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Distribution and Insecticide Resistance of Pink Stem Borer, Sesamia inferens (Lepidoptera: Noctuidae), in Taiwan 【Research report】

台灣大螟的危害分布與抗藥性調查研究【研究報告】

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Abstract

The pink stem borer, Sesamia inferens (Walker), which was once an important insect pest of sugarcane, has shifted its infestation to rice and has dispersed over all of western Taiwan. It has gradually replaced the striped stem borer, Chilo suppressalis (Walker), and became the predominant pest in the Japonica rice fields of southern and central counties and yet remains a minor pest for Japonica rice fields in northern counties and for the Indica rice fields. Among the insecticides that were used to control C. suppressalis, cartap and permethrin were more effective than chlorpyrifos and carbofuran against Se. inferens. Compared to the Hsinchu susceptible strain, < 3-fold resistance of cartap, chlorpyrifos and carbofuran, 3- to 9-fold resistance of permethrin, and up to 17-fold resistance of spinosad have been found in the field strain of Se. inferens. However, Se. inferens was 25-fold less sensitive to chlorpyrifos than C. suppressalis whcih has developed > 1000-fold resistance to carbofuran. The differential insecticide susceptibility between Se. inferens and C. suppressalis suggests that chlorpyrifos should be avoided in rice paddies with both borers coexistence, carbofuran can only be applied in the areas without or with carbofuran susceptible C. suppressalis, and cartap is still useful for both stem borers in the rice fields of Changhua, Taichung and Miaoli Counties.

摘要

大螟 (Sesamia inferens (Walker)) 在台灣曾經是甘蔗的五大害蟲之一，因蔗田栽種面積大量減少，轉而危害水稻。本調查研究發現目前大螟不但已經遍佈台灣西部的水稻栽植區，同時也逐漸取代二化螟 (Chilo suppressalis (Walker)) 成為中南部梗稻田的主要害蟲。在秈稻與苗栗以北的梗稻栽植區，大螟則仍為次要的蛀心蟲。以目前用於防治水稻二化螟的藥劑對台灣西部地區大螟進行感受性試驗發現：培丹對大螟的防治效果比陶斯松及加保扶好。與新竹感性品系相較，各地大螟對培丹、陶斯松與加保扶的抗藥性均小於三倍，對百滅寧有 3 ~ 9 倍抗藥性，對未曾推薦使用的賜諾殺則高達 17 倍。然而由於陶斯松對大螟防治效果比二化螟差 25 倍，而二化螟對加保扶又有超過千倍的抗藥性，因此在大螟與二化螟同時存在的水稻田必須審慎使用防治藥劑。根據本研究結果建議：(一) 避免使用陶斯松於大螟與二化螟同時存在的水稻田，(二) 加保扶只能用於沒有二化螟或二化螟不具抗藥性的大螟危害區，(三) 培丹可用於防治彰化、台中與苗栗地區的蛀心蟲。

Key words: Sesamia inferens, Chilo suppressalis, resistance, differential insecticide susceptibility

關鍵詞: 大螟、二化螟、抗藥性。

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ABSTRACT

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Key words: *Sesamia inferens*, *Chilo suppressalis*, resistance, differential insecticide susceptibility

Introduction

The pink stem borer, *Sesamia inferens* (Walker), has been considered to be the least destructive among several rice stem borers because its outbreak in rice paddies usually results from an overflow from adjacent fields of sugarcane or other hosts (Dale, 1994). In Taiwan, for many years this polyphagous stem borer has been an important insect pest of sugarcane while remaining only as a minor one in late

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planting rice and interval crops (Liu, 1990). However, *Se. inferens* in paddy rice has become prevalent since the planting areas of sugarcane were reduced from 101,660 hectare in 1982 to 10,394 hectare in 2006 (Huang *et al*., 2008). In rice fields, it usually coexists with the striped stem borer, *Chilo suppressalis* (Walker) (Liu, 1990; Huang *et al*., 2008).

In Taiwan, both biological and chemical controls have been used for the management of *Se. inferens* in sugarcane. For the biological control, *Tetrastichus inferens* (Yoshimoto), *Trichospilus diatraeae* Cherian and Margabandhu were used as control agents (Su, 1971a, b). For the chemical control, sumithion and EPN were recommended (Anonymous, 2007). In the meantime, the infestation of *Se. inferens* in rice fields was largely overlooked and insecticides used for this borer, such as fipronil, cartap, carbofuran and quinalphos, were those recommended for *C. suppressalis* (Anonymous, 2009). Recently, Fang *et al*. (2008) have shown differential fipronil susceptibility between *Se. inferens* and *C. suppressalis*. In addition, *Se. inferens* was found to be 47-fold less susceptible than *C. suppressalis* to Cry1Ba expressed by Bt transgenic rice (Gao *et al*., 2010). These studies implied that these two borers may also have differential susceptibility to other insecticides. For effective pest management, it is important to know the distribution and insecticide susceptibility of both stem borers in the rice paddy fields. Responses of *C. suppressalis* from Taiwan to a range of insecticides have already been examined (Cheng *et al*., 2010). Therefore, the aims of this study include surveying the distribution of *Se. inferens* in the western region of this island and evaluating its susceptibility to several insecticides which have been used for *C. suppressalis* control.

Materials and Methods

Insects

To survey the distribution of rice stem borers, larvae of rice stem borers were gathered from rice stalks showing damage symptoms, i.e., deadhearts or whiteheads, from different counties of western Taiwan (Fig. 1) between 2006 and 2008. For each sampling, about 150-600 rice stalks were picked from most rice paddies. Species and numbers of borers in each stalk were counted and recorded to analyze the numbers of stalks, total stem borers, each stem borer, the percentage of these stem borers in each county in each year, and the geography distribution of each stem borer in western Taiwan. *Se. inferens* collected from different counties were reared separately in plastic containers (21 cm diameter x 7 cm high) with an artificial diet modified from Cheng (1995) by replacing half of the corn flour with soybean flour. The pupation of pink stem borers was facilitated by putting corrugated papers in the container, and pupae were collected and put in a 47 x 45 x 100 cm^3 aluminum net case with a pot of rice. Eggs laid on leaf sheathes were soaked in 0.05% benomyl for 10 min, put on wet filter paper in a Petri dish until their color turned black, and moved into diet-filled containers for hatching. Larvae were reared in the growth chamber and adults in an aluminum net case at 25 ± 1℃ and a 16:8 h light:dark photoperiod.

Insecticides

Technical grade carbofuran (984 g/kg), chlorpyrifos (953 g/kg), cartap (950 g/kg), and permethrin (920 g/kg) were provided by Sinon Corporation (Taichung, Taiwan). Analytical grade standard spinosad (980 g/kg) was purchased from ChemService.

Bioassays

A filter paper method (Cheng *et al*., 2010) was used to test the susceptibility of *Se. inferens*. In brief, 0.5 ml of various concentrations of insecticides was added to Whatman® no.1 filter paper (with a diameter of 7 cm) in each glass Petri dish (with a diameter of 9 cm). After air drying

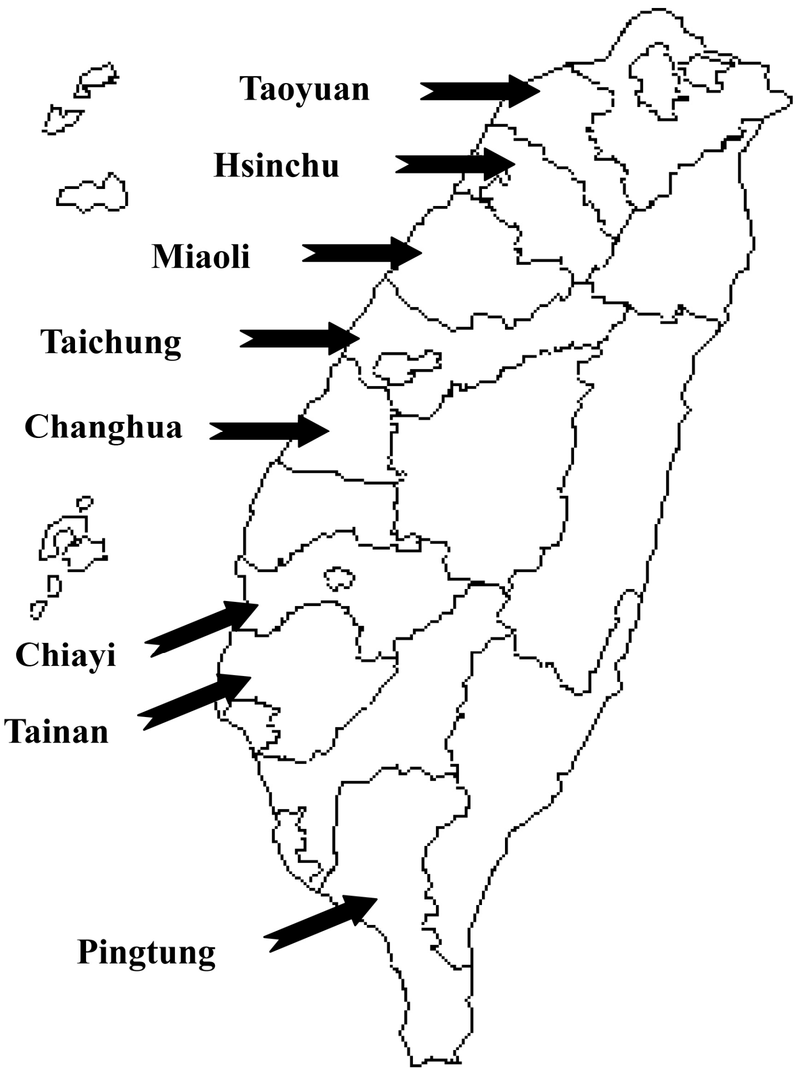


Fig. 1. Collection sites of *Sesamia inferents* in the western counties of Taiwan.

for 30 min, 10 third-instar larvae were placed directly on the insecticide-impregnated paper in the Petri dish. At least four concentrations for each insecticides and three independent replicates for each concentration of all insecticides were performed. The controls used water-impregnated filter papers for cartap and acetone-impregnated filter papers for other insecticides. Mortality of pink stem borers in each Petri dish was determined 24 h after treatment.

Statistical Analysis

Mortality data in dose response bioassays were analyzed by probit analysis (Finney, 1971), using a computer program developed by Chi (2009). The resistance

Table 1. Total numbers of rice stalks and rice stem borers collected from each site of rice paddy in different counties during 2006-2008

Counties	Rice stem borers (Rice stalks)				
	2006 Spring	2006 Fall	2007 Spring	2007 Fall	2008 Spring
Pingtung (J[a])	56 (267)	29 (302)			
Tainan (J)	596 (265)	451 (296)	76 (161)	15 (314)	
Chiayi (J)	125 (158)	32 (170)			
Chiayi (I*[b])			101 (670)	151 (704)	
Chiayi (I[c])		147 (108)		297 (367)	758 (298)
Changhua (I)	521 (164)	447 (244)	144 (408)	457 (283)	334 (420)
Taichung (J)	735 (234)	215 (288)	75 (100)	83 (56)	15 (33)
Miaoli (J)	488 (514)	267 (416)	44 (217)	80 (172)	83 (326)
Hsinchu (J)	186 (312)	235 (328)	292 (1028)	151 (671)	1083 (626)
Taoyuan (J)	272 (217)	494 (208)	7 (172)	101 (528)	

[a] J: Rice stem borers were collected from Japonica rice paddies.
[b] I*: Organic Indica rice paddies.
[c] I: Indica rice paddies with chemical control.

ratio (RR) was calculated by dividing the LC_{50} of each field population by the corresponding LC_{50} of the susceptible Hsinchu population (Cheng *et al*., 2010).

Results

Distribution of *Se. inferens* in rice paddies of western Taiwan

The total numbers of rice stalks with deadheart or whitehead and rice stem borers collected from each county in different year were summarized in Table 1. In general, more than 150 rice stalks were picked each time from each rice paddy. Number of rice stem borers in each stalk varied depending on the development stage of stem borers. In early development stage, more than one stem borers could be found in one stalk while only one late instar larvae was usually found in one stalk. The percentages of the pink stem borer and the other two borers in Japonica rice fields during 2006-2007 are presented in Fig. 2. *Se. inferens* has been found in all surveyed rice paddies of western Taiwan. It is the predominant borer in southern counties, including Chiayi, Tainan and Pingtung, and yet still a minor one in northern counties of Taiwan. The infestation of *Se. inferens* in the Taichung City increased gradually from 2006 to 2007. In Indica rice fields (Fig. 3), *Se. inferens* became a minor pest in chemical-controlled rice paddies of Changhua and Chiayi Counties while it was still the predominant pest in "organic" Indica rice paddies of Chiayi County (Fig. 2A and 2B). An overall geographic distribution of these three stem borers in Japonica rice fields is shown in Fig. 4, *Se. inferens* was the major stem borer of central and southern counties and was surpassed by *C. suppressalis* and *Sc. incertulas* in the rice fields of northern counties. *Sc. incertulas* Walker was only found in northern counties, e.g. Miaoli, Hsinchu and Taoyuan.

Susceptibility of *Se. inferens* populations to five insecticides

The baseline susceptibility of Hsinchu population of *Se. inferens* to carbofuran, chlorpyrifos, cartap, permethrin and spinosad is given in Table 2. Among these five insecticides, permethrin and spinosad were the most effective insecticides against *Se. inferens*. On the contrary, chlorpyrifos was the least effective, ca. 27- and 20-fold

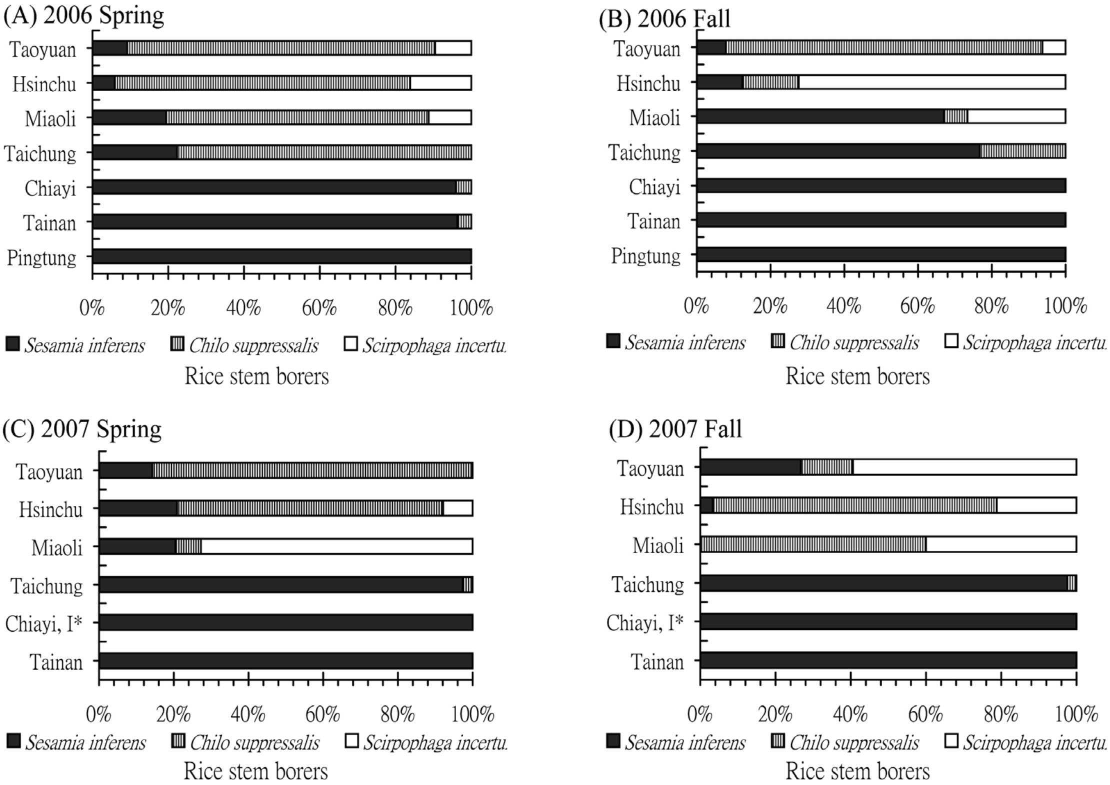


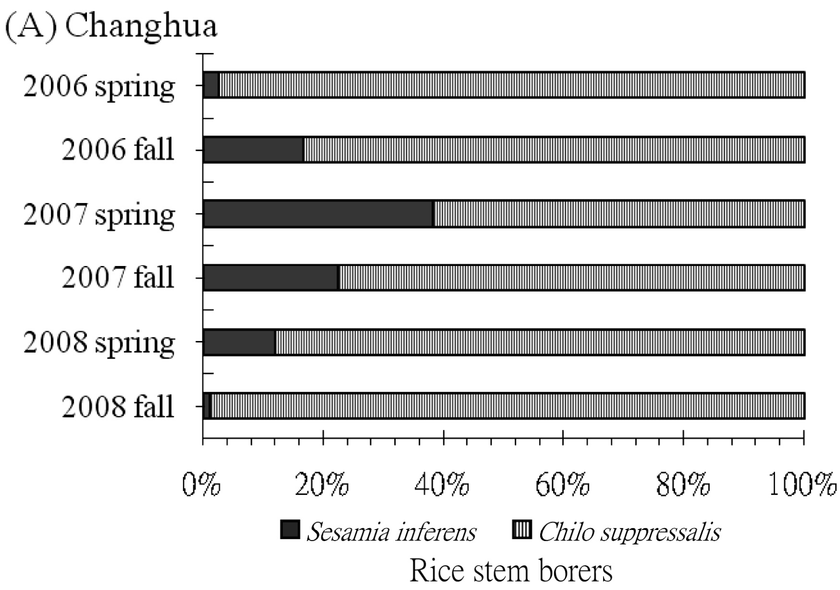
Fig. 2. Distribution of *Sesamia inferents* and the other two rice stem borers in the Japonica rice fields of western Taiwan. I*: organic Indica rice paddies.

less effective than permethrin and spinosad, respectively. Compared to the Hsinchu susceptible strain, *Se. inferens* collected from the other five counties had less than 5-fold resistance to carbofuran, chlorpyrifos and cartap. On the other hand, between 3.2- and 8.6-fold resistances to permethrin was found in most *Se. inferens* populations. To spinosad, a 17-fold resistance was observed in the Chiayi population and more than 5-fold resistance occurred in the Miaoli, Hsinchu and Tainan populations.

Discussion

Since rice stem borers usually produce similar damage symptoms to the rice plants, e.g. yellow stem, dead heart or white head, it is difficult to identify the one or ones actually causing the infestation, inappropriate control strategies might subsequently be adopted in the management of this group of insect pests on rice.

An earlier survey of the distribution and infestation of rice stem borers in central (Liu, 1990) and southern (Huang *et al.*, 2008) Taiwan showed that *C. suppressalis* was the major insect pest in Indica rice, *Se. inferens* was more prevalent than *C. suppressalis* in Japonica rice, and *Sc. incertulas* was only observed in certain rice paddies along the Ta-cha river in Taichung County. In this study, with the surveyed areas extending from the southernmost Pingtung County to Taoyuan County, we found that the pink



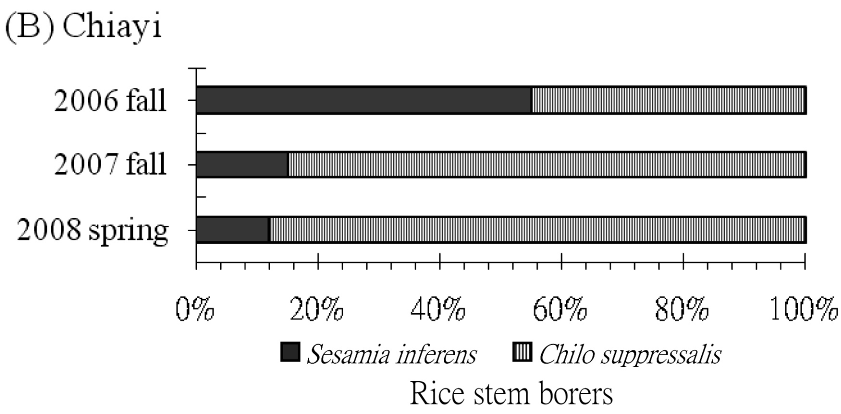


Fig. 3. Distribution of *Sesamia inferents* and *Chilo suppressalis* in the Indica rice fields of western Taiwan.

stem borer has already dispersed all over the rice paddies of western Taiwan. It has become the predominant and even the only pest in the Japonica rice fields of southern counties, e.g., Pingtung, and Tainan. Although *Se. inferens* remained the major stem borer in "organic" Indica rice paddy which is right next to Japonica rice fields, it was a minor pest in the fields where only Indica rice was planted and insecticides were applied. *Sc. incertulas*, observed in Taichung area in an earlier survey (Liu, 1990), also appeared in the Japonica rice fields of northern Taiwan, e.g. Miaoli, Hsinchu and Taoyuan Counties. The differential distribution of these three stem borers could be due to three folds: first, *Se. inferens* started to invade the rice plants from southern Taiwan where most sugarcanes were planted and they might not be controlled by the insecticides recommended for *C. suppressalis*; second,

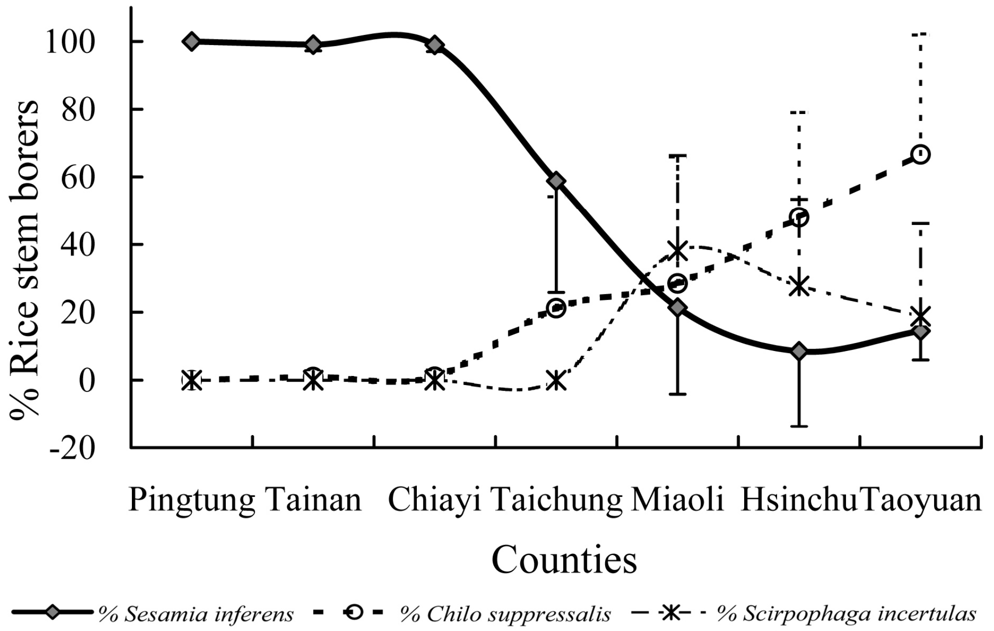


Fig. 4. Geographic distribution of three rice stem borers collected from Japonica rice fields of western Taiwan. The y-axis represents average percentage of each kind of rice stem borers from different counties collected during 2006-2007 according to Table 1.

C. suppressalis prefers to feed on the Indica and glutinous rice plants which are planted mainly in Changhua County (Liu *et al.*, 1991a, b; Liu, 1994) and they has developed high resistance to the recommended insecticides (Cheng *et al.*, 2010); third, less insecticides have been used in the northern than southern Taiwan so that all three stem borers have been coexisting in Miaoli, Hsinchu and Taoyuan Counties. The concurrence of *Se. inferens* and *C. suppressalis* in Japonica rice fields of southern counties and a number of Indica rice fields, as well as the coexistence of *Se. inferens*, *C. suppressalis* and *Sc. incertulas* in the Japonica rice fields of northern counties have raised an important issue that an improper application of insecticides may increase the possibility of resistance development in these insect pests, and replacement or resurgence of minor pest. Therefore, the susceptibility of these three stem borers to a variety of insecticides should be monitored in order to recommend proper control agents.

Our previous study determined the responses of *C. suppressalis* to four major classes of insecticides (Cheng *et al.*, 2010), and herein we further examined the susceptibility of the pink stem borer *Se. inferens* to these compounds. Chropyrifos, which was very effective against *C. suppressalis* with an average LC_{50} of ca. 41 ng/cm^2, was 25-fold less toxic to *Se. inferens* (Fig. 5). Fipronil, a highly effective insecticide against *C. suppressalis* with an average LC_{50} around 51 ng/cm^2 (Cheng *et al.*, 2010), could not produce any mortality with a concentration of up to 1 mg/ml (or 13 μg/cm^2) on the *Se. inferens* from all locations (data not shown). Mixed function oxidase, which activated fipronil into fipronil sulfone, was thought to be responsible for the differential fipronil susceptibility in *Se. inferens* and *C.*

Table 2. Susceptibility of six field populations of *Sesamia inferens* to five insecticides

Insecticide/ population	n	Slope (SE)	χ^2 (df)	LC_{50} ($\mu g\ cm^{-2}$)	95% FL	RR[a]
Carbofuran						
Hsinchu	240	2.54 ± 0.36	2.12 (3)	1.25	0.97-1.70	1.00
Miaoli	200	2.09 ± 0.32	2.16 (2)	2.32	1.21-5.64	1.84
Taichung	240	2.88 ± 0.43	4.26 (3)	5.96	3.85-8.12	4.75
Changhua	240	2.36 ± 0.40	4.25 (3)	4.01	1.48-5.79	3.20
Chiayi	240	1.97 ± 0.28	4.08 (3)	2.97	1.85-5.00	2.37
Tainan	240	2.50 ± 0.42	4.61 (3)	3.25	0.86-4.84	2.59
Chlorpyrifos						
Hsinchu	200	2.41 ± 0.36	0.92 (2)	4.38	3.16-6.39	1.00
Miaoli	240	5.63 ± 1.20	0.35 (3)	19.91	19.05-20.74	4.55
Taichung	240	3.98 ± 0.62	0.19 (3)	11.87	11.33-12.42	2.71
Changhua	240	5.05 ± 0.77	4.18 (3)	12.78	10.23-15.59	2.92
Chiayi	180	2.46 ± 041	2.33 (3)	6.70	4.52-9.06	1.53
Tainan	240	2.70 ± 0.43	5.06 (3)	7.25	4.52-13.02	1.67
Cartap						
Hsinchu	180	1.72 ± 0.31	0.73 (3)	0.43	0.33-0.54	1.00
Miaoli	180	2.01 ± 0.36	8.44 (3)	0.38	0.08-1.22	0.88
Taichung	180	1.37 ± 0.32	1.46 (3)	0.57	0.29-0.86	1.33
Changhua	240	2.88 ± 0.33	2.49 (3)	0.38	0.29-0.49	0.88
Chiayi	240	2.33 ± 0.29	2.70 (3)	1.57	0.88-2.37	3.65
Tainan	240	3.46 ± 0.43	4.72 (3)	1.33	0.95-1.85	3.09
Permethrin						
Hsinchu	240	2.92 ± 0.36	2.78 (3)	0.16	0.13-0.22	1.00
Miaoli	200	2.93 ± 0.41	5.11 (2)	1.40	0.05-4.92	8.58
Taichung	240	3.06 ± 0.49	2.08 (2)	1.30	0.83-2.35	7.97
Changhua	240	2.94 ± 0.38	1.58 (3)	1.05	0.86-1.29	6.45
Chiayi	240	2.57 ± 0.34	4.60 (3)	0.95	0.63-1.46	5.83
Tainan	200	2.83 ± 0.42	2.55 (2)	0.53	0.22-0.87	3.22
Spinosad						
Hsinchu	200	2.28 ± 0.40	2.28 (2)	0.22	0.13-0.40	1.00
Miaoli	280	1.35 ± 0.21	1.86 (4)	1.77	1.30-2.34	8.21
Taichung	240	1.65 ± 0.29	4.30 (3)	0.64	0.26-1.10	2.98
Changhua	240	1.26 ± 0.26	2.55 (3)	1.44	0.43-2.39	6.70
Chiayi	150	2.41 ± 0.41	0.73 (2)	3.65	2.56-5.22	17.01
Tainan	200	2.11 ± 0.33	5.25 (2)	1.51	0.05-2.11	7.03

[a]RR: Resistance Ratio = LC_{50} of field population / LC_{50} of Hsinchu susceptible population.

suppressalis (Fang *et al*., 2008). On the contrary, carbofuran, to which *C. suppressalis* could develop extremely high resistance, was equally effective against *Se. inferens* and susceptible *C. suppressalis*.

A comparison of the toxicity of carbofuran, chlorpyrifos, cartap and permethrin against *C. suppressalis* and *Se. inferens* (Fig. 5) suggests several criteria for the application of insecticides to manage these two stem borers. First, although chlorpyrifos can control *C. suppressalis* efficiently, it may not be proper to use this organophosphorus

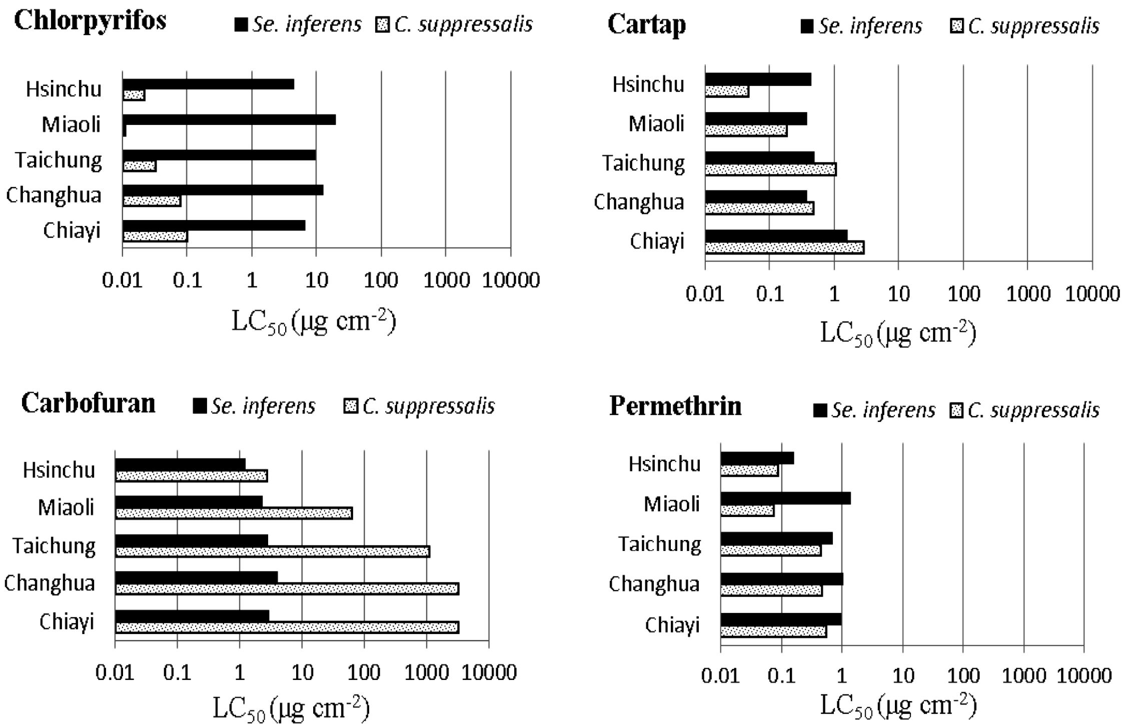


Fig. 5. Comparative toxicity of carbofuran, chlorpyrifos, permethrin and cartap to *Chilo suppressalis* and *Sesamia inferens*. The LC_{50} data of *C. suppressalis* are from Cheng *et al*., 2010.

insecticide in the field where *Se. inferens* and *C. suppressalis* coexist. Second, carbofuran which is effective against *Se. inferens* should only be applied in rice paddies where *C. suppressalis* remains susceptible, such as in Hsinchu county. Third, cartap may be applied to control both stem borers in the rice fields of Changhua, Taichung and Miaoli Counties.

Spinosad, a spinosyn insecticide first registered for diamondback moth control in Taiwan in 1999, has not been recommended for the control of rice insect pests. However, a significant and unexpected resistance level detected in *Se. inferens* from Miaoli, Changhua, Chiayi and Tainan Counties, could have been due to the application of neonicotinoids, e.g., imidacloprid and clothianidin, which act on acetylcholine receptors like spinosad (Millar and Denholm, 2007), for the control of brown planthoppers and green leafhoppers on rice (Anonymous, 2009). A low level of cross resistance to spinosad was observed in *Leptinotarsa decemlineata* (Say) and B-type *Bemisia tabaci* which have developed high imidacloprid resistance (Mota-Sanchez *et al*., 2006; Wang *et al*., 2009).

For a long-term management plan, more insecticides which are effective against all three stem borers coexisting in rice fields need to be screened. Since it is difficult to propagate and maintain a suitable population of *Sc. incertulas* in the laboratory, an artificial diet for its mass rearing should be developed.

Acknowledgments

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台灣大螟的危害分布與抗藥性調查研究

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摘　　要

大螟 (*Sesamia inferens* (Walker)) 在台灣曾經是甘蔗的五大害蟲之一，因蔗田栽種面積大量減少，轉而危害水稻。本調查研究發現目前大螟不但已經遍佈台灣西部的水稻栽植區，同時也逐漸取代二化螟 (*Chilo suppressalis* (Walker)) 成為中南部梗稻田的主要害蟲。在秈稻與苗栗以北的梗稻栽植區，大螟則仍為次要的蛀心蟲。以目前用於防治水稻二化螟的藥劑對台灣西部地區大螟進行感受性試驗發現：培丹對大螟的防治效果比陶斯松及加保扶好。與新竹感性品系相較，各地大螟對培丹、陶斯松與加保扶的抗藥性均小於三倍，對百滅寧有 3～9 倍抗藥性，對未曾推薦使用的賜諾殺則高達 17 倍。然而由於陶斯松對大螟防治效果比二化螟差 25 倍，而二化螟對加保扶又有超過千倍的抗藥性，因此在大螟與二化螟同時存在的水稻田必須審慎使用防治藥劑。根據本研究結果建議：(一) 避免使用陶斯松於大螟與二化螟同時存在的水稻田，(二) 加保扶只能用於沒有二化螟或二化螟不具抗藥性的大螟危害區，(三) 培丹可用於防治彰化、台中與苗栗地區的蛀心蟲。

關鍵詞：大螟、二化螟、抗藥性。

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