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Joint Toxic Action of Bifenthrin and Prothiofos Mixture for the Control of Insecticide-Resistant Diamondback Moth, *Plutella xylostella* L.

살충제 저항성 배추좀나방 방제를 위한 Bifenthrin과 Prothiofos혼용의 연합작용

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ABSTRACT Mixture study of bifenthrin and prothiofos was conducted to control insecticide resistant diamondback moth (DBM), *Plutella xylostella*, which had shown 581, 18, 19, 11 fold resistance to fenvalerate, cypermethrin, furathiocarb, and prothiofos in Chinju strain, respectively and 38 and 9 fold resistance to fenvalerate and furathiocarb in Seosang strain, respectively. Optimal mixture ratios of bifenthrin and prothiofos was selected against Seosang strain of DBM by leaf dipping method in laboratory and by field test. Maximum co-toxicity coefficient by dipping method was shown at a ratio of 1:50 mixture of bifenthrin 1EC and prothiofos 50EC in active ingredient(a.i.) by 273.2 and then suddenly decreased. The mixed formulation from the dipping test was examined at the cabbage field of Seosang, Hamyang. Although insecticides were reduced to half, control efficacy was similar to farmer's conventional method. In addition, the mixture combination was also more effective against Chinju DBM population which had very high level of resistance to several representative insecticides. Mixture methods of insecticides will be effective countermeasures to the resistance problem of pests.

KEY WORDS **joint toxic action, bifenthrin, prothiofos, resistance,** *Plutella xylostella*

초 록 Fenvalerate, cypermethrin, furathiocarb 및 prothiofos에 대해 각각 581, 18, 19, 11배의 저항성을 보인 진주계통과 fenvalerate와 furathiocarb에 대해 각각 38배와 9배의 저항성을 나타내고 있는 함양 · 서상계통을 bifenthrin과 prothiofos의 혼합조합으로 방제하기 위해 실내 엽침지법과 포장방제시험을 수행하였다. Bifenthrin 1EC와 prothiofos 50EC을 1:50으로 혼합하여 실내엽침지법으로 처리하였을 때 공력계수가 273.2로 최고점에 도달한 후 급격히 감소하는 양상을 보였다. 침지법에서 가장 효과적이었던 혼용비율의 조합을 함양 · 서상현지 농가에서 실증시험을 수행한 결과, 처리구에서 처리약량을 절반으로 줄였음에도 배추좀나방의 방제효과가 농가관행구와 마찬가지로 우수하였다. 또한 이 조합은 여러가지 대표적인 살충제에 대해 높은 저항성을 나타내고 있는 진주지역계통에 대해서도 합리적인 농약혼합으로 저항성문제에 적절히 대처할 수 있음을 보여주었다.

검색어 연합독작용, bifenthrin, prothiofos, 저항성, 배추좀나방

INTRODUCTION

Commercialization of the formulation of insecticide mixture renders manufactures having competitive edge in the market by reducing relatively expensive component in the formulation. Additionally the application of a mixed formulation is a practical strategy for the control of insect pest to save labor of farmers and for wide range of broad spectrum of target pest species (Ryu *et al.* 1987, Song *et al.* 1987). The importance of the application of a premixed formulation (Ryu *et al.* 1987, Song *et al.* 1987) and tank mixture weighed rather more for increasing potency of insecticide with reduced active ingredient (Ahn *et al.* 1980, Chung *et*

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al. 1987) for coping with the resistance by exquisite combination ratio (Ahn *et al.* 1980, 1989, El-Guindy *et al.* 1983, Kim *et al.* 1992, 1993, Ozaki *et al.* 1984, Stone *et al.* 1988) and by the inhibition of resistant acetylcholinesterase (Kyomura and Takahashi. 1979, Takahashi *et al.* 1978), and for arresting resistance development by the insect pests (Curtis 1985, MacDonald *et al.* 1983, Immaraju *et al.* 1990).

Curciferous crops which are host plants for the DBM have been annually cultivated in Chinju area, except for hot summer season. Therefore the field population of DBM from this area has high potential to develop insecticide resistance against most of insecticides. Meanwhile the agronomic characteristics of Seosang district of Hamyang county was marketing chinese cabbage in summer season by taking advantage of its geographic merits placed at altitude at 420 m from sea level because growing the crop in hot season was possible only at a few highly elevated places due to high contents of fiber which caused deteriorating its quality for making crisp Kimchi pickle. The farmers in this mountainous isolated area have been heavily dependent upon planting the cabbage at hot season for their living so that they had sprayed fenvalerate as an effective control mean against DBM for long time, finally facing a serious problem caused by resistant population in 1988.

A few researches have been done to control insecticide resistant insect pests with a mixture in field test. In this paper, we assessed a combination of bifenthrin and prothiofos for controlling insecticide resistant DBM population in field conditions.

MATERIALS AND METHODS

Chemicals

Bifenthrin 95.8%, cypermethrin 76.4%, fenvalerate 90%, furathiocarb 87.3%, and prothiofos 95% were supplied from The Institute of Agricultural Science and Technology, Rural Development Administration (RDA), Suwon, Korea and bifenthrin 1EC, chlorpyrifos 25WP, cypermethrin 5EC, fenvalerate 5EC, furathiocarb 10EC, prothiofos 50EC, and teflubenzuron 5SC were purchased from an agrochemicals market.

Insects

DBM was collected from the overwintering population of chinese cabbage field at Chojeon, Chinju in late March, 1992. Seosang population was collected from farmer's cabbage field at Seosang, mountainous area in Hamyang in late August 1991. Collected insects were kept for the successive generations without spraying insecticides. Susceptible strain was obtained from Korea Research Institute of Chemical Technology, Taejon, Korea.

Bioassay

For microtopical method the 4th instar larvae(15 individuals/replicate) were treated by Burkard microtopical applicator after anesthetization with carbon dioxide gas with the method of Chung *et al* (1992).

For leaf dipping method the 5×5 cm leaf segments of chinese cabbage were dipped into the standard solution of bifenthrin 1EC and prothiofos 50EC mixture for 15 seconds, dried at room temperature, and then 4th instar larvae were placed onto the treated leaves. Co-toxicity coefficient of active ingredients of mixture was calculated by the method of Sun and Johnson (1960) modified after microtopical application method (Chung *et al.* 1992).

Field test

Effectiveness of bifenthrin 1EC and prothiofos 50EC mixture compared with farmer's conventional method was evaluated at a field of Seosang. The farmer's conventional was left all spray decisions to the farmer who was asked for recording the control practice without giving any information on spraying time, combinations and kinds of insecticides, and occurrences of insect pests after planting. The mixture of bifenthrin 1EC, 2000X and prothiofos 50EC, 2000X was sprayed four times on June 24 and July 2, 15 and 27 with knapsack sprayer. Spray decisions were made with information based upon occasional telephone communications with other farmers nearby Hamyang Medicinal Herb Experiment Station. The field was finally observed.

Field test was conducted at the experimental farm of Kyongnam Provincial RDA at Chinju. Insecticides were sprayed not to overflow on leaves with knapsack sprayer just after counting DBM larvae on the 35th day of chinese cabbage ('Chunhawang' variety) transplanting.

Alive insects were counted on the 3rd and 7th days after treatment. Corrected mortality was calculated by Abbott's (1925) formula. Field tests at Seosang and Chinju were conducted by completely randomized block design with three replications.

RESULTS AND DISCUSSIONS

Results from microtopical insecticide tests for Chinju and Seosang strains were shown in Table 1. Chinju strain showed the highest resistance ratio in fenvalerate by 581.4. However, those were 17.7 in cypermethrin, 18.6 in furathiocarb, and 10.8 in prothiofos. Although Seosang strain showed resistance to fenvalerate, furathiocarb, and prothiofos, the ratios were lower than those of Chinju strain.

When the fenvalerate resistant Seosang strain DBM was exposed to the mixture of bifenthrin 1EC and prothiofos 50EC by dipping method, co-toxicity coefficient was high up to 273.2 at the ratio of 1:50 with 5.20 ppm of LC_{50} value. LC_{50} value of this mixture was lower than any single formulations or any other combination ratio.

Bifenthrin was successfully used as a key component for ten premixed formulations (Anonymous 1995) and was considered to be as an agent for increasing insecticidal potency or for widening target pests. Prothiofos showed low mortality by 61% in spring and 78% in autumn in 1990 (Chung *et al.* 1991) and 58% in spring in 1991 (Chung 1992) at Chinju ex-

Table 1. Development of insecticide resistance in Chinju and Seosang strain of diamondback moth

Insecticide	Strain	n	Slope ± SE	LD_{50} (95% FL) (mg/g)	Resistance ratio
Fenvalerate	Chinju	393	0.94 ± 0.12	2.50(0.15-3.59)	581.4
	Seosang	73	0.77 ± 0.30	0.16(0.0038-0.44)	37.2
	Susceptible	390	1.84 ± 0.27	0.0043(0.0023-0.0064)	1.0
Cypermethrin	Chinju	373	0.90 ± 0.17	0.69(0.090-2.03)	17.7
	Seosang	71	0.70 ± 0.30	0.076(0.000-0.25)	1.9
	Susceptible	497	1.40 ± 0.14	0.039(0.026-0.053)	1.0
Furathiocarb	Chinju	291	1.24 ± 0.25	0.26(0.043-0.69)	18.6
	Seosang	89	1.45 ± 0.34	0.13(0.069-0.23)	9.3
	Susceptible	410	1.72 ± 0.27	0.014(0.0065-0.026)	1.0
Prothiofos	Chinju	321	1.42 ± 0.15	0.43(0.24-0.46)	10.8
	Seosang	44	1.38 ± 0.50	0.16(0.033-0.34)	4.0
	Susceptible	520	1.30 ± 0.11	0.040(0.030-0.053)	1.0

Table 2. Co-toxicity of the mixture of bifenthrin 1EC and prothiofos 50EC to the Seosang strain of diamondback moth

Mixed ratio in a.i.		n	Slope ± SE	LC_{50} (95% FL) (ppm)	Co-toxicity coefficients
Bifenthrin	: Prothiofos				
1	: 0	75	2.69 ± 0.68	48.1(22.5-102.9)	-
1	: 12.5	100	1.50 ± 0.31	26.9(12.6-61.4)	54.8
1	: 25	97	2.07 ± 0.41	7.9(3.9-16.6)	180.9
1	: 50	73	1.67 ± 0.41	5.2(1.7-15.3)	273.2
1	: 100	75	1.50 ± 0.37	12.2(3.5-42.8)	115.6
0	: 1	91	1.44 ± 0.39	14.1(0.2-32.4)	-

perimental farm where an effective control means was needed for DBM.

We tried to evaluate the results obtained from dipping test in laboratory to the farmer's field at Seosang to compare with the farmer's conventional control practice (Table 3). Controlling insecticide resistant insects by mixing insecticides could be resulted from taking advantage of fitness adversities of the resistant pest by nullifying by adopting an insecticide causing different resistance mechanism or by the synergistic contribution in the inhibition of insect defense mechanism (Takahashi *et al.* 1978).

When holes in leaf and DBM larvae were checked at harvest, the conventional method was apparently superior. However, the figures in the mixture treatment of bifenthrin and prothiofos were not statistically significant and the damage by DBM was negligible to the purchasing agents for marketing as far as damage caused by DBM.

However the mixture was sprayed at reduced rate in the field.

Table 4 shows the effects of bifenthrin and prothiofos mixture on the control of Chinju strain DBM. The mixture had the tendency of the highest corrected mortality by 67.8% at 7DAT, though there were no statistical differences at 5% level. Mortality value in the mixture of bifenthrin and prothiofos was far from any practical meaning in the control of Chinju strain DBM. However, the mixture showed quite effective compared with the others. Rational mixture could be a positive and effective short term measure for the control of a resistance DBM at emergency, if the generations of resistance development would not be shorten (Curtis 1985).

Mortalities in the other mixtures such as bifenthrin plus cypermethrin and cypermethrin plus prothiofos were lower than that of bifenthrin plus prothiofos mixture. These data indicated that applying irrational mixture without testing be very dangerous for the control of resistant insect pests and for environment. Although we did not try to find the cause of the low mortality in the mixtures in Chinju strain, it was highly expected

Table 3. Field test of the mixture to the Seosang strain diamondback moth in summer season chinese cabbage

Treatment	No. of diamondback moth larvae per cabbage	No. of holes in leaf with diameter of 1 cm
Bifenthrin 1EC, 2000X+Prothiofos 50EC, 2000X[1]	0.9±0.4a[3]	8.1±1.4a
Conventional method[2]	0.1±0.1a	4.6±2.3a
Untreatment	3.8±0.9b	24.4±3.0b

[1]The mixture was treated on June 24, July 2, 15, and 27. [2]The insecticides treated were chlorpyrifos 25WP, 1000X on July 1, prothiofos 50EC, 1000X+bifenthrin 1EC,1000X on July 12, fenvalerate 5EC, 1000X+furathiocarb 10EC, 1000X+teflubenzuron 5SC, 1000X+metalaxyl 25WP, 2000X, thiophanate-methyl 70WP, 1000X on July 15, and fenvalerate 5EC, 1000X+furathiocarb 10EC, 1000X on July 29. [3]Duncan's multiple range test at $P<0.05$.

Table 4. Chinese cabbage field test of mixture to Chinju strain of diamondback moth in spring

Rate for field spraying	No. of per plot insects	7DAT	
		Control value[1]	Corrected mortality[2]
Bifenthrin 1EC, 2000X+Prothiofos 50EC, 2000X	63.3± 3.1	57.8±13.0a	67.8
Bifenthrin 1EC, 2000X+Cypermethrin 5EC, 2000X	55.0±15.6	-104.9±90.6c	0
Cypermethrin 5EC, 2000X+Prothiofos 50EC, 2000X	61.3±19.6	22.3±38.7ab	40.7
Cypermethrin 5EC, 2000X	46.7±13.0	-44.2±26.5bc	0
Prothiofos 50EC, 1000X	52.7± 8.5	44.6±30.2ab	57.7
Untreatment	69.3±28.5	-31.1±71.9abc	0

[1]Control value(%)=[1-(No. of insects alive after treatment/No of insects alive before treatment)]×100. [2]Corrected mortality (%)=[(% control value of treatment-% control value of untreatment)/(100-% control value of untreatment)]×100. [3]Duncan's multiple range tests at $p<0.05$.

that the strain would have multiple resistance to various insecticides because chinese cabbage has been cultivated year round at Chinju even winter season except for hot summer period.

It is concluded that spraying the mixture of bifenthrin and prothiofos was effective in the control of insecticide resistance DBM as well as in reducing the spray rate.

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