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

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Abstract
Organophosphorus insecticide susceptibility or the diamondback moth has been examined in various areas of Shimane Prefecture since 1980. The first incidence of high resistance to organophosphorus insecticides was observed in Yokota, where cruciferous crops had been grown on a large scale under frequent applications of insecticides. The occurrences of high resistance to fenvalerate have been observed in various fields in Shimane Pref. since 1985, which was only two years after the introduction of this insecticide. Susceptibility to various insecticides depends heavily on their application frequencies. A decline trend in susceptibility to tertiary amine cartap and BT was still moderate as of 1992.

Discipline: Insect pest
Additional key words: crucifer, organophosphate, pyrethroid

Introduction

The diamondback moth, *Plutella xylostella* is one of the serious pests for cruciferous crops in various parts of Japan, where frequent incidences of high resistance to organophosphorus and fenvalerate insecticides have been observed[5–7,10]. Control of this insect pest has primarily depended on insecticides, and their heavy applications have most probably led to the acquisition of resistance by the diamondback moth.

In Shimane Prefecture, the decline of effectiveness of organophosphorus insecticides was observed for the first time in cabbage fields in Yokota in 1971[8]. Since 1984, synthetic pyrethroids had been used extensively because they were highly effective at the initial stage of their use. However, resistance of the moth to synthetic pyrethroids developed very rapidly in Shimane, and in 1987 and thereafter their use was prohibited accordingly. It has therefore become extremely difficult at present to control the multiple-resistant moth by means of insecticides. The present paper describes the changes in the insecticide susceptibility of the diamondback moth in Shimane Pref., Japan.

Materials and methods

Cabbage is an economically important crop of crucifers in Shimane Pref., where its cultivation extends over a large area. The locations of diamondback moth populations under survey are shown in Fig. 1. Moth samples were collected from each of major production areas, Yokota, Matsue, Izumo, Hikawa and Masuda districts, where insecticides were used intensively. A moth population was also collected from wild radish in Chibu Island, where no insecticides were sprayed.

Yokota is located in a 700 m high hilly land, where cruciferous crops are grown in the period from spring to autumn, while in Masuda they are cultivated throughout the year due to its relatively warm climate in winter. In Matsue, Izumo and Hikawa, cruciferous crops are planted mainly in autumn. Chibu is a a small island in the Japan Sea, located about 20 km away from the main land.

A strain of the diamondback moth susceptible to insecticides was provided by Sumitomo Chemical Co., Ltd. Rape seedlings were used to feed the larvae of the diamondback moth[9]. The susceptibility of the diamondback moth to insecticides was

Fig. 1. Locations of Shimane Pref. and collection of diamondback moth populations

determined by the leaf-dip method in 3rd to 4th instar larvae. In the field tests, all the insecticides were used in the form of 1,000-times dilutions of commercial products, and surviving larvae were counted 3 and 10 days after the treatment.

Susceptibility to organophosphorus insecticides

Susceptibility of the three populations of the diamondback moth, collected in Shimane Pref. during the period 1980 to 1982, to 4 organophosphorus insecticides is shown in Table 1. Susceptibility to organophosphorus insecticides was different among the populations examined. The susceptibility to acephate was low in all the three populations. The susceptibility to prothiofos was low in the acephate Yokota population, while that to dichlorvos was

Table 1. Susceptibility of the diamondback moth to some organophosphates

Insecticide	Population	Year	LC_{50} (ppm)	Resistance ratio
Dichlorvos	Yokota	1980	365	1.8
	Yokota	1981	915	4.6
	Hikawa	1982	899	4.5
	Masuda	1982	360	1.8
Acephate	Yokota	1980	1,290	22.7
	Yokota	1981	515	8.9
	Hikawa	1982	566	9.7
	Masuda	1982	407	7.0
Prothiofos	Yokota	1980	1,228	19.7
	Yokota	1981	221	3.5
	Hikawa	1982	329	5.3
	Masuda	1982	157	2.7
Cyanofenphos	Yokota	1980	116	-
	Yokota	1981	313	-

Table 2. Effects of organophosphates on the diamondback moth in cabbage fields in Yokota (1981)

Insecticide[a)]	No. of diamondback moth larvae/10 plants		
	Before treatment	3 days after	10 days after
Cyanofenphos	13	2 (37.8)[b)]	8 (16.6)[b)]
Acephate	30	5 (40.9)	30 (27.0)
Prothiofos	14	4 (70.1)	24 (46.3)
Phenthoate	22	12 (133.9)	55 (67.5)
Dichlorvos	5	9 (441.8)	41 (221.4)
Check	27	11	100

a): All chemicals were used as 1,000-times dilution of the commercial products.
b): Values in parentheses indicate indices of relative density.

relatively high. The R/S ratios of the Yokota and Masuda populations were both below 2. The susceptibility to cyanofenphos was high in the Yokota population. The susceptibility to organophosphorus insecticides was however dependent on the frequencies of their application. In Shimane Pref., dichlorvos has never been widely used for controlling the diamondback moth since 1972 because of its low effectiveness. In the field tests in Yokota, effect of cyanofenphos with the leaf-dip method was relatively high (Table 2). The use of cyanofenphos was started after 1972 to control the diamondback moth. Unfortunately, however, in 1983 the production of cyanofenphos was discontinued.

Hama[2] divided the populations under testing into five groups based on their resistance patterns. The Yokota population collected in 1982 showed the highest resistance, belonging to the R4 group characterized by its extremely high R/S ratio. Seasonal changes in the resistance level to organophosphorus insecticides were also observed: it was low in spring and early summer and high in autumn[2].

Susceptibility to synthetic pyrethroid insecticides

Fenvalerate was introduced to Shimane in 1983, when it was highly effective in controlling the diamondback moth. As a consequence, it had been widely used as an alternative to organophosphorus insecticides. However, high resistance to fenvalerate had been identified in many locations in Shimane Pref. since 1985, which was only two years after the introduction of this insecticide (Table 3). However, fenvalerate continued to be effective even in 1989 in Chibu Island, where insecticide applications were very limited. It is presumed that the resistant diamondback moth could migrate to the small island in the Japan Sea. However, the cause for maintaining effectiveness of pyrethroids is yet to be identified. Hama[5,6] reported a similar situation in Ishigaki Island of Okinawa.

Seasonal fluctuations of insecticide resistance were observed in the three populations tested (Table 4). The resistance level tended to be low in spring and early summer, while high in autumn as Hama described[5]. It is reported that the effectiveness of pyrethroids to the moth is more stable than that of organophosphorus insecticides[1].

Hama[4], indicating the stability of pyrethroid resistance, divided the moth populations into three groups. The Masuda population (Table 5) belonged to the second group[4], the resistance level of which decreased gradually with the lapse of generations.

Table 3. Annual changes of the effect of fenvalerate on the diamondback moth in Shimane Pref.

Year	Frequency and mortality (%)[a]			
	0–25	25–50	50–75	75–100
1984	0	0	0	2
1985	1	1	0	0
1986	9	4	2	4
1987	11	0	1	1
1988	4	2	2	1[b]
1989	3	3	1[b]	0
1990	3	2	1[b]	0
1991	2	1	0	0

a): 2,000-times dilution of fenvalerate malathion.
b): Chibu population collected from wild radish.

Table 4. Seasonal changes of susceptibility to fenvalerate in Shimane Pref. (1986)

Population	LC_{50} (ppm)	
	Spring	Autumn
Matsue	6.0	112.3
Yokota	17.2	8,487.0
Masuda	525.1	10,743.1

Conclusions

A few insecticides are effective at present to control the diamondback moth in Shimane Pref. (Table 6). Cartap, thiocyclam and BT (crystal toxin) are effectively applied. However, a sign of acquisition of resistance to cartap and BT has already been recognized in Masuda and Matsue. In Wakayama and Osaka Prefs., BT resistance was also observed in the fields under its continuous applications[10,11].

Pyrethroid application on cruciferous crops has been restricted in Shimane Pref. since 1987. However, susceptibility of the moth to pyrethroids is still low. The fenvalerate-resistant populations show high resistance to new pyrethroid insecticides.

Some organophosphorus insecticides, such as phenthoate and dimetylvinphos, were more effective than other organophosphates. However, they may be used for cabbage only once in its growing season for the

Table 5. Stability of fenvalerate resistance in Shimane Pref.

Generation	Concentration and mortality (%)						
	250	500	1,000	2,000	4,000	8,000	16,000
1	0	0	0	0	0	0	0
4	-	30.8	17.5	10.8	2.4	2.4	2.6
12	-	50.0	39.0	47.6	47.5	10.4	22.5
16	67.0	53.0	33.0	6.7	10.0	-	-

Table 6. Effects of some insecticides on 5 populations of the diamondback moth (1989)

Insecticide[a)]	Population and mortality (%)				
	Matsue	Yokota	Izumo	Masuda	Chibu
Cartap	77.4	71.8	97.2	37.3	90.2
Thiocyclam	87.1		81.0	18.7	87.3
Toarrow-CT	21.9	65.8	69.0	83.4	20.4
Phenthoate	61.3	68.1	55.1	66.7	72.2
Dimethylvinphos	53.1		81.0	64.5	75.1
Dichlorvos	44.8	43.3	28.2	32.7	57.1
Prothiofos	37.9		28.1	17.0	66.1
Acephate	25.8	43.3	23.5	17.8	30.0
Isoxathion + dichlorvos	13.3		34.7	12.4	51.1
Chlorfenvinphos	21.3		19.4	15.1	18.0
Cyanophos	9.7		31.4	27.1	23.3
Permethlyn	43.3	18.6	25.9	12.9	48.1
Fenvalerate + malathion	41.9	30.1	19.4	15.6	51.6
Ethofenprox	55.2		10.4		37.8
Methomyl	10.0	27.8	16.2	12.1	9.3

a): All chemicals were used in the form of 1,000-times dilution of the commercial products.

purpose of avoidance of developing resistance.

In order to put off the rapid development of insecticide resistance, a rotational application of various kinds of insecticides is recommended[3,4]. In addition, an effective method for integrated pest management will have to be developed to control the diamondback moth resistant to insecticides, incorporating their rotational applications with other techniques, including avoidance of continuous growing of cruciferous crops, use of plant covering materials, and use of sex pheromones, pathogens, parasites and predators, as Hama[6] proposed earlier.

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