Development of Pyrethroid Resistance in the Diamondback Moth, *Plutella xylostella* LINNÉ (Lepidoptera: Yponomeutidae)¹

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Susceptibility of various populations of the diamondback moth, *Plutella xylostella* LINNÉ, to fenvalerate was determined using fourth instar larvae by a topical application method. This survey revealed a high level of resistance to fenvalerate in several populations collected in 1984 in the southern part of Kyushu and on Okinawa Island and in populations collected in the southern part of the Japanese mainland in 1985 one or two years after the introduction of fenvalerate. The high pyrethroid-resistant populations, which had previously exhibited high resistance to organophosphorus or carbamate insecticides, also showed a high level of resistance to some combinations of fenvalerate and organophosphorus or carbamate insecticides. Although pyrethroid-resistant populations showed a high level of cross-resistance to all pyrethroids tested, the resistance level to permethrin was rather low. Synergistic activity of piperonyl butoxide with fenvalerate was low for the susceptible strain, but high for pyrethroid-resistant populations. The results suggested that microsomal oxidative metabolism contributed to pyrethroid resistance in this insect.

INTRODUCTION

Since 1971, the effectiveness of control of the diamondback moth, *Plutella xylostella* LINNÉ, using the organophosphorus insecticide dichlorvos has decreased (YAMADA, 1979). A moderate decrease in susceptibility to dichlorvos was confirmed by laboratory tests of field populations which were exposed to dichlorvos pressure (TOKAIRIN and NOMURA, 1975). A decrease in susceptibility to organophosphorus insecticides such as prothiophos, phenthoate and cyanophos was reported in two populations collected in the southern areas of Japan by MIYATA et al. (1982) and NOPPUN et al. (1983). Recently, the author evaluated the susceptibility of more than thirty populations collected all over Japan to various insecticides. A high level of resistance to various organophosphorus and carbamate insecticides was found in populations distributed over most of Japan except for Hokkaido, whereas there was a moderate decrease in susceptibility to cartap and thiocyclam (HAMA, 1986).

In Southeast Asia a high level of resistance to most classes of insecticides such as organochlorines, organophosphates, carbamates and pyrethroids has already been reported (ANKERSMIT, 1953; KALRA and CHAWLA, 1977; SUDDERUDDIN and KOK, 1978; SUN et al., 1978; CHENG, 1981; LIU et al., 1981, 1982; Ho et al., 1983). In Japan the

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organophosphorus- and carbamate-resistant moth did not show cross-resistance to the synthetic pyrethroid, fenvalerate (MIYATA et al., 1982; NOPPUN et al., 1983). Subsequently, fenvalerate formulations combined with malathion or dimethoate were introduced in 1983 and widely used for the control of cruciferous vegetable pests including the diamondback moth.

However, in June of the following year, 1984, it was found by our laboratory tests that a population collected at Haeburu in Okinawa Island exhibited a high level of resistance to fenvalerate. That summer and autumn the control of the diamondback moth with fenvalerate met with failure in the cabbage fields in the highlands around Kirishima mountain in the southern part of the Kyushu district. The failure of control was confirmed to be caused by the development of resistance to fenvalerate formulations (MAKINO and HORIKIRI, 1985). In the following year, 1985, pyrethroid resistance was detected in various areas of southwestern Japan.

In this paper, the status of pyrethroid resistance of the diamondback moth in Japan and some of its properties of cross-resistance and the effect of synergists are presented.

MATERIALS AND METHODS

Populations. One susceptible strain (Nichino) and eighteen populations of the diamondback moth were used in this study (Table 1). Each population was collected from cruciferous vegetables, mostly cabbage, and reared for more than one generation in the laboratory at $23 \pm 1^\circ\text{C}$ under a photoperiod of 16L-8D according to the method by KOSHIHARA and YAMADA (1976) with slight modifications. More than 100 larvae or pupae were collected for each population and more than fifty adults were retained for reproduction of the next generation. Pupae were placed in a screened cage ($30 \times 30 \times 40$ cm) together with rolled paper towel placed in a flask filled with 5% honey solution for adult diet and a leaf of *Brassica chinensis* (Pak-choi) for oviposition. Eggs attached to the leaf were placed on germinating Japanese radish seeds cultured in a plastic vessel ($11 \times 19 \times 7$ cm, with two holes 2 cm in diameter on two sides plugged with a cotton ball for ventilation). Hatched larvae were reared on the seeds. For arrangement of development larvae and pupae were sometimes stored at 15°C and eggs at 5°C within one week. Final (fourth) instar larvae were removed with forceps and used for toxicity tests.

Insecticides. The following insecticides were used: fenvalerate, 95.6%, permethrin, 92.8%, resmethrin, 94.1%, cypermethrin, 96.2%, *d*-cyphenothrin, 94.1%, phenothrin, 97.3%, fenpropathrin, 98.6%, tetramethrin, 93.5%, pyrethrins, 21.6% (Sumitomo Chemical Co., Ltd.); fluvalinate, 91.8% (Mitsubishi Chemical Industries Ltd.); malathion, 97.7%, cyanofenphos, 93.3% (Sumitomo Chemical Co., Ltd.); profenofos, 95.1% (CIBA-GEIGY (Japan) Ltd.); methomyl, 90.8% (Nihon Nohyaku Co., Ltd.); BPMC, 98.3% (Mitsubishi Chemical Industries Ltd.) and carbaryl, 99.3% (Nagase & Co., Ltd.). DDT (85%) was provided by Dr. N. MOTOYAMA, Chiba University. TBPT (*S, S, S*-tributyl phosphorotrithionate, 74%) was supplied by Prof. G. P. GEORGHIOU, University of California. Piperonyl butoxide (PB) was purchased from Tokyo Kasei Kogyo Co., Ltd.

Toxicity test. Susceptibility to insecticides was determined by the topical application method recommended by FAO (1979). One-half microliter of an acetone solution of an insecticide was applied to the dorsal region of individual fourth instar larvae

anaesthetized with CO₂ using an automatic micro-applicator (Burkard, England). Treated larvae were transferred to a plastic vessel (6 cm in diameter × 3 cm in height) containing the cut leaf of cabbage and kept at $23 \pm 1^\circ\text{C}$ and a 16 hr light regime. After 48 hr, treated larvae were checked to determine if they were dead or alive and poisoned larvae were counted as dead ones. Five or more concentrations of each insecticide were evaluated using 10 larvae per concentration and replicated 3 to 4 times. Results of the tests were calculated by probit analysis to obtain LD₅₀ values. In the toxicity tests of combinations of fenvalerate and organophosphate, carbamate insecticides or synergists, acetone solution of each chemical was prepared separately and mixed at an appropriate ratio.

RESULTS

Susceptibility of various populations to fenvalerate

The LD₅₀ values of fenvalerate for the various populations are given in Table 1. The tested populations were arranged in order of location from north to south. Among them, dosage-mortality relationships are shown in Fig. 1 for a moderately-resistant population, Naha, collected in 1983 and super-resistant populations collected in 1984 and in Fig. 2 for the super-resistant populations collected in 1985. The LD₅₀ value of fenvalerate for the Naha population was 9-fold higher than for the S strain, but the slope of its regression line was just as steep as the S strain. On the other hand, the regression lines of most of the super-resistant populations were extremely slight and in some populations there was a wide plateau from 1 to 20 µg/larva.

Susceptibility of several populations to combinations of fenvalerate and organophosphorus or carbamate insecticides

Susceptibility of the S strain and four pyrethroid-resistant populations to combinations of fenvalerate and organophosphorus or carbamate insecticides is shown in Table 2. Synergistic action was observed in some combinations: fenvalerate and malathion in the Haebaru ② population, fenvalerate and cyanofenphos in the Kobayashi population and fenvalerate and profenofos in the S strain. However, resistant populations showed a high level of resistance to all these combinations and their LD₅₀ values were high, greater than 3.8 µg/larva.

Insecticidal activity of combinations of fenvalerate and carbamate insecticides for a super-resistant population, Nakijin, was low and their LD₅₀ values were too high to determine their joint action.

Susceptibility of several populations to pyrethroids and DDT

The susceptibility of the S strain and super-resistant populations to various pyrethroids and DDT is shown in Table 3. Among the pyrethroids tested, permethrin showed the best insecticidal activity against the S strain, followed by fenvalerate, resmethrin and others. Resistant populations exhibited a high level of resistance to all these pyrethroids and DDT. Among them, the LD₅₀ values of permethrin for the resistant populations were rather low, below 1 µg/larva, and their resistance ratios were 110- to 280-fold.

Table 1. Susceptibility of various populations of the diamondback moth to fenvalerate

Population	Place of collection	Host of collection	Time of collection	Generation for test after collection	LD ₅₀ of fenvalerate $\mu\text{g/larva}$	Resistance ratio ^a
S (Nichino)	Kawachinagano in Osaka Pref.	Collected in 1968 and reared without insecticidal pressure in the laboratory of Nihon Nohyaku Co., Ltd.			0.0041(1.3) ^b	
Sapporo	Sapporo in Hokkaido	Cabbage	Mid. July 1984	2	0.0085	2.1
Tsumagoi	Tsumagoi in Gunma Pref.	do.	Early Oct. 1984	3	0.0031	0.76
Godo	Godo in Gifu Pref.	Japanese radish	Late May 1985	1-2	0.0011	0.27
Seki	Seki in Gifu Pref.	do.	do.	2	0.0015	0.37
Kusatsu	Kusatsu in Shiga Pref.	Turnip (Hinona)	Early July 1985	1	5.1	1,200
Gobō ①	Gobō in Wakayama Pref.	Cabbage	Late Feb. 1983	13	0.0069	1.7
Gobō ②	do.	do.	Early June 1985	1	0.5-5	120-1,200
Yokota ①	Yokota in Shimane Pref.	do.	Early Oct. 1982	4-5	0.0093	2.3
Yokota ②	do.	do.	Mid. Sep. 1984	1	0.0094	2.3
Masuda	Masuda in Shimane Pref.	do.	Late Oct. 1985	2	3.0	730
Kurume	Kurume in Fukuoka Pref.	do.	Early June 1984	4	0.0051	1.2
Mizuho	Mizuho in Nagasaki Pref.	do.	Mid. Oct. 1985	1-2	>20	>4,900
Kobayashi	Kobayashi in Miyazaki Pref.	do.	Mid. Sep. 1984	2-3	>20	>4,900
Mizobe	Mizobe in Kagoshima Pref.	do.	Late Sep. 1984	2-3	1-20	240-4,900
Naha	Naha in Okinawa Pref.	do.	Late July 1983	4-6	0.037	9.0
Haebaru ①	Haebaru in Okinawa Pref.	do.	Mid. June 1984	2-4	10	2,400
Haebaru ②	do.	do.	Early Oct. 1984	1-2	>50	>12,000
Nakijin	Nakijin in Okinawa Pref.	do.	Early Dec. 1984	1	30	7,300

^a Ratios of LD₅₀ values of each population to that of the S strain.^b LD₅₀ value of fenvalerate as $\mu\text{g/g}$.*Effects of PB and TBPT on susceptibility of fenvalerate for several populations*

Joint action of PB and TBPT on susceptibility of fenvalerate to the S strain, the moderately-resistant Naha population and the super-resistant populations are shown in Table 4. Synergistic activity of the two synergists with fenvalerate was low for the S strain and the Naha population, but high for all the super-resistant populations. The synergistic activity of PB was extremely high so that the LD₅₀ values of fenvalerate when applied with PB resulted in an LD₅₀ one-tenth or less that of fenvalerate applied alone.

Fig. 1. Dosage-mortality relationships of moderately- and super-pyrethroid-resistant populations of the diamondback moth collected in 1983 and 1984 to fenvalerate. $\uparrow$: mortality 100%, $\downarrow$: mortality 0%. $\circ$: Kobayashi (Miyazaki, mid. Sep. 1984), $\blacktriangle$: Mizobe (Kagoshima, late Sep. 1984), $\odot$: Naha (Okinawa, late July 1983), $\triangle$: Haebaru ① (Okinawa, mid. June 1984), $\blacksquare$: Haebaru ② (Okinawa, early Oct. 1984), $\bullet$: Nakijin (Okinawa, early Dec. 1984).

Fig. 2. Dosage-mortality relationships of super-pyrethroid-resistant populations of the diamondback moth collected in 1985 to fenvalerate. $\triangle$: Kusatsu (Shiga, early July), $\blacktriangle$: Gobō ② (Wakayama, early June), $\circ$: Masuda (Shimane, late Oct.), $\bullet$: Mizuho (Nagasaki, mid. Oct.).

Table 2. Susceptibility of the S strain and pyrethroid-resistant populations of the diamondback moth to combinations of fenvalerate and organophosphorus or carbamate insecticides

Insecticide	LD ₅₀ (μ g/larva) ^a				
	S	Kobayashi	Mizobe	Haebaru ②	Nakijin
Fenvalerate	0.0041	>20 (>4,900)	1-20 (240-4,900)	>50 (>12,000)	30 (7,300)
Malathion	20	>50 (>2.5)	>50 (>2.5)	>50 (>2.5)	—
Cyanofenphos	0.031	6.9 (220)	39 (1,300)	>50 (>1,600)	—
Profenofos	0.073	4.1 (56)	5.7 (78)	7.1 (97)	—
Methomyl	0.86	—	—	—	>50 (>58)
BPMC	3.5	—	—	—	50 (14)
Carbaryl	34	—	—	—	>50 (>1.5)
Fenvalerate+ malathion (1:1)	0.0057	33 (5,800)	16 (2,800)	28 (4,900)	—
Fenvalerate+ cyanofenphos (1:1)	0.0055	3.8 (690)	7.9 (1,400)	>50 (>9,100)	—
Fenvalerate+ profenofos (1:1)	0.0034	5.5 (1,600)	4.7 (1,400)	17 (5,000)	—
Fenvalerate+ methomyl (1:1)	0.0063	—	—	—	>20 (>3,200)
Fenvalerate+ BPMC (1:1)	0.0045	—	—	—	>20 (>4,400)
Fenvalerate+ carbaryl (1:1)	0.0052	—	—	—	>20 (>3,800)

^a Values in parentheses are resistance ratios (ratios of LD₅₀ values for each population to that for the S strain).

Table 3. Susceptibility of the S strain and super-pyrethroid-resistant populations of the diamondback moth to pyrethroid insecticides and DDT

Insecticide	LD ₅₀ (μ g/larva) ^a				
	S	Mizobe	Haebaru ①	Haebaru ②	Nakijin
Permethrin	0.0023	—	0.25 (110)	0.63 (270)	0.65 (280)
Fenvalerate	0.0041	1-20 (240-4,900)	10 (2,400)	>50 (>12,000)	30 (7,300)
Resmethrin	0.0054	—	—	—	2.3 (430)
Cypermethrin	0.0085	—	—	—	8.5 (1,000)
<i>d</i> -Cyphenothrin	0.0085	—	—	—	5.9 (690)
Phenothrin	0.015	4.4 (290)	7.5 (500)	>50 (>3,300)	12 (800)
Fenpropathrin	0.019	4.2 (220)	6.7 (350)	27 (1,400)	17 (890)
Fluvalinate	0.041	—	—	—	>50 (>1,200)
Pyrethrins	0.090	—	—	—	7.1 (79)
DDT	0.095	>50 (>530)	—	>50 (>530)	—
Tetramethrin	0.15	>50 (>330)	48 (320)	>50 (>330)	—

^a Values in parentheses are resistance ratios (ratios of LD₅₀ values for each population to that for the S strain).

DISCUSSION

Susceptibility of the S strain used in this study to fenvalerate is almost the same as the susceptible strain, France, reported by SUDDERUDDIN and KOK (1978), although the S strain was less susceptible to some organophosphorus and carbamate insecticides than the France strain (HAMA, 1986).

There were two different levels of pyrethroid resistance in this insect: a moderate resistance of about 10-fold, i.e., the Naha population and a super resistance of more than 100-fold. This was found in several populations collected in the southern part of the Kyushu district and on Okinawa Island in 1984 and in several areas of southwestern Japan in 1985. A moderate-pyrethroid resistance was detected in Naha in 1983 when pyrethroid formulations were introduced. Although organophosphorus and carbamate resistance of this insect in Japan did not show a cross-resistance to fenvalerate (MIYATA et al., 1982; NOPPUN et al., 1983), it was reported that diazinon resistance in the Taiwan population exhibited a significant cross-resistance to synthetic pyrethroids including fenvalerate (LIU et al., 1981). Therefore, it might be possible that moderate resistance in the Naha population was induced as the result of cross-resistance to organophosphate insecticides.

In the areas where a pyrethroid super-resistance was detected, control of the diamondback moth with fenvalerate formulations had been successful. In fact, the Gobō population collected in 1983, where one year later a super resistance was detected, was susceptible to fenvalerate (Table 1). From these observations it was concluded that the super resistance had been induced by selection pressure of fenvalerate formulations for only one or two years. In these areas fenvalerate formulations had been used numerous times, in some cases more than 10 applications.

In a crossing experiment, super resistance to fenvalerate exhibited an incompletely recessive trait (HAMA, unpublished), as reported in the Taiwan population by Liu et al. (1981). It is well known that a rare recessive gene is selected much more slowly than

Table 4. Susceptibility of the S strain, moderately-resistant population (Naha) and super-resistant-populations of the diamondback moth to fenvalerate applied with PB or TBPT

Insecticide	S	LD ₅₀ (μg/larva) ^a									
		Naha	Kusatsu	Gobō ②	Masuda	Mizuho	Kobayashi	Mizobe	Haebaru ①	Haebaru ②	Nakijin
Fenvalerate	0.0041	0.037 (9.0)	5.1 (1,200)	0.5-5 (120-1,200)	3.0 (730)	>20 (>4,900)	>20 (>4,900)	1-20 (240-4,900)	10 (2,400)	>50 (>12,000)	30 (7,300)
Fenvalerate + PB (1:1)	0.0026	0.032 (12)	—	—	—	—	0.71 (270)	0.61 (230)	1.3 (500)	0.75 (290)	1.6 (620)
+ PB (1:5)	0.0021	—	0.10 (48)	0.089 (42)	0.45 (210)	0.40 (190)	—	—	—	—	—
Fenvalerate + TBPT (1:1)	0.0027	—	—	—	—	—	2.3 (850)	1.2 (440)	—	6.1 (2,300)	—

^a LD₅₀ values did not contain dose of synergists. PB and TBPT did not induce any lethal activity within the applied doses.

Values in parentheses are resistance ratios (ratios of LD₅₀ values for each population to that for the S strain).

a rare dominant one (GEORGHIOU, 1972). With computer simulation studies (GEORGHIOU and TAYLOR, 1977; WOOD and MANI, 1981), however, it was suggested that even a recessive resistance gene could be selected rather quickly when there is a high frequency of the resistance gene present, the population is not diluted with immigrants and does not escape exposure to insecticidal pressure. Considering these suggestions, there may be a rather high frequency of pyrethroid resistance gene(s) which has not been identified, susceptible individuals of emigration and immigration may be rather few, if any, and the isolated populations may have been heavily pressured with fenvalerate.

Organophosphorus resistance in the diamondback moth could be grouped into five resistance levels (HAMA, 1986). Most of the pyrethroid-resistant populations belonged to R4 or R5 groups, which show a high level of resistance to organophosphorus insecticides. For the multiple-resistant populations, some combinations of fenvalerate and organophosphorus insecticides showed synergistic activity, but their LD₅₀ values were more than 1 µg/larva. In practice, the combination of fenvalerate and malathion was not effective in the control of super-resistant populations (MAKINO and HORIKIRI, 1985; others, personal communications).

Pyrethroid-resistant populations exhibited a high cross-resistance to all other pyrethroids tested, but permethrin is rather effective on the super-resistant populations. However, permethrin was not highly effective in the control of the super-resistant populations in the field (MAKINO and HORIKIRI, and others, personal communications). It has been shown that resistance levels to pyrethroids in this insect differ among synthetic pyrethroids, although a high cross-resistance was demonstrated. In pyrethroid-resistant populations from Taiwan, the resistance level to permethrin was much lower than to α -cyano 3-phenoxybenzyl esters: cypermethrin, decamethrin and fenvalerate (LIU et al., 1981, 1982). It was also reported that selection pressure with fenvalerate induced a high level of resistance to fenvalerate and decamethrin, but a low level of resistance to cypermethrin and permethrin (CHOU and CHENG, 1983).

Although super-resistant populations also showed a high level of resistance to DDT, it is difficult to evaluate how much of the pyrethroid resistance contributes to DDT resistance, since certain organophosphorus-resistant populations, which were susceptible to fenvalerate, had already exhibited a high level of resistance to DDT (HAMA, 1986).

Synergistic activity of PB with fenvalerate in the super-resistant populations suggests that microsomal oxidases contributed to synthetic pyrethroid resistance in this insect, as already reported by LIU et al. (1981) and Ho et al. (1983).

On the other hand, it was speculated by LIU et al. (1981) that nervous system insensitivity, the so-called *Kdr*-factor, might be involved in the fenvalerate resistance, because this resistance was controlled by an incompletely recessive factor and a rather high level of resistance remained even when applied with PB. Recently, electrophysiological studies showed that the exposed central nerve of a larva was less sensitive to fenvalerate in pyrethroid-resistant populations than in a susceptible strain (HAMA et al., 1987). From these observations, it may be concluded that super resistance to pyrethroids is the result of at least two major resistance factors: increased detoxication mediated by microsomal oxidases and decreased sensitivity at the site of action in the nervous system.

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REFERENCES

- ANKERSMIT, G. W. (1953) DDT-resistance in *Plutella maculipennis* (CURT.) (Lep.) in Java. *Bull. Entomol. Res.* **44**: 421-425.
- CHENG, E. Y. (1981) Insecticide resistance study in *Plutella xylostella* L. II. A general survey (1980-81). *J. Agric. Res. China* **30**: 285-293.
- CHOU, T. M. and E. Y. CHENG (1983) Insecticide resistance study in *Plutella xylostella* (L.). III. The insecticide susceptibilities and resistance response of a native susceptible strain. *J. Agric. Res. China* **32**: 146-154.
- FAO (1979) Recommended methods for the detection and measurement of resistance of agricultural pests to pesticides. Method for the diamondback moth (*Plutella xylostella* L.) FAO method No. 21. *FAO Plant Prot. Bull.* **27**: 44-46.
- GEORGHIOU, G. P. (1972) The evolution of resistance to pesticides. *Ann. Rev. Ecol. Syst.* **2**: 133-168.
- GEORGHIOU, G. P. and C. E. TAYLOR (1977) Genetic and biological influences in the evolution of insecticide resistance. *J. Econ. Entomol.* **70**: 319-323.
- HAMA, H. (1986) Resistance spectrum to various insecticides in the diamondback moth, *Plutella xylostella* LINNÉ (Lepidoptera: Yponomeutidae). *Jpn. J. Appl. Ent. Zool.* **30**: 277-284 (in Japanese with an English summary).
- HAMA, H., Y. KONO and Y. SATO (1987) Decreased sensitivity of central nerve to fenvalerate in the pyrethroid-resistant diamondback moth, *Plutella xylostella* LINNÉ (Lepidoptera: Yponomeutidae). *Appl. Ent. Zool.* **22**: 176-180.
- HO, S. H., B. H. LEE and D. SEE (1983) Toxicity of deltamethrin and cypermethrin to the larvae of the diamond-back moth, *Plutella xylostella* L. *Toxicol. Lett.* **19**: 127-132.
- KALRA, R. L. and R. P. CHAWLA (1977) Evaluation of bioassay techniques for the detection of insecticide resistance in *Plutella xylostella*. *FAO Plant Prot. Bull.* **25**: 85-87.
- KOSHIHARA, T. and H. YAMADA (1976) A simple mass-rearing technique of the diamond-back moth, *Plutella xylostella* (L.), on germinating rape seeds. *Jap. J. appl. Ent. Zool.* **20**: 110-114 (in Japanese with an English summary).
- LIU, M. Y., Y. J. TZENG and C. N. SUN (1981) Diamondback moth resistance to several synthetic pyrethroids. *J. Econ. Entomol.* **74**: 393-396.
- LIU, M. Y., Y. J. TZENG and C. N. SUN (1982) Insecticide resistance in the diamondback moth. *J. Econ. Entomol.* **75**: 153-155.
- MAKINO, S. and M. HORIKIRI (1985) Reduced susceptibility of the diamondback moth, *Plutella xylostella* LINNÉ, to pyrethroid insecticides. *Proc. Assoc. Plant Prot. Kyushu* **31**: 175-178 (in Japanese with an English summary).
- MIYATA, T., H. KAWAI and T. SAITO (1982) Insecticide resistance in the diamondback moth, *Plutella xylostella* L. (Lepidoptera: Yponomeutidae). *Appl. Ent. Zool.* **17**: 539-542.
- NOPPUN, V., T. MIYATA and T. SAITO (1983) Susceptibility of four strains of the diamondback moth, *Plutella xylostella* L., against insecticides. *J. Pesticide Sci.* **8**: 595-599.
- SUDDERUDDIN, K. I. and P. F. KOK (1978) Insecticide resistance in *Plutella xylostella* collected from the Cameron Highlands of Malaysia. *FAO Plant Prot. Bull.* **26**: 53-57.
- SUN, C. N., H. CHI and H. T. FENG (1978) Diamondback moth resistance to diazinon and methomyl in Taiwan. *J. Econ. Entomol.* **71**: 551-554.

- TOKAIRIN, O. and K. NOMURA (1975) Comparative studies on the effectiveness of dichlorvos and *Bacillus thuringiensis* preparations between three strains of the diamond-back moth, *Plutella xylostella* L. *Jap. J. appl. Ent. Zool.* **19**: 298–299 (in Japanese).
- WOOD, R. J. and G. S. MANI (1981) The effective dominance of resistance genes in relation to the evolution of resistance. *Pestic. Sci.* **12**: 573–581.
- YAMADA, H. (1979) Insecticide resistance problem in the diamond-back moth. In *Proceedings of Symposium on Insecticide Resistance in Vegetable Insect Pests* (Japan Plant Protection Association, ed.), Tokyo, pp. 33–40 (in Japanese).