Insecticide susceptibilities of the diamondback moth in each location
Data taken in June 1988.

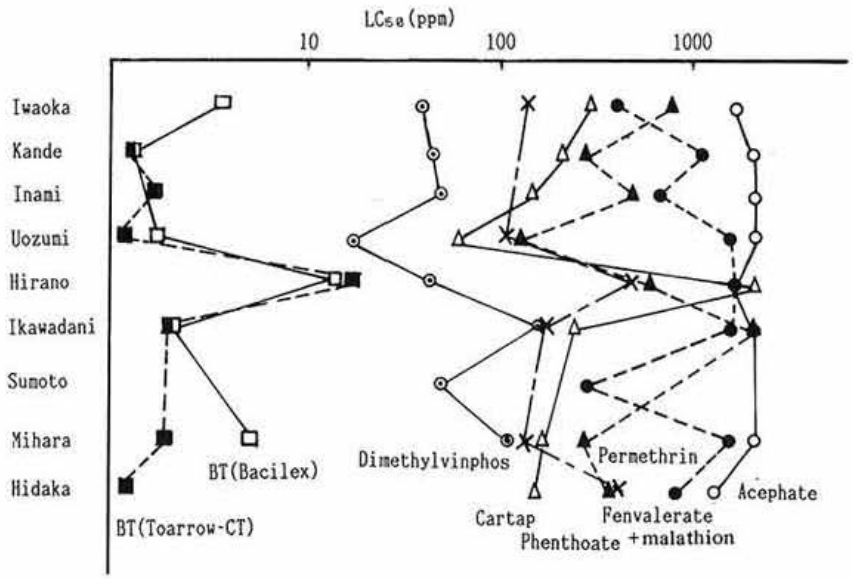

Fig. 4. Insecticide susceptibilities of the diamondback moth in each location
Data taken in October–November 1989.

The Hirano population sampled from the crop chingensai was under intensive sprays of insecticides, since it was very dense in the fields.

Although the susceptibility to cartap varied in each location, it was generally low. However, it varied among the years; some decline was observed in 1989 as compared with that in 1988. Cartap is expected to be one of the recommendable insecticides for controlling the diamondback moth because of its rather stable effectiveness. Phenthoate also showed fluctu-

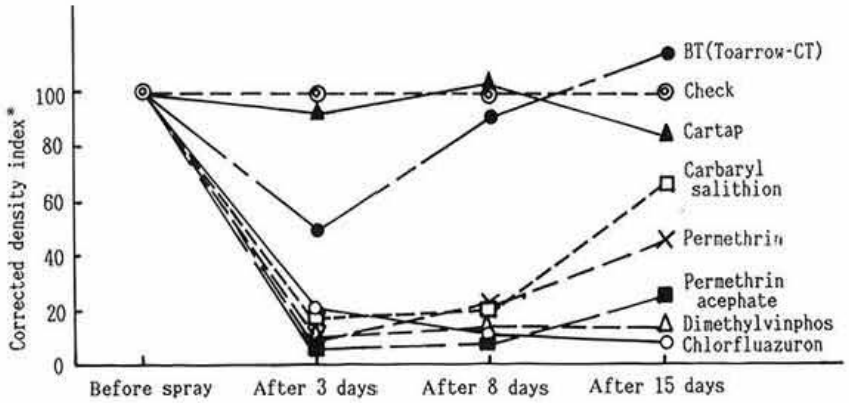

Fig. 5. Effects of insecticides for controlling the diamondback moth in cabbage fields in Iwaoka

Data taken in June 1989.

*The corrected density index (CDI) is calculated by the following equation:

$$CDI = \frac{Cb \times Ta}{Tb \times Ca} \times 100,$$

where Cb: number of larvae on the check plot before treatment, Ca: number of larvae on the check plot after treatment, Tb: number of larvae on the treated plot before treatment, Ta: number of larvae on the treated plot after treatment.

ations of effectiveness in each location, and its effectiveness was lower than that of cartap, declining year by year. Permethrin had the highest effectiveness among the pyrethroids tested, though some fluctuations of its effectiveness were observed in each location. Dimethylvinphos and chlorfluazuron showed the highest effectiveness against all the populations tested. These two insecticides were most promising for practical use among the insecticides registered.

The comparative analyses on the susceptibilities of the diamondback moth among the populations showed that the Hidaka population was the most susceptible to almost all insecticides. The populations except the moth from Hidaka generally showed low susceptibility. The Hidaka population was collected from cabbage fields in highlands. The cultivation system of this area was different from that in other locations. Since the population of the diamondback moth in Hidaka was relatively small, insecticides were applied only 2 to 3 times per crop season, while they were applied generally 6 to 7 times in other areas. It seems that for this reason, the development of insecticide resistance has been slow in Hidaka.

On the contrary, as chingensai is grown in Hirano all the year round 6 to 7 times a year, the diamondback moth is also observed in chingensai fields throughout the year. Insecticides are applied 4 to 5 times per cropping lasting approximately 40 days. Such a great pressure of insecticide applications in this area seems to have developed insecticide resistance so quickly in Hirano.

Taking into account the fact that the development of insecticide resistance is heavily dependent on the frequencies of insecticide applications, it is very necessary to establish an effective method for pest management which would not induce insecticide resistance.

References

1) Adachi, T. et al. (1989): Study on the diamondback moth (*Plutella xylostella* L.) with reference to observation on the occurrence and control. 1. Susceptibility to insecticide and its fluctuation in Hyogo Prefecture. *Bull. Hyogo Pref. Agr. Inst.*, **37**, 79–82 [In Japanese].

2) Hama, H. (1986): Insecticide resistance in the diamond-

back moth (*Plutella xylostella* L.). *Plant Protec.*, **40**, 366–372 [In Japanese].
3) Hama, H. (1986): Resistance spectrum to various insecticides in diamondback moth (*Plutella xylostella* L.). *Jpn. J. Appl. Ent. Zool*, **30**, 277–284 [In Japanese with English summary].
4) Hama, H. (1987): Development of pyrethroid resistance in the diamondback moth, *Plutella xylostella* Linne (Lepidoptera: Yponomeutidae). *Jpn. J. Appl. Ent. Zool.*, **22**, 166–175.
5) Hama, H. (1988): Stability of resistance to organophosphorus insecticides in the diamondback moth, *Plutella xylostella* Linne (Lepidoptera: Yponomeutidae). *Jpn. J. Appl. Ent. Zool.*, **32**, 205–209 [In Japanese with English summary].
6) Morishita, M. & Azuma, K. (1987): Susceptibility to insecticides of the diamondback moth (*Plutella xylostella* L.). *Proc. Kansai Plant Protec. Soc.*, **29**, 17 [In Japanese].
7) Yamada, Y. (1977): Occurrence of the diamondback moth (*Plutella xylostella* L.). *Plant Protec.*, **31**, 202–205 [In Japanese]
8) Yasuoka, H. et al. (1991): Occurrence and susceptibility to insecticides of the diamondback moth, *Plutella xylostella* L. in the cabbage cultivated in the highland. *Odokon—Chugoku*, **33**, 24–29 [In Japanese].

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