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Insecticide Resistance in *Plutella xylostella* L. XI. Resistance to Newly Introduced Insecticides in Taiwan (1990~2001)[1]

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Abstract: The diamondback moth (*Plutella xylostella*, DBM) has developed resistances to almost all conventional insecticides, for example, carbamates, organophosphorus compounds, synthetic pyrethroids, and insect growth regulators. The resistance and cross-resistance amongst these insecticides had been studied and clarified. A strategy by rotating selected insecticides to manage the resistant DBM has been proposed and tested in field, and the result is acceptable to farmers. From 1990 to 2000, many new insecticides with unique mode of actions were registered, and DBM control is no longer a problem for farmers. However, whether DBM also slowly develops resistance to those new insecticides is worth to study. DBM strains were collected from two largest vegetable districts, Hsi-hu and Lu-chu, for testing the resistance profile to newly registered insecticides. The test results confirmed that field DBM has developed resistance to new insecticides except diafenthiuron. The resistance ratios of abamectin and emamectin benzoate between two field DBM populations are 2500~5000 and 300~150 respectively; the resistance ratio of another GABA inhibitor, fipronil, between these two populations is 65~104. The resistance ratio of derivatives of cartap and carbamate, bensultap and benfuracarb between two different populations are 20~30 and 10~30 respectively. The resistance ratio of chlorfenapyr and spinosad between two different populations are 10 and 60 respectively. The DBM resistance to commercial product of neem extract, azadirachtin, is too high for field application practically since the high viscosity of the extracted product plugged the spray nuzzle of sprayer when the concentrated product was used.

Key words: *Plutella xylostella*, Insecticide, Resistance, Resistance monitoring.

INTRODUCTION

Crucifer crop is the most important group of vegetable in Asian countries. The major insect problem of crucifer crop is the diamondback moth (*Plutella xylostella* L., DBM). During 1950s to 1960s, synthetic insecticides such as DDT and parathion were introduced for DBM control. Bt products also were used since

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1960s. Following more restricted safety consideration, many early registered insecticides were banned in recent years. Nevertheless, there're still a great number of carbamates and organophosphorus insecticides registered for DBM control[21], meanwhile synthetic pyrethroids were introduced around 1980s. All of them had confronted with strong resistance problem[4, 12, 20], and DBM has become a perennial insect problem for crucifer production. Taiwan Agricultural Research Institute (TARI) has monitored and studied this resistance problem since 1980[2, 3]. After sorting out the interrelation of cross-resistance among various insecticides, we are able to propose a resistance management strategy[5] by rotating selected insecticides with minimum cross-resistance effect, and the results are acceptable by farmers[7].

On the other hand, pesticide industry has been continuous making efforts in developing new insecticides to counter the resistance problem. For example, the BPU-type IGRs were introduced in early 1980s, although very promising at the beginning, it met strong MFO resistance and the effectiveness was vanished in just one year[10]. Later on, abamectin, a new GABA inhibitor, was registered, and this biological-originated insecticide had been very effective. However, the low-quality generic products of abamectin were massively marketed without the consideration of resistance management[13]. Another GABA inhibitor, fipronil, was subsequently registered in late 1990s. From 1990 to 2001, there are several other insecticides with new modes of action been registered for DBM control, which are either chemicals or biological-originated products (Table 1). Currently, DBM control is not a significant problem in Taiwan due to the introduction of these products[22], but whether DBM has gradually developed new resistance is a question that needs to be studied. TARI has re-initiated the resistance study on DBM in two major vegetable production areas, Lu-chu and Hsi-hu, on the above mentioned

Table 1. DBM control agents registered in Taiwan

Insecticide categories	Common names	Number
Chemical insecticides		
Organophosphorus compounds	Diazinon, salithion, phenthoate, quinalphos, cyanophos, profenofos, naled, pirimiphos-methyl, prothiophos, mevinphos, acephate, pyridaphenthion, mephosfolan	13
Carbamates	Methomyl, carbofuran, benfuracarb[z]	3
Synthetic pyrethroids	Fenvalerate, permethrin, cypermethrin, deltamethrin, flucythrinate, fenpropathrin[z]	6
Organonitrogens	Cartap, thiocyclam hydrogenoxalate, bensultap[z]	3
Mixtures	Phenthoate+dimethoate, teflubenzuron+fluvalinate, prothiophos+mevinphos, chlorpyrifos+cypermethrin	4 x 2
Insect growth regulators	Teflubenzuron[z], chlorfluazuron[z]	2
Others	Fipronil[z], chlorfenapyr[z], diafenthiuron[z]	3
Bioinsecticides		
Bacillus thuringiensis (Bt)	Dipel, Thuricide, Javelin, Turex[z], MVP[z], Cutlass[z], Xentari[z], Quark[z], Batik[z]	9
Streptomyces avermitilis	Abamectin[z], emamectin benzoate[z]	2
Neem extaract	Azadirachtin (Neemix)[z]	1
Saccharopolyspora spinosa	Spinosad[z]	1
Total		47

[z]Compounds registered after 1990.

newly registered insecticides such as abamectin, emamectin benzoate, bensultap, benfuracarb, diafenthiuron, fipronil, chlorfenapyr, spinosad, azadirachtin and the new Bt products.

MATERIALS AND METHODS

Insecticides used:

Commercially formulated insecticides were used for comparison which include abamectin, 2% EC; emamectin benzoate, 2.15% EC; bensultap, 50% WP; benfuracarb, 20% EC; diafenthiuron, 25% FP; fipronil, 4.95% FP; chlorfenapyr, 10% SF; spinosad, 2.5% SF; azadirachtin, 4.5% EC; Javelin, 6.4% WP; Thuricide, 3% WP; Turex, 3.8%WP; Xentari, 10.3% WP; MVP, 10% FP; Cutlass, 10.3% SW; and Batik 10.4% SF.

Insects used:

Two field-resistant DBM strains collected from Hsi-hu and Lu-chu were tested against a native susceptible IL strain. Both areas are major vegetable growing districts in Taiwan, and are nearly 150 kilometer apart and geographically separated by non-vegetable growing areas.

I. Susceptible strain: I-lan (IL) DBM strain was collected in 1983[9].

II. Field-collected resistant strains: Collected in 1996, 1997, 1998 and 2001, respectively, and only the offspring of the first and the second generation were used.

  i. Hsi-hu strain: collected from vegetable growing district in central Taiwan.

  ii. Lu-chu strain: collected from vegetable district in southern Taiwan.

Bioassay methods:

I. Spray tower method:

The susceptibilities of DBM to bensultap, benfuracarb, diafenthiuron, fipronil and chlorfenapyr were tested as described by Cheng *et al.*[14]. One milliliter of insecticide solution was pipetted into the holding tube of Burkard Potter Spray Tower and sprayed on leaf disc. After air-dried, the leaf disc was inverted and loaded with fifteen third instar DBM larvae, and sprayed with another milliliter of the same insecticide solution. Treated larvae and leaf discs were transferred into the petri dish, and total of 60 larvae in 4 subsets was treated for each dosage. The post-treatment holding condition was controlled at 25 ℃ in a constant temperature growth chamber. The leaf discs used were 24 cm^2 and changed to fresh untreated leaf discs after 48 hours.

II. Leaf dipping method:

The susceptibilities of different DBM strains to abamectin, emamectin benzoate, Javelin, Thuricide, Xentari, MVP, Cutlass, Batik, azadirachtin and spinosad were determined as described by IRAC Method No. 7[6]. Cabbage leaves were washed and air-dried first, and leaves were punched into discs of 3.5 cm in diameter. Total of 20 leaf discs were prepared for each dosage and leaf discs were dipped for 5 seconds in testing solutions containing 333ppm Triton X-100 and left to air-dry. For the control test, cabbage leaf discs were dipped in a 333ppm Triton X-100 solution only and air-dried on wire rack. In each petri dish, three leaf discs were used in the beginning and 15-20 third instar DBM larvae were put on the treated leaves. Forty-eight hours after treatment, these leaf discs were discarded and changed to the other two treated leaf discs that been stored at 5 ℃ until pupation.

Assessments:

Mortalities of DBM to besultap, benfuracarb, diafenthiuron, fipronil and chlorfenapyr were recorded at 48 and 72 HR after the spray tower treatment. For abamectin, emamectin benzoate, Bt products, azadirachtin and spinosad, the mortalities were recorded at 24, 48, 72, 96 and 120 HR after the start of treatment. Analysis was made by correcting with the control first, then analyzed by Probit analysis[15]. If the DBM mortality in the control test was over 8%, the test was abandoned and a new test was repeated for compensation.

RESULTS AND DISCUSSION

It has been demonstrated in the past that DBM is capable of developing resistance to all conventional synthetic insecticide groups such as organophosphorus compounds, carbamates, pyrethroids[4, 20], insect growth regulator[10, 12, 17], and even the biologically originated Bt products[16, 24, 25, 26]. A program of rotating selected insecticides for managing resistant DBM has been mandated in several counties and gained successful results [7], which confirmed that certain insecticides are still useful in rationally rotation to minimize the resistance problem.

When TARI re-started the DBM resistance study program on these new insecticides in 1996, we experienced a five-year work span because previous reports showed that field DBM did develop resistance to insecticides within one to three years[5]. The monitored result confirmed DBM has developed resistance to the most potent insecticide ever registered for DBM for example, abamectin. The resistances to fipronil and spinosad are also noticed, even they have different modes of action. The sensitivities of the susceptible and resistant DBM to eight new insecticides were presented in Tables 2 and 4, as well as the resistance ratios were calculated and listed in Tables 3 and 5.

Two derivatives of traditional insecticides, bensultap and benfuracarb, are discussed first. Bensultap, an analog of cartap, was registered in 1995 and rapidly developed 20 to 30 times resistance in 1997, which was much higher than previously recorded cartap-resistance[8, 9, 14]. This high resistance may build upon the already existed cartap-resistance; hence bensultap was not considered to be an effective insecticide for DBM control anymore. Benfuracarb belongs to the carbamate group, and its effective dosage for DBM has already exceeded 2000 - 5000 ppm in two monitored areas. The obvious cross-resistance from carbamates[11] made the bensultap application not realistic in practice.

The field DBM was not very sensitive to azadirachtin (neemix), a natural product extracted from neem, even without too extensive usage. Strong resistance in DBM had occurred as the LC_{50} is 0.24 ppm in the susceptible strain, while the resistance ratio in both field strains exceeded 1000. This material also has high viscosity that caused spray problem in operation at higher dosage.

Table 2. Susceptibilities of Lu-chu strain DBM to newly registered insecticides

Insecticide	LC_{50} in ppm/slope				
	Suscep. -IL	1996	1997	1998	2001
Abamectin	0.01/1.58	2.02/1.46	3.30/1.58	6.06/1.49	49.88/1.88
Emamectin benzoate	0.004/1.67	-	-	-	0.61/1.90
Bensultap	194.73/2.11	1214.70/1.32	4450.36/1.28	-	-
Benfuracarb	164.03/1.30	610.40/3.87	1990.82/2.59	1594.58/2.20	-
Diafenthiuron	346.77/2.71	406.58/2.12	362.98/2.05	337.28/1.84	-
Fipronil	0.82/3.60	2.18/4.62	12.53/4.49	22.91/1.95	85.57/3.59
Chlorfenapyr	17.32/3.93	-	29.72/5.52	24.45/3.57	167.05/1.70
Spinosad	0.41/3.80	-	-	-	24.06/2.41
Azadirachtin	0.24/0.047	-	-	-	>300ppm

Table 3. The resistance ratios of Lu-chu strain DBM to newly registered insecticides

Insecticide	Resistance ratio				
	Suscep. -IL	1996	1997	1998	2001
Abamectin	1.0	202.0	330.0	606.0	4988.0
Emamectin benzoate	1.0	-	-	-	152.5
Bensultap	1.0	6.2	22.9	-	-
Benfuracarb	1.0	3.7	12.1	9.7	-
Diafenthiuron	1.0	1.2	1.1	1.0	-
Fipronil	1.0	2.7	15.3	27.9	104.4
Chlorfenapyr	1.0	-	1.7	1.4	9.6
Spinosad	1.0	-	-	-	58.7
Azadirachtin	1.0	-	-	-	>1000

Table 4. Susceptibilities of Hsi-hu strain DBM to newly registered insecticides

Insecticide	LC_{50} in ppm/slope				
	Suscep. -IL	1996	1997	1998	2001
Abamectin	0.01/1.58	1.44/1.04	3.33/1.85	3.71/1.30	24.97/1.50
Emamectin benzoate	0.004/1.67	-	-	-	1.22/1.07
Bensultap	194.73/2.11	-	6123.52/1.39	-	-
Benfuracarb	164.03/1.30	4755.60/1.53	4976.68/1.73	2262.06/2.13	-
Diafenthiuron	346.77/2.71	562.88/1.83	345.11/1.96	319.71/1.45	-
Fipronil	0.82/3.60	7.61/3.09	9.38/4.80	6.87/2.68	53.62/4.34
Chlorfenapyr	17.32/3.93	-	20.56/4.76	32.91/4.50	159.86/1.71
Spinosad	0.41/3.80	-	-	-	26.77/3.24
Azadirachtin	0.24/0.047	-	-	-	>300ppm

Table 5. The resistance ratios of Hsi-hu strain DBM to newly registered insecticides

Insecticide	Resistance ratio				
	Suscep. -IL	1996	1997	1998	2001
Abamectin	1.0	144.0	333.0	371.0	2497.0
Emamectin benzoate	1.0	-	-	-	305.0
Bensultap	1.0	-	31.5	-	-
Benfuracarb	1.0	29.0	30.3	13.8	-
Diafenthiuron	1.0	1.6	1.0	0.9	-
Fipronil	1.0	9.3	11.4	8.4	65.4
Chlorfenapyr	1.0	-	1.2	1.9	9.2
Spinosad	1.0	-	-	-	65.3
Azadirachtin	1.0	-	-	-	>1000

There're compounds with only minor resistance problem e.g., diafenthiuron did not show any sign of resistance up to 1998. Since diafenthiuron was not used extensively, this may be the reason that resistance was not found and hence was not tested in 2001.

Chlorfenapyr belongs to a new category of insecticide developed by the American Cyanamid Company. The commercial product is a pro-insecticide (AC303.630), which has to be activated by MFO to AC303.268, then acted on mitochondria and influenced the electron flow in the cell [1]. The unbalance in ion concentration finally blocked the production of ATP and caused death. Processes of actual poisoning of chlorfenapyr include at least three steps i.e., the absorption through stomach, the activation by MFO, and the biochemical lesion on mitochondria. Hence, more than one step may be involved in the resistance mechanism. The multi-steps poisoning makes things more complicated and possibly lengthens the resistance development, which may be the reason why only minimum change in susceptibility of field DBM to chlorfenapyr were recorded in 1998. However, almost 10 times resistance was recorded in both DBM in 2001. The high resistance causes the effective dosage of chlorfenapyr reached the upper limit of its registered concentration, and currently the field efficacy of chlorfenapyr for DBM control is remained in question.

Both abamectin and fipronil act on the GABA transmission in the neural system [19, 23]. Aabamectin resistance in both DBM strains of Hsi-hu and Lu-chu areas has increased progressively from 100/200-fold in 1996, 400/600-fold in 1998, and has already reached 2500/5000-fold in 2001. Since the generic abamectin products once occupied 90% of abamectin market, the resistance induced in DBM might be the consequence of those generic products rather than abamectin. These generic products contain a lot of toxin impurities [13], and may induce more complicated resistance mechanism in DBM. The purified B1a/B1b mixture, emamectin benzoate, was registered for DBM control in March 2000, and is the most potent DBM control agent as its LC_{50} is 0.5-1.0 ppm for both Lu-chu and Hsi-hu strains. Emamectin benzoate suffered 150~300 fold resistance of DBM in the test of 2001, and the cross-resistance from abamectin is obvious but in lesser degree. The difference may be contributed from purified B1a/B1b active ingredients, and suffered less cross-resistance from other toxins.

Fipronil, another GABA inhibitor, was registered in Taiwan in 1996 but has already confronted with 10- to 30-fold resistance since 1998, and its resistance ratios increased to 60/100 fold in 2001. Although current DBM resistance did not hamper the effectiveness of abamectin and fipronil seriously, the trend of resistance development is alarming. It is unclear whether the cross-resistance has developed between abamectin and fipronil, but the introduction of abamectin for field application is much earlier. Since both compounds share the similar action site, the GABA transmission, the resistance mechanism study is needed. The registered concentrations of both abamectin and fipronil for DBM are comparatively high, and that is why farmers are still able to use these compounds despite the strong resistance.

Spinosad was registered in 1996 and tested for resistance for the first time. This bio-originated insecticide acts as a stimulator on central nerve system. Surprisingly, we found the spinosad-resistance has occurred in both tested field strains and the resistance ratio between resistant and susceptible populations is around 60-fold. Whether this resistance is the cross effect from other insecticide is unknown, but this consequence already raised the LC_{50} dosage to 25 ppm, which is comparable to the current LC_{50} of abamectin .

The Bt resistance in DBM has been studied and reported [16, 17, 18, 23, 24, 25], and TARI has developed an empirical testing system. Four discriminating dosages, 2000-, 4000-, 32000- and 128000-fold dilution, were chosen for all tested Bt products, and the 50% mortality is used to distinguish the resistance development. Two higher dosages are used mainly for identifying the field resistant strains, and the two lower dosages are used for confirming the test standard for the susceptible strain. When the 50% mortality occurred between 4000- and 32000-fold dilutions of Bt, we consider there is no alarm for Bt resistance. While the 50% mortality occurred at the dosage higher than the 4000-fold dilution, a warning for Bt resistance should be issued.

Bt mortalities in DBM collected from Lu-chu and Hsi-hu from 1996 to 2001 were recorded in Tables 6 and 7, which confirm at that field DBM did develop resistance when compared to the susceptible strain. More than 50 % mortality in the susceptible strain was found in the first three dosages of all Bt products; while in both field strains, only two higher dosages caused more than 50% mortality. For the past five years, most Bt products still maintained reasonable efficacy in Hsi-hu DBM, while Xentari, Turex and Cutlass had met resistance in Lu-chu DBM since 1998. In general, the result of Xentari testing in 2001 is almost the same as in 1998, and the Bt resistance of field DBM is rather stable when compared to chemical insecticides.

Table 6. Susceptibilities of Lu-chu strain DBM to commonly used Bt products (1996-2001)

Bt products	Dilution	% Mortality					
		Suscep.-IL	1996	1997-1	1997-2	1998	2001
Javelin, 6.4%	2000X	100	95.7	100	96.3	87.9	-
	4000X	100	90.5	95.0	79.1	79.1	-
	32000X	93.5	51.2	63.1	15.6	41.7	-
	128000X	77.4	20.7	39.7	13.3	35.8	-
Thuricide, 3%	2000X	100	89.3	83.1	63.0	82.1	-
	4000X	100	72.7	73.9	48.7	80.0	-
	32000X	70.6	25.2	20.5	26.5	25.0	-
	128000X	30.9	13.4	19.5	18.3	18.2	-
Xentari, 10.3%	2000X	100	88.5	95.9	83.6	91.9	77.7
	4000X	95.4	65.3	63.7	68.5	42.3	52.0
	32000X	55.5	18.6	16.2	22.8	18.4	14.7
	128000X	24.7	7.2	2.6	17.2	6.3	5.0
MVP, 10%	2000X	100	81.0	83.1	66.0	-	-
	4000X	89.7	63.3	81.3	56.9	-	-
	32000X	85.6	13.5	26.4	23.6	-	-
	128000X	64.0	7.7	11.2	12.3	-	-
Turex, 3.8%	2000X	100	95.3	98.3	95.2	74.5	-
	4000X	80.9	84.4	88.1	78.3	50.4	-
	32000X	69.1	31.7	24.2	31.3	18.7	-
	128000X	40.9	14.3	20.4	6.9	6.4	-
Cutlass, 10.3%	2000X	100	96.3	99.2	96.9	50.0	-
	4000X	97.6	94.3	93.2	83.2	32.8	-
	32000X	68.4	52.2	54.2	31.3	13.4	-
	128000X	32.3	28.8	30.5	16.0	1.6	-
Batik, 10.4%	2000X	100	-	-	-	87.2	-
	4000X	95.0	-	-	-	67.4	-
	32000X	59.5	-	-	-	26.2	-
	128000X	22.0	-	-	-	11.9	-

Table 7. Susceptibilities of Hsi-hu strain DBM to commonly used Bt products (1996-2001)

Bt products	Dilution	% Mortality				
		Suscep.-IL	1996	1997	1998	2001
Javelin, 6.4%	2000X	100	91.8	97.4	95.7	-
	4000X	100	69.7	93.3	88.7	-
	32000X	93.5	15.7	43.3	49.7	-
	128000X	77.4	13.2	28.8	36.7	-
Thuricide, 3%	2000X	100	92.4	79.3	-	-
	4000X	100	71.6	50.8	-	-
	32000X	70.6	28.7	25.7	-	-
	128000X	30.9	19.3	16.9	-	-
Xentari, 10.3%	2000X	100	98.4	100	-	82.0
	4000X	95.4	65.0	85.0	-	71.1
	32000X	55.5	21.7	29.2	-	19.8
	128000X	24.7	16.7	30.5	-	10.9
MVP, 10%	2000X	100	85.3	82.5	-	-
	4000X	89.7	68.0	42.9	-	-
	32000X	85.6	31.3	26.8	-	-
	128000X	64.0	11.7	15.5	-	-
Turex, 3.8%	2000X	100	99.2	100	-	-
	4000X	80.9	77.0	83.1	-	-
	32000X	69.1	20.4	23.0	-	-
	128000X	40.9	13.0	22.2	-	-
Cutlass, 10.3%	2000X	100	98.7	91.7	-	-
	4000X	97.6	90.9	84.9	-	-
	32000X	68.4	32.1	39.2	-	-
	128000X	32.3	10.1	28.2	-	-
Batik, 10.4%	2000X	100	-	87.1	87.0	-
	4000X	95.0	-	62.9	63.3	-
	32000X	59.5	-	14.3	8.2	-
	128000X	22.0	-	12.1	8.1	-

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REFERENCES

1. American Cyanamid Company. 1995. RAMPAGE* Insecticide-Miticide, Technical Bulletin, 17pp. Princeton, New Jercy, USA.
2. Cheng, E. Y. 1981. Insecticide resistance study in *Plutella xylostella* L. I. Developing a sampling method for surveying. J. Agric. Res. China 30: 277-284.
3. Cheng, E. Y. 1981. Insecticide resistance study in *Plutella xylostella* L. II. A general survey (1980-81). J. Agric. Res. China 30: 285-293.
4. Cheng, E. Y. 1986. The resistance, cross resistance, and chemical control of diamondback moth in Taiwan. *In*: Proceedings of the First International Workshop on "Diamondback Moth Management" (N.S. Talekar and T. D. Griggs, eds.), pp. 329-

345. AVRDC, Tainan, Taiwan, ROC.

5. Cheng, E. Y. 1988. Problem of control of insecticide-resistant *Plutella xylostella*. Pestic. Sci. 23: 177-188.
6. Cheng, E. Y., and C. H. Kao. 1998. Validation of a field monitoring system for BPU-type IGR resistance in the diamondback moth, *Plutella xylostella* - Presumed working scheme based on IRAC Method No. 7 (leaf dipping method). J. Agric. Res. China 47: 142-158.
7. Cheng, E. Y., C. N. Chen, and C. H. Kao. 1996. Management of resistant diamondback moth and other crucifer pests in Taiwan. J. Agric. Res. China 45: 89-104.
8. Cheng, E. Y., T. M. Chou, and C. H. Kao. 1984. Insecticide resistance study in *Plutella xylostella* (L.) V. The induction, cross resistance and glutathione-S-transferase in relation to mevinphos-resistance. J. Agric. Res. China 33: 73-80.
9. Cheng, E. Y., T. M. Chou, and C. H. Kao. 1985. Insecticide resistance study in *Plutella xylostella* (L.) VI. An experimental analysis of organophosphorus and synthetic pyrethorid resistances. J. Agric. Res. China 34: 96-104.
10. Cheng, E. Y., C. H. Kao, and C. S. Chiu. 1990. Insecticide resistance study in *Plutella xylostella* L. X. The IGR-resistance and the possible management strategy. J. Agric. Res. China 39: 208-220.
11. Cheng, E. Y., C. H. Kao, and C. S. Chiu. 1990. Insecticide resistance study in *Plutella xylostella* L. VIII. The specificity of oxidative detoxication mechanism in larval stage. J. Agric. Res. China 35: 375-386.
12. Cheng, E. Y., C. H. Kao, and C. S. Chiu. 1992. Resistance, cross-resistance and chemical control of diamondback moth in Taiwan: Recent developments, *in* Proceedings of the Second International Workshop on "Diamondback Moth and Other Crucifer Pests (N. S. Talekar, ed.)". pp. 465-475. AVRDC, Tainan, Taiwan, ROC.
13. Cheng, E. Y., C. H. Kao, and Y. B. Hwang. 2002. The toxin components study on generic products of abamectin (in press).
14. Cheng, E. Y., D. F. Lin, T. C. Tsai, and C. H. Kao. 1988. Insecticide resistance in *Plutella xylostella* L. IX. The selective metabolism of insecticides. J. Agric. Res. China 37: 328-339.
15. Finney, D. J. 1971. Probit Analysism, 333pp. University Press, Cambridge.
16. Kao, C. H., and E. Y. Cheng. 1994. The resistance and cross resistance of diamondback moth, *Plutella xylostell*a to *Bacillus thuringiensis* in Taiwan. J. Agric. Res. China 43: 425-432.
17. Kao, C. H., and E. Y. Cheng. 1999. Study on cross-resistance between BPU-type IGRs and other insecticides including *Bacillus thuringiensis* and abamectin in the diamondback moth, *Plutella xylostella* L. J. Agric. Res. China 48: 84-95.
18. Kao, C. H., C. S. Chiu, and E. Y. Cheng. 1990. Field evaluation of microbial and chemical insecticides for diamondback moth and other lepidopterous pests control on cabbage. J. Agric. Res. China 39: 221-227.
19. Lasota, J. A., and R. A. Dybas. 1991. Avermectins, a novel class of compounds: implications for use in arthropod pest control. Ann. Rev. Entomol. 36: 91-117.
20. Liu, M. Y., Y. J. Tzeng, and C. N. Sun. 1982. Insecticide resistance in the diamondback moth. J. Econ. Entomol. 75: 153-155.
21. Plant Protection Manual. 1980. Department of Agriculture and Forestry, Taiwan Provincial Government, Nantou, Taiwan, ROC.
22. Plant Protection Manual. 2000. pp.209~218. TACTRI, Taichung, Taiwan, ROC.
23. Rhone-Poulenc. 1996. FIPRONIL Insecticide, Technical Bulletin/APZ, 18pp. Agro Asia-Pacific Zone, Singapore.
24. Shelton, A. M., J. L. Robertson, J. D. Tang, C. Perez, S. D. Eigenbrode, H. K. Preisler, W.T. Wilsey, and R. J. Cooley. 1993. Resistance of diamondback moth (Lepidoptera: Plutellidae) to *Bacillus thuringiensis* subspecies in the field. J. Econ. Entomol. 86: 697-705.
25. Tabashinik, B. E., N. L. Cushing, N. Finson, and M. W. Johnson. 1990. Field development of resistance to *Bacillus thuringiensis* in diamondback moth (Lepidoptera: Plutellidae). J. Econ. Entomol. 83: 1671-1676.
26. Tabashinik, B. E., N. Finson, M. W. Johnson, and W. J. Moar. 1993. Resistance to toxins from *Bacillus thuringiensis* subsp. *kurstaki* causes minimal cross-resistance to *B. thuringiensis* subsp. *aizawai* in the diamondback moth (Lepidoptera: Plutellidae). Appl. Environ. Microbiol. 59: 1332-1335.

小菜蛾抗藥性之研究

十一、對數種新型殺蟲劑之抗性(1990~2001)[1]

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摘要

小菜蛾對傳統殺蟲劑氨基甲酸鹽劑、有機磷劑、合成除蟲菊精劑及昆蟲生長調節劑等抗性之偵測研究已於1980~1990年間完成，並經田間測試減緩抗性發展之對策，以因應此一易發生抗藥性害蟲之防治。而農藥工業界也於1990~2000年間陸續推出各類作用不同的新殺蟲劑，其中登記於小菜蛾者包括免速達、免扶克、阿巴汀、汰芬隆、芬普尼、克凡派、賜諾殺、因滅汀、印楝素及多種新型蘇力菌。但此一期間，本省之小菜蛾田間族群對上列新型藥劑是否已產生抗性則尚有待瞭解。本研究選定溪湖及路竹兩大蔬菜專業區進行採集及藥效測試，結果顯示除了汰芬隆因使用不多，未發現明顯抗藥性外，兩地區之小菜蛾對所有新登記藥劑均產生不同程度之抗性，尤甚者爲效果極佳之阿巴汀及經純化之同型藥劑因滅汀，分別有2500~5000倍及150~300倍之抗藥性，而作用同爲抑制GABA 傳導之另一藥劑芬普尼，也有65~100倍抗性產生。分屬氨基甲酸鹽及培丹類似物之免扶克及免速達，於1997年時之抗性倍數已達20~30倍。作用於粒線體之克凡派抗性約10倍，小菜蛾對賜諾殺之抗性也已有60倍。印楝素亦有抗性產生，且因該藥劑本身極爲黏稠，提高濃度更使噴藥不易，而無法使用。1996~97年監測時發現，溪湖及路竹小菜蛾對蘇力菌均有中等程度之抗性，路竹地區「向前走」及「獨佳」兩種製劑之效果均有下降趨勢，但2001年之測試結果仍維持原有之抗性程度。由以上資料研判，近10年來小菜蛾之防治因新藥劑不斷推出，而獲良好之控制，惟因對各類新藥之抗性已逐漸形成，未來5~10年間小菜蛾仍可能因對新藥劑之嚴重抗藥性，再度成爲十字花科蔬菜之首要害蟲，故吾人應持續對新型藥劑進行抗性監測及抗藥性對策之研究。

關鍵詞：小菜蛾、新型殺蟲劑、抗藥性、監測。

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