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Insecticide Resistance of Diamondback Moth, *Plutella xylostella* in Japan

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Abstract

There was a wide range of resistance levels to organophosphates in more than 30 populations of diamondback moth (Plutella xylostella) collected from various locations throughout Japan. Based on their resistance levels and spectra, those populations were divided into five groups. The resistance ratio in thiono-type insecticides was higher than that in phosphate- and dithio-types. High resistance to organophosphates was found in the areas where crucifers had been grown on a large scale throughout the year under frequent applications of insecticides. Organophosphate resistance could be readily build up by selecting under the use of organophosphates. However, the resistance was not stable. High resistance to pyrethroids has been observed in various places of southwest Japan since 1984 which was only a few years after the introduction of insecticides pyrethroid. The pyrethroid resistance of the moth, indicating cross-resistance to a number of types of pyrethroids, was more stable than the organophosphate resistance. Decrease in susceptibility to tertiary amine cartap, BT and IGR is still moderate.

Discipline: Insect pest
Additional key words: cross-resistance, crucifers, organophosphates, pyrethroids

Introduction

Diamondback moth, *Plutella xylostella* is known to be a cosmopolitan pest of cruciferous vegetables. In Japan, occurrence of this moth has gradually increased since approximately 1960, when crucifers, cabbage in particular, had been grown in many parts of the country almost throughout the year[23]. In the 1960's, this moth could be easily controlled by organophosphates such as dichlorvos. During that period, more than 50 types of insecticides, most of which being organophosphates and their mixtures, were registered for controlling the moth. However, in the mid-1970's, the effectiveness of several organophosphates for the moth control started declining in various places of Japan due to the development of insecticide resistance[4,20,24].

In the 1980's, it was recognized that high resistance to various kinds of insecticides, including organophosphates and carbamates, distributed in many places of the southwestern part of Japan. In controlling such insecticide-resistant moths, pyrethroids were highly effective at the initial period of the use starting in 1983. However, an incidence of high resistance to the pyrethroids took place only a few years after the introduction of pyrethroids[7,13]. It has now become further difficult in Japan to control these multiple-resistant moths with insecticides.

Reflecting the fact that insecticide resistance in moth has been a serious common problem over the world, especially in Southeast Asia, this problem received a top priority of considerations at the International Workshop on Diamondback Moth Management, held in Taiwan in 1985[22].

This paper reviews the present status of insecticide resistance of the diamondback moth in Japan and of relevant research activities.

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Susceptibility to various kinds of insecticides

Table 1 shows susceptibility of a susceptible strain (S) and two resistant strains of the diamondback moth determined on the basis of 4th-instar larvae by the topical application method[6]. LD_{50} values of the S strain under the tested 23 organophosphates indicate a great variation from 0.031 μg of cyanofenphos/larva, or 11 μg/g, to more than 45 μg of Estox®/larva, or beyond 16,027 μg/g. Toxicity of carbamate (methomyl) to the S strain is not high, while tertiary amines, cartap and thiocyclam have moderate toxicity, and pyrethroid (fenvalerate) is the most toxic to the S strain.

Table 1. Susceptibility of a susceptible strain (S) and two resistant strains (R4, R5) of the diamondback moth to various kinds of insecticides

Insecticide		LD_{50} (μg/larva)*				Resistance ratio	
		S		R4 (Yokota)	R5 (Gobō)	R4 (Yokota)	R5 (Gobō)
Organophosphorus							
Dithio type >P(S)-S-	Methidathion	0.068	(24)	1.6	1.6	24	24
	Phenthoate	0.13	(46)	8.3	27	64	208
	Dialifos	0.71	(253)	>45	>50	>63	>70
	Dimethoate	2.4	(855)	—	—	—	—
	Malathion	20	(7,123)	>45	—	>2.3	—
Thiono type >P(S)-O-	Cyanofenphos	0.031	(11)	29	>50	935	1,613
	Profenofos	0.073	(26)	5.6	12	77	164
	Prothiofos	0.089	(32)	24	39	270	438
	Cyanophos	0.10	(36)	9.6	21	96	210
	Isoxathion	0.14	(50)	>45	>50	>321	>357
	Salithion	0.43	(153)	11	19	26	44
	Pirimiphos-methyl	0.48	(171)	8.7	31	18	65
	Chlorpyrifos-methyl	1.3	(463)	>45	—	>35	—
	EPN	1.5	(534)	37	—	25	—
	Diazinon	1.6	(570)	>45	—	>28	—
	Fenitrothion	1.6	(570)	>45	—	>28	—
	Chlorpyrifos	2.3	(819)	>4.5	—	>2.0	—
Phosphate type >P(O)-O-	Dimethylvinphos	0.046	(16)	1.9	1.6	41	35
	Dichlorvos	0.73	(260)	9.6	19	13	26
	Chlorfenvinphos	1.1	(392)	7.7	—	7.0	—
Thiol type >P(O)-S-	Estox®	>45	(>16,027)	—	—	—	—
Amidate type >P(O)-N-	Acephate	1.7	(605)	>4.5	—	>2.6	—
Phosphonate type >P(O)-C-	Trichlorfon	13	(4,630)	>45	—	>3.5	—
Carbamate	Methomyl	0.86	(306)	>45	>50	>52	>58
	BPMC	3.5	(1,247)	—	27	—	7.7
	Carbaryl	34	(12,110)	—	>50	—	>1.5
Tertiary amine	Cartap	0.16	(57)	1.2	1.2	7.5	7.5
	Thiocyclam	0.19	(68)	0.39	1.4	2.1	7.4
Pyrethroid	Fenvalerate	0.0073	(2.6)	0.013	0.0089	1.8	1.2
	Phenothrin	0.030	(11)	0.034	—	1.1	—

* LD_{50} values are determined on the basis of 4th-instar larvae by topical application method.
Values of the S strain in parentheses indicate LD_{50} as μg/g.

The other types of insecticides which are of microbial nature or growth regulators, have also been registered, though not included in Table 1. They are toxin of *Bacillus thuringiensis* (BT) and chitin synthesis inhibitors. They act as stomach poisons through feeding, so that susceptibility of the moth to them is usually determined on the basis of 2nd to 3rd-instar larvae by a leaf-dip method. LC_{50} values of BT formulations, chlorfluazuron or teflubenzuron determined by the leaf-dip method center around 1 ppm or below[5,11,16].

Resistance to organophosphates

1) Resistance spectrum to organophosphates and others

There was a wide range of resistance levels to organophosphates in more than 30 populations collected from various locations throughout Japan during the period 1983 to 1985[6,10]. Based on their resistance levels and spectra, the populations were divided into five groups as follows: resistance level 1 (R1) corresponding to the resistance ratio* of below 10 fold; R2 to around 10 fold; R3 to 10–100 fold; R4 to around 100 fold; and R5 to more than 100 fold (Fig. 1)[6]. Yokota and Gobo strains shown in Table 1 correspond to R4 and R5, respectively. Resistance spectra of each level were similar to one another except for R1, the resistance ratio of which to thionotype such as cyanofenphos, prothiofos, cyanophos and isoxiathion was higher than that to phosphate type dimethylvinphos or dithio type methidathion.

Resistance to methomyl is too high to determine accurate LD_{50} values in many populations. On the other hand, the levels to cartap and thiocyclam remain low at resistance ratio of around of 10 fold (Table 1).

2) Distribution of organophosphate resistance

Resistance levels to organophosphates were low, rating R1 to R2, in Hokkaido, while they were high, rating R4 to R5, in the southern part of Kyushu and Okinawa Island. A moderate organophosphate resistance corresponding to approximately R3 level distributed from the Tohoku district to the northern part of Kyushu. High organophosphate resistance at R4 or R5 levels was detected in the areas, where crucifers were grown on a large scale throughout the year and insecticides were frequently applied. On the other hand, in the crucifer fields that were surrounded by paddy fields or mountains, resistance level was rather low even in the southwestern part of Japan[6].

In the areas where the moth did not to hibernate in winter due to snow, a seasonal fluctuation of the resistance level was observed; the resistance level tended to be low in spring and early summer, while high in autumn[6].

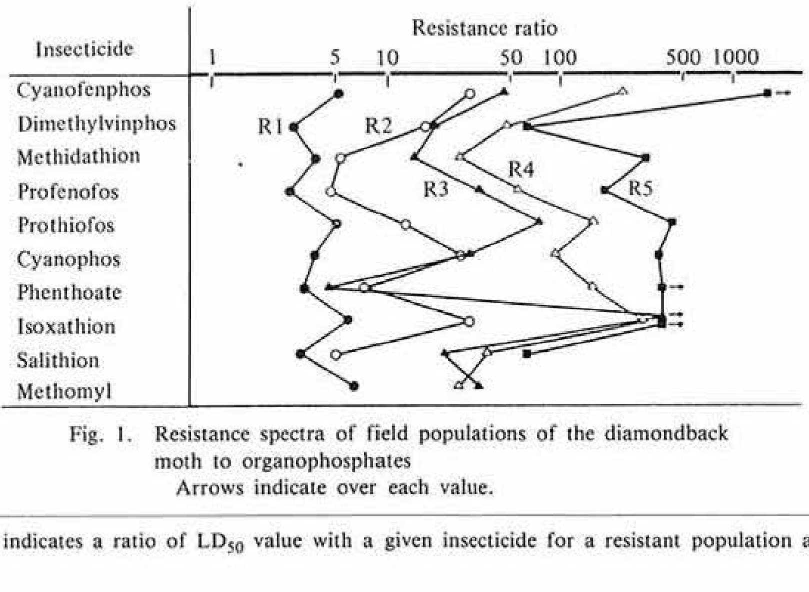

Fig. 1. Resistance spectra of field populations of the diamondback moth to organophosphates
Arrows indicate over each value.

* Resistance ratio indicates a ratio of LD_{50} value with a given insecticide for a resistant population against that for a susceptible one.

3) Cross-resistance in organophosphate resistance

According to Sasaki[21], three strains which were derived by selecting a susceptible strain to dichlorvos, prothiophos and cyanophos, respectively exhibited resistance to almost all of the 20 organophosphates tested. Resistance ratios of two resistant strains selected with thiono type cyanophos or prothiophos were more than 10 fold to almost the same thiono type insecticides, but were low to dithio type such as phenthoate and dialifos. On the other hand, the dichlorvos-selected strain exhibited higher resistance to the same phosphate type insecticides, but lower resistance to thiono type than the other resistant strains did.

Noppun et al.[18] reported an interesting result on the cross-resistance to organophosphate. Both of the two resistant strains, OKR-R and OSS-R, derived from a former organophosphate-resistant strain and a susceptible strain, respectively developed the same level of high resistance to phenthoate used in selection. However, the OKR-R strain exhibited high resistance to prothiophos and cyanophos at more than 100 fold, whereas the OSS-R strain exhibited to them only 10 fold resistance. These two strains hardly showed cross-resistance to dichlorvos and acephate. They showed also cross-resistance to methomyl but not to cartap and pyrethroid (fenvalerate)[18].

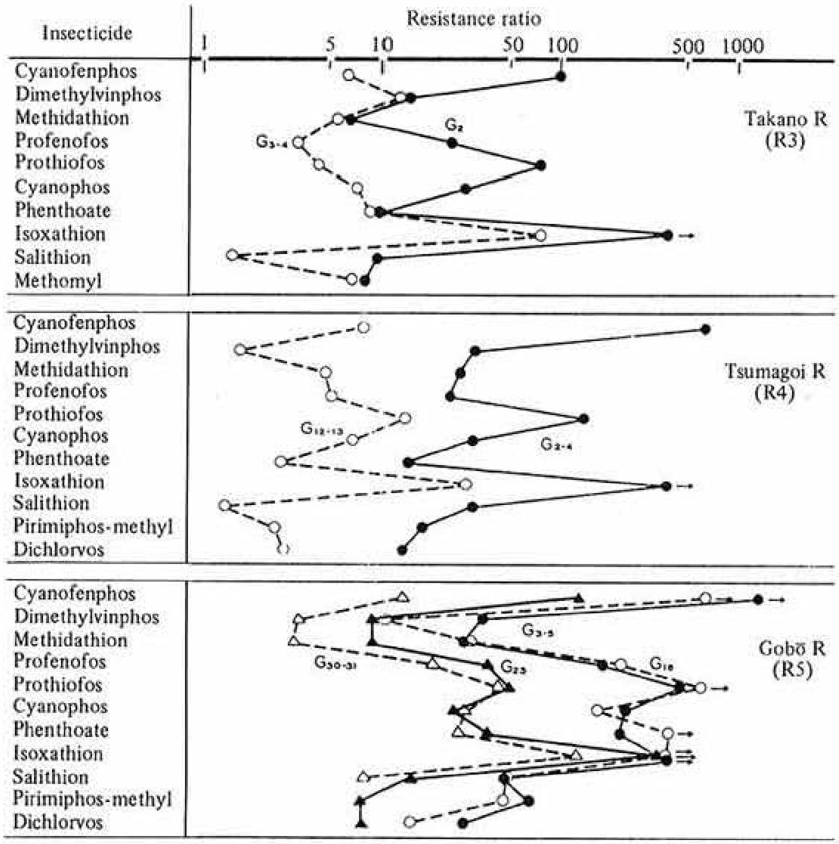

Fig. 2. Fluctuations of organophosphate resistance spectra of the diamondback moth reared without insecticidal selections
Numbers attached to Gs indicate generations after collection, during which the tests were conducted. Arrows indicate over each value.

4) Development and stability of organophosphate resistance

On one hand, high resistance to organophosphates could be readily built up in moth by selecting susceptible strains to organophosphates for several generations in laboratory[17,21]. On the other hand, the organophosphate resistance decreased as generations proceeded without any application of insecticides[1,15]. The author's study[8] showed that the moderate resistance to organophosphates decreased drastically via only a few generations after collection, whereas the decrease in high resistance needed 10 to 20 generations or more (Fig. 2).

Resistance to pyrethroid insecticides

1) Development of pyrethroid resistance in the crop fields

Fenvalerate was introduced to Japan in 1983, when it was highly effective in controlling multiple-resistant moths with continued effectiveness for more than three weeks. Therefore, it had been used widely as an alternative to organophosphates in many areas. However, high resistance to this insecticide had been found in many locations in the southwestern part of Japan since 1984, which was only a few years later after the introduction of fenvalerate (Fig. 3)[7,10].

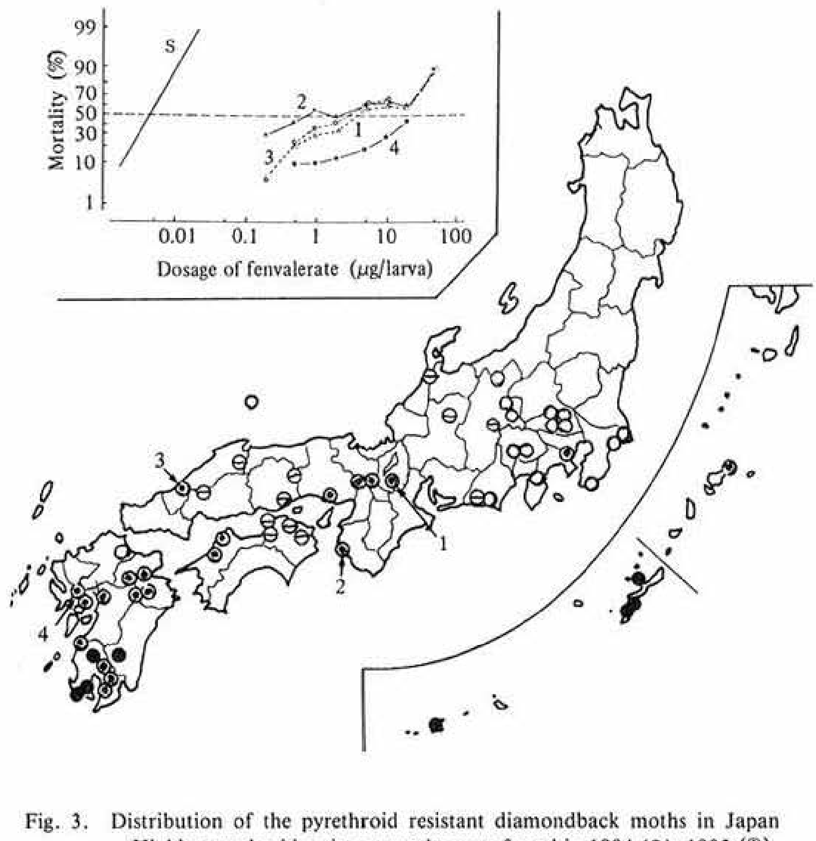

Fig. 3. Distribution of the pyrethroid resistant diamondback moths in Japan
Highly pyrethroid-resistant moths were found in 1984 (●), 1985 (⊛), 1986 (⊖) and 1987 (○).
The inner figures attached indicate relationships between the dosage of fenvalerate and the mortality of field populations collected at the locations corresponding to the respective numbers shown in the map and a susceptible strain (S).

In these locations, pyrethroids were used more than 10 times in the aggregate before the development of pyrethroid resistance took place in the moth populations[7,10].

Thus, the development of pyrethroid resistance was extremely rapid in the crop fields, though genetic behavior of the resistance was incompletely recessive[10,12]. It is suggested that insecticide resistance be suppressed by immigration of susceptible individuals[3]. Therefore, probable causes of such fast development might be: (1) a pyrethroid resistance gene(s) might have already been present in a high frequency when the pyrethroid was introduced to Japan; (2) migration and immigration of susceptible individuals were very limited in the areas where the moth had emerged throughout most of the year; and (3) such closed population had been subjected to heavy application of pyrethroids[10].

Pyrethroid resistance was observed in Okinawa and Ishigaki Islands in 1984. The primary cause of the development of resistance in Okinawa Island is likely the same with that in many other areas as mentioned above. However, in Ishigaki Island where insecticidal control was rarely conducted, the cause for pyrethroid resistance is not indentified yet[10].

High resistance to fenvalerate has also been detected since 1986 at several locations in the highlands of Kanto, Chubu and Chugoku districts, where the moths did not hibernate in winter. The fast development of the resistance in these highlands was likely caused in the following manner: there had been an increased frequency of the resistance gene(s) in the migrants which came from areas where the moths had emerged throughout the year, having resulted in a rapid increase of the resistant individuals under even limited applications of pyrethroids[10].

2) Cross-resistance in pyrethroid resistance

Pyrethroid-resistant populations indicated high resistance to all the 10 types of pyrethroids under testing, while their resistance ratios to permethrin were fairly low[7]. A majority of the pyrethroid-resistant populations showed high resistance to organophosphates, with a few exceptions where low resistance to organophosphates was detected in some populations highly resistant to pyrethroids. This result indicates that pyrethroid-resistance in the moths has limited cross-resistance to organophosphates[10].

3) Development and stability of pyrethroid resistance

The change of moth populations to pyrethroid resistance takes place usually in a few years after the introduction of pyrethroids. However, such a rapid development of the insecticide-resistance cannot be foreseen in selecting populations collected in a field under fenvalerate application in laboratory[17]. In cases where the populations had been originally resistant to pyrethroids but became susceptible under rearing without insecticidal selections, a few selections under pyrethroid application resulted in the development of pyrethroid resistance, which was as high as the initial resistance level[9,19].

It is reported that pyrethroid resistance of the moth is more stable than organophosphate resistance[1]. The author's study indicated that stability of pyrethroid resistance varied among the populations tested[9]. Based on the stability of resistance, the populations were divided into the following three groups. In the first group, the resistance level decreased rapidly within 10 generations after the collection. In the second group, in which many populations were involved, the resistance level decreased gradually with the lapse of generations. In the third group, the high resistance did not change over 10 generations (Fig. 4). Among these groups, there was no difference of any specific characteristics which might relate to the stability of insecticide resistance.

Countermeasures

In the areas where crucifers are grown on a large scale or throughout the year, insecticides available for effective control of the resistant moths are seriously limited. However, some organophosphates remain still effective as follows: tertiary amines, microbial insecticide BT and chitin synthesis inhibitors. These insecticides, however, might possibly induce a resistance problem, since they are widely used at present. In fact, a sign of resistance to cartap and BT has already been found in some locations of Japan. According to Morishita and Azuma[16] and Horikiri and Makino[11], the LC_{50} values of cartap determined by the leaf-dip method in the populations collected in Wakayama and Kagoshima Prefectures increased to the level of

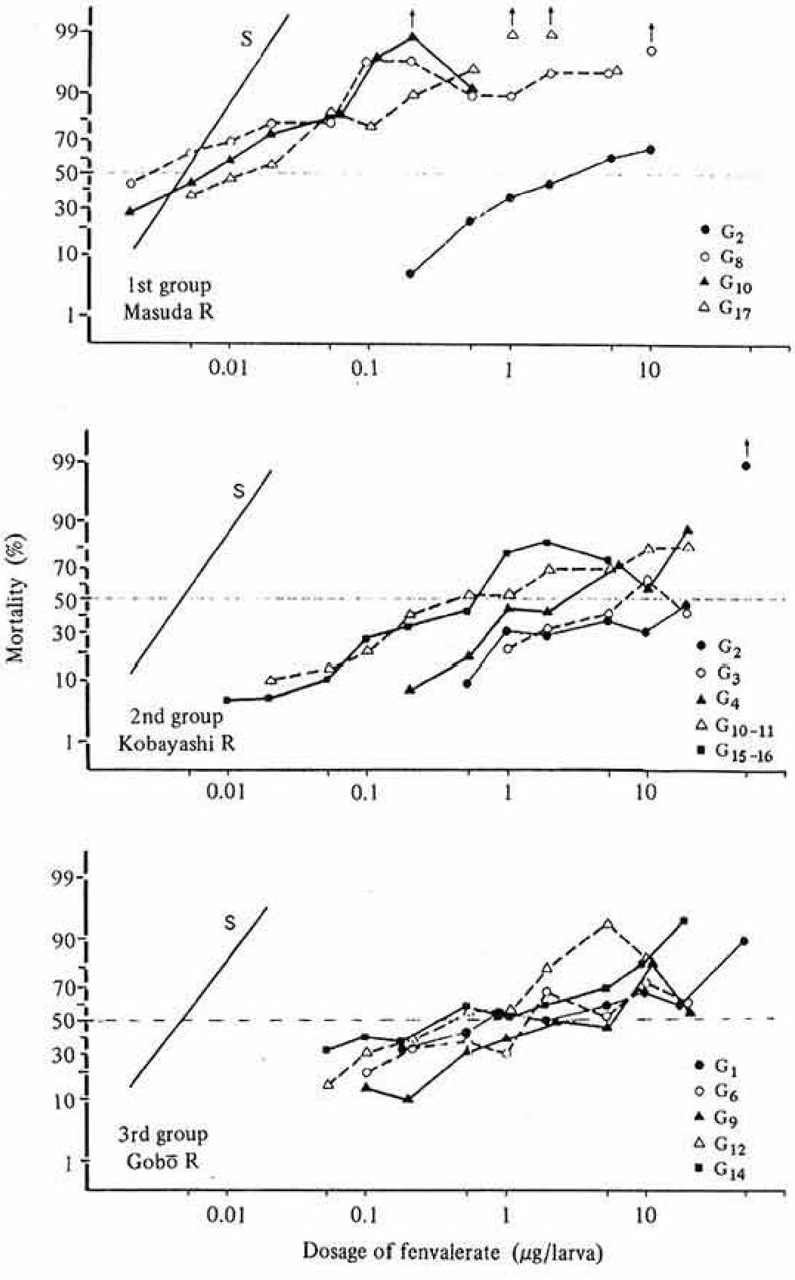

Fig. 4. Fluctuation of pyrethroid resistance of the diamondback moths reared without insecticidal selection

Numbers attached to Gs indicate generations after collection, during which the tests were conducted.

Arrows indicate 100% mortality.

approximately 500 ppm, whereas the LC_{50} values of cartap in a majority of the field populations were 22-313 ppm[20]. They also reported that the LC_{50} values of BT had changed from approximately 1 ppm or below to approximately 20 ppm due possibly to selections with BT on the field[14,16].

A special attention is required to the effective application of an insecticide with a pricking-in hole treatment, or plant foot treatment, of systemic chemicals such as acephate, carbosulfun or benfracarb at the transplanting stage. The high effectiveness continued to be valid for three weeks or more even in the resistant populations[11]. Such a high effectiveness of the treatment might be attributed to the death of hatching of the moths.

In order to delay or suppress the rapid development of insecticide resistance, a rotational application of various kinds of insecticides is recommended[2]. They should be different in terms of mode of their functions or of resistance mechanisms. In making the rotational application effective, the intervals between insecticide applications need to be long enough so that the developed resistance to a certain insecticide could be fully distinguished before that insecticide is reused. In fact, however, the intervals between insecticide applications in the southwestern part of Japan are usually very short, or a few times for 10 days. Under such frequent applications of insecticides, it is very difficult to delay or repress the rapid development of resistance even if a rotational application is employed.

It is therefore suggested that in overcoming the relevant problems, a method of integrated pest management need to be developed in order to reduce times of insecticidal application, incorporating the above-stated rotational application with other techniques. They should include avoidance of continuous growing of crucifers, covering plants with materials, introduction of races resistant to the moth, and uses of sex pheromones, pathogenes, parasites and predators[22].

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