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Insecticide Resistance Study in *Plutella xylostella* (L.)

III. The Insecticide Susceptibilities and Resistance Response of a Native Susceptible Strain. [1]

by

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Abstract：The toxicity information of twenty-two insecticides on the diamondback moth was obtained by testing a native susceptible I-lan strain. Top five insecticides of all tested compounds are synthetic pyrethroids. Decamethrin is the most effective insecticide and carbaryl is the worst one. Mevinphos and carbofuran are the most effective compound for organophosphates and carbamates respectively. The overall result of toxicity test of I-lan strain is quite comparable to that of a susceptible strain introduced from France. Carbofuran can rapidly induce the resistance developed in the diamondback moth with only minor cross resistance problem in other insecticides. Fenvalerate induced the resistance at a rate slower than that of carbofuran, but it caused severe cross resistance in the moth. Cartap can only induce the resistance at a very slow rate and result in a moderate cross resistance problem. Both the cartap-resisted and the fenvalerate-resisted strains responded to fenvalerate and decamethrin in a similar fashion but were different from cypermethrin and permethrin.

In the general survey of insecticide resistance in the diamondback moth, *Plutella xylostella* (L.), a strain from I-lan found to be very sensitive to insecticides [2], and was used to study the insecticide susceptibilities and resistance development. We pressed the strain with several commonly used insecticides to induce the resistant strains, and then examine the scope and the extent of cross resistance of different resistant strains when they were tested against other insecticides.

Carbofuran, cartap and fenvalerate, three officially recommended insecticides in the diamondback moth control [5], were tested in this study. We hoped that the information obtained will help the plant protection personnel to compare the advantage and disadvantage of an insecticide before it was used in the field. Particularly, results of cross resistance investigation will help us to choose a good substitute to replace the ineffective insecticide in a resistance-proned area.

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We also hoped that the collective knowledge of this and future studies will provide enough information for us to set up a rational insecticide substitution sequence for the diamondback moth control, and to prevent or slow down the resistance development in field strains.

Materials and Methods

The IL-strain diamondback moth of our 1980—81 collection was chosen for the study because of its high sensitivity to insecticides. All insecticides used in this study were commercial products and their formulations were listed in Table 1. For the resistance induction, carbofuran, cartap and fenvalerate were used to press three sub-lines of IL-strain. In the sensitivity and cross resistance tests, twenty-two insecticides registered for the diamondback moth control [10] were used. All formulated insecticides were diluted in the distilled water and sprayed within the Burkard Spray Tower. The spraying operation was the same as that of our previous study [2].

表1. 二十二種殺蟲劑對宜蘭品系小菜蛾之毒效測定

Table 1. The toxicities of twenty-two insecticides to the I-lan strain diamondback moth.

Insecticides & formulations	LC_{25}	LC_{50} (in ppm)	LC_{75}	Slope
Decamethrin 2.8% E. C.	1.18	3.58	1.1×10^{1}	0.605
Fenvalerate 20% E. C.	2.96	8.28	2.3×10^{1}	0.656
Permethrin 10% E. C.	6.25	1.4×10^{1}	3.0×10^{1}	0.853
Cypermethrin 5% E. C.	7.28	1.9×10^{1}	5.3×10^{1}	0.678
UCX-33 34% E. C.*	2.5×10^{1}	6.3×10^{1}	1.6×10^{2}	0.735
Mevinphos 25.3% E. C.	5.9×10^{1}	7.3×10^{1}	1.8×10^{2}	1.213
Profenofos 43% E. C.	4.5×10^{1}	1.0×10^{2}	2.3×10^{2}	0.834
Carbofuran 40.6% W. P.	2.0×10^{1}	1.2×10^{2}	6.9×10^{2}	0.383
Prophos 70.6% E. C.	1.1×10^{2}	1.7×10^{2}	2.6×10^{2}	1.576
Cyanophenphos 25% E. C.	7.7×10^{1}	1.9×10^{2}	4.4×10^{2}	0.775
Diethquinalphion 25% E. C.	1.0×10^{2}	2.3×10^{2}	5.0×10^{2}	0.833
Methidathion 40% E. C.	1.6×10^{2}	2.7×10^{2}	4.4×10^{2}	1.339
Cartap 98% P.	1.4×10^{2}	2.9×10^{2}	5.8×10^{2}	0.974
Tokuthion 50% E. C.	1.7×10^{2}	3.1×10^{2}	5.6×10^{2}	1.125
Mephosfolan 25% E. C.	1.4×10^{2}	3.6×10^{2}	9.0×10^{2}	0.735
Methamidophos 50% S.	2.2×10^{2}	5.6×10^{2}	1.4×10^{3}	0.716
Phenthoate 50% E. C.	2.6×10^{2}	6.7×10^{2}	1.7×10^{3}	0.713
Chlorpyrifos 40.8% E. C.	3.4×10^{2}	7.7×10^{2}	1.7×10^{3}	0.829
Methomyl 24% S.	1.7×10^{3}	3.4×10^{3}	7.1×10^{3}	0.924
Fenitrothion 50% E. C.	5.4×10^{3}	8.7×10^{3}	1.4×10^{4}	1.432
Malathion 50% E. C.	7.4×10^{3}	1.6×10^{4}	3.2×10^{4}	0.904
Carbaryl 85% W. P.	6.8×10^{3}	2.7×10^{4}	1.1×10^{5}	0.491

*Permethrin formulated by Union Carbide.

The sensitivity test : For every tested insecticide, seven dosage levels within the range of LC_{10} to LC_{90} were made in distilled water, and each concentration was tested on forty to sixty third-instar diamondback moth larvae. Results of the tests were analyzed in probits.

The induction of resistant strains : Usually one thousand diamondback moth larvae were sprayed with selected insecticide at the dosage of LC_{75}, and subsequently survived insects were collected for propagating the next generation. The LC_{75} level was re-determined for each generation on 100—200 early emerged larvae of that generation.

The rate of LC_{75} level increase from generation to generation was counted as the resistance development rate for that insecticide in the diamondback moth.

The cross resistance test : Once the resistance of a pressed strain had reached a significant level, usually to a range of 10 to 20 folds in the resistance ratio, the strain was then subjected to the same sensitivity test again. Newly obtained LC_{75} of various insecticides in the resistant strains were compared to that of IL-strain to detect any possible occurrence and extent of cross resistance.

Results

The toxicities of twenty-two registered insecticides to the IL-strain diamondback moth were reported in Table 1, and the order was arranged according to the effectiveness. Of all tested insecticides, decamethrin and carbaryl were the most and the least effective compound with the LC_{50} at 3.58ppm and 2.7×10^4ppm respectively. Five top insecticides on the list were synthetic pyrethroids, mevinphos and carbofuran were the most effective compound for organophosphates and carbamates and their LC_{50} were 73ppm and 120 ppm respectively.

The results were further compared and calibrated to the result of Liu et al [8], and the comparison were tabulated in Table 2. The response of IL-strain to four synthetic pyrethroids, commonly tested in both studies, matched perfectly to that of FSstrain, a susceptible strain introduced from France, in Liu's study. However the sensitivity of IL-strain to organophosphates was much lower than the FS-strain. The PH-strain is the native susceptible strain in Liu's study but its response in the synthetic pyrethroids were quite different from both FS-strain and our IL-strain. Instead, the most effective insecticide was permethrin and the same fact was also demonstrated in the BC-strain or a native resistant strain used by them.

Although methomyl has been considered as a good insecticide in controlling the diamondback moth [4], its effectiveness was not up to the standard as expected in both the FS-strain and the IL-strain.

Cartap showed stronger killing action toward the IL-strain than the FS-strain when decamethrin was referred as the common standard in Table 2. Since the cartap resistance has not developed and spread significantly [2], its effectiveness has also been confirmed in the PH-strain in Liu's study, and we believed that cartap is still an effective insecticide and can be used for the diamondback moth control.

Tokuthion is very effective toward the FS-strain [8] but was not so desirable when

表2.、試以第滅靈為標準，比較劉明毅等研究之 FS. PH. BC 三品系與吾人研究之 IL 品系小菜蛾毒效資料。

Table 2. The comparison of insecticide sensitivity (LC_{50}) of I-lan strain to Liu's result [8] in referring decamethrin as the common standard.

Insecticides	IL	FS	PH	BC
Decamethrin	1.0[a]	1.0[b]	1.0[c]	1.0[d]
Fenvalerate	2.3	2.0	1.1	2.5
Tokuthion	86.6	2.0	14.8	5.4
Permethrin	3.8	4.0	0.3	0.2
Cypermethrin	5.5	5.0	2.0	2.1
Cyanofenphos	53.1	10.0	13.1	> 220.0
Mevinphos	20.4	—	—	—
Methyl parathion	—	23.5	4,468.5	> 220.0
Profenofos	27.9	—	—	—
Carbofuran	33.5	—	—	—
Prophos	47.5	—	—	—
Dichlorvos	—	84.0	65.2	11.3
Cartap	81.0	125.0	36.0	11.1
Malathion	4,469.0	137.0	1,396.0	> 220.0
Diazinon	—	146.5	114.4	27.1
DDT	—	174.0	1,991.0	> 220.0
Methomyl	949.7	253.0	316.2	119.0
Propoxur	—	1,690.0	$>10^4$	> 220.0
Carbaryl	7,541.9	2,160.0	910.0	> 220.0

1.0[a]=3.58ppm, 1.0[b]=0.2ppm, 1.0[c]=11.10ppm, 1.0[d]=447ppm
the testing method of (*a*) is different from (*b*), (*c*) and (*d*).

it was tested against three Taiwan strains (Table 2). Several insecticides were definitely not suitable for the diamondback moth control any longer in Taiwan and they were methomyl, malathion and carbaryl.

The response of diamondback moth to the selection pressure at the LC_{75} level of three insecticides were different (Fig. 1). The moth responded to carbofuran most drastically and developed 36 folds of resistance in merely eight generations. Two other insecticides also induced the resistance but at much slower rates, and they were 15 folds for fenvalerate in 12 generations and 10 folds for cartap in 10 generations. Of three tested insecticides, cartap has the lowest capability in inducing the resistance.

The cross resistance of three artificially induced resistant strains to other registered insecticides were studied and were presented in Table 3. The carbofuran-resisted strain showed very little cross resistance to other nineteen insecticides. On the

Fig. 1. The induction rates of resistance in the diamondback moth by carbofuran, fenvalerate and cartap at the selection pressure of LC_{75}.

圖1. 加保扶，芬化利及培丹誘發小菜蛾抗性能力之比較

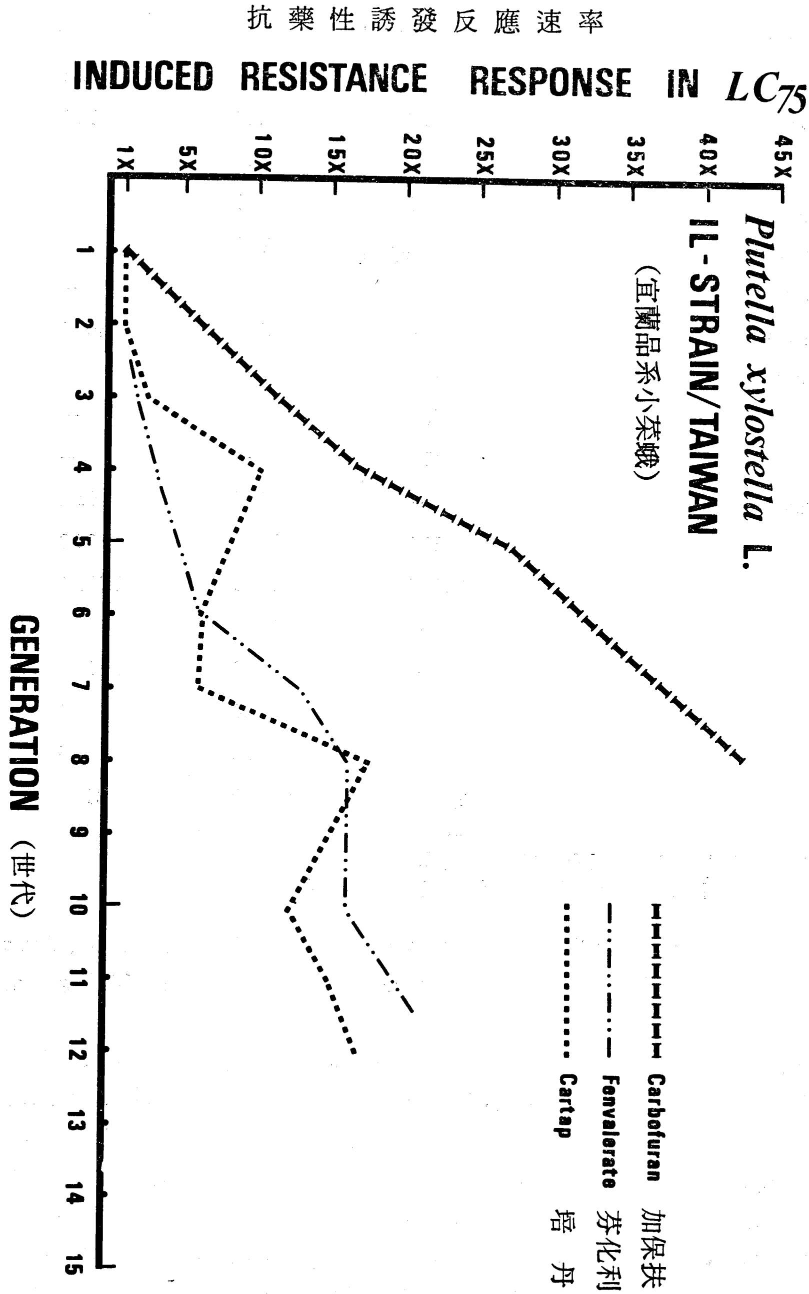

Table 3. The cross-resistance of three artificially induced resistant strains of diamondback moth to twenty-one other insecticides.

表 3. 人工誘發三種小菜蛾抗性品系對其他21種殺蟲劑之交互抗性測定

Insecticdiees	Carbofuran-resis.		Fenvalerate-resis.		Cartap-resis.	
	LC_{75}*	R. R.	LC_{75}*	R. R.	LC_{75}*	R. R.
Carbofuran	2.5×10^4	36.23	4.4×10^3	6.38	2.2×10^3	3.19
Fenvalerate	4.1×10^1	1.78	3.3×10^2	14.34	1.1×10^2	4.78
Cartap	2.3×10^3	3.97	2.9×10^3	5.00	5.6×10^3	9.66
Decamethrin	1.8×10^1	1.64	1.2×10^2	10.91	5.7×10^1	5.18
Permethrin	9.3×10^1	3.01	1.0×10^2	3.30	4.2×10^1	1.83
Cypermethrin	—	—	2.3×10^2	4.34	—	—
UCX-33	—	—	1.4×10^2	0.88	—	—
Mevinphos	5.9×10^2	3.28	6.7×10^2	3.72	4.6×10^2	2.56
Profenofos	7.9×10^1	0.34	5.0×10^2	2.17	4.3×10^2	1.87
Prophos	1.1×10^2	0.42	8.3×10^2	3.19	3.8×10^2	1.46
Cyanophenphos	1.2×10^2	0.27	1.6×10^3	3.64	1.5×10^3	3.41
Diethquinalphion	3.1×10^2	0.62	4.1×10^3	8.20	5.1×10^2	1.02
Methidathion	4.5×10^2	1.02	1.3×10^3	2.95	6.4×10^2	1.45
Tokuthion	3.0×10^2	0.54	2.1×10^3	3.75	1.1×10^3	1.96
Mephosfolan	9.6×10^2	1.07	7.3×10^2	0.81	4.3×10^2	0.48
Methamidophos	1.0×10^3	0.71	1.9×10^3	1.36	1.5×10^3	1.07
Phenthoate	1.1×10^3	0.65	4.2×10^3	2.47	1.3×10^3	0.76
Chlorpyrifos	3.0×10^3	1.76	8.0×10^3	4.71	5.6×10^3	3.29
Methomyl	5.7×10^3	0.80	1.5×10^4	2.11	5.4×10^3	0.76
Fenitrothion	2.3×10^4	1.64	1.0×10^5	7.14	1.7×10^4	1.21
Malathion	2.3×10^4	0.72	4.5×10^4	1.36	1.7×10^4	0.52
Carbaryl	9.8×10^4	0.93	1.3×10^5	1.24	6.4×10^4	0.61

* PPM

other hand, stronger cross resistance were observed in both the cartap-resisted and the fenvalerate-resisted strains. The cartap-resisted strain became less sensitive to decamethrin, fenvalerate, cyanophenphos, chlorpyrifos and carbofuran. In the fenvalerate-resisted strain , strong response of resistance to both fenvalerate and decamethrin were again observed. Besides, a universal increase in resistance at various degree against other insecticides were appeared in the fenvalerate-resisted strain. Most significantly, the susceptibility dropped sharply in regard to diethquinalphion, fenitrothion, cartap, chlorpyrifos, cypermethrin, tokuthion and cyanophenphos.

Discussion

The reason of diamondback moth can survive under the heavy pressure of chemical control is because they can build up the resistance very fast [1,2,3,4,6,7,8]. Before other control measures become practical, the increasing demand in vegetable production still depends heavily on the usage of insecticides. Besides, we felt that an insecticide should be continually investigated for its side-effects and undesirable consequence when it was recommended for the field application.

The result of this study has indicated that in the diamondback moth, the resistance induction rate and the extent of cross resistance were different from one insecticide to others. Since the effective longevity of an insecticide in field application is in inverse ratio to its resistance induction rate, and to select a substituting insecticide depend on how much we know about the scope and extent of cross resistance of that resistant strain, it is unavoidable that more research is needed to reshape the chemical control scheme of diamondback moth in Taiwan.

The superiority of synthetic pyrethroids in the sensitivity aspect has been clearly demonstrated, and how to preserve their effectiveness in the threat of resistance is a very important matter and the subject has been intensively investigated by Sun [9] currently. Of four studied synthetic pyrethroids, the diamondback moth responded to fenvalerate and decamethrin in a similar fashion, and responded to cypermethrin and permethrin more closely. It seems that the α-cyano group is not the only functional group which causes the difference, and more research is needed in the mechanism study to explain the cross resistance difference in relation to the molecular structures.

Carbofuran is the most toxic compound of three carbamates tested in the sensitivity study, unfortunately, the undesirable nature of its resistance inducing ability has excluded the only carbamate which was good in the diamondback moth control.

In organophosphates, mevinphos, profenofos and tokuthion are three most promising compounds and they were currently been investigated in our laboratory in the aspect of resistance.

Cartap is still a fair choice as the control agent for the diamondback moth, and can be recommended in many areas in Taiwan.

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小菜蛾抗藥性之研究

Ⅲ.對三種殺蟲劑之抗性發展及引發之交互抗性[1]

周桃美 鄭 允[2]

本試驗係利用本所於民國69—70年間於宜蘭所採得之感性品系小菜蛾 *Plutella xylostella* (L)，測定22種登記於防治此蟲之殺蟲劑的基本毒理資料。所測得最有效之前五種均屬人工合成除蟲菊精（Synthetic pyrethroids），而其中，又以第滅靈（Decamethrin）最爲有效。數種有機磷劑效果均佳，但以美文松爲第一，氨基甲酸鹽類之效果均不理想，僅加保扶尚可，加保利爲所有供試藥劑中感度最差者（見表1.）。總體而言，所測得結果與劉明毅等人所測之 FS-品系反應類似（見表2.）。但宜蘭品系對有機磷類殺蟲劑之感度偏低，似與該類藥劑已在本省使用多年，可能有某種程度之抗藥性發生有關。

在抗藥性誘發試驗中，係以加保扶，培丹及芬化利等三種殺蟲劑之百分之七十五致死濃度（LC_{75}）進行汰選，各世代所需用之 LC_{75} 隨汰選次數而增加，故每代均需重新測定，吾人係以各世代需用之 LC_{75} 增加速率爲該藥劑誘發抗藥能力之指標（見圖1 ）。一旦抗性品系之抗藥力達十至二十倍時，即可進行交互抗性之測定，測定仍依基本毒理測定方式進行，將所得結果與原有宜蘭品系毒理資料比較，以檢查各抗藥性品系對不同殺蟲劑之交互抗性是否發生及發生程度。

所得結果顯示，加保扶誘發抗藥能力最强，經過8世代之汰選，可誘發36倍抗藥能力。芬化利則次之，12代即可誘發15倍之抗藥力。三種供試殺蟲劑中，以培丹之抗性誘發能力最低，經10代僅誘發約10倍之抗藥力。

抗加保扶品系僅對其他殺蟲劑產生輕微或全無交互抗性，因此，如需於田間換用其他藥劑對付抗加保扶之小菜蛾時，選藥範圍較寬。抗芬化利者，則完全不同，其交互抗性範圍廣泛，程度較嚴重。抗培丹者居中，只對部分殺蟲劑發生中等程度之交互抗性（見表3.）。

由以上結果，可預測使用不同化學防治藥劑時，小菜蛾之可能反應，因而選用較理想之藥劑進行防治。

1.臺灣農業試驗所 研究報告第 1091 號。本計畫承國科會補助（編號 72-0409-B055-03），簡珠碧、簡淑貝協助工作，劉淸博士協助統計分析僅一併致謝。
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