The Status and Effectiveness of IKI-7899 in Controlling Diamondback Moth in the Lowlands and Highlands of Malaysia

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Abstract

IKI-7899 (N-2, 6-difluorobenzoyl-N'-4-(3-chloro-5-trifluoromethyl pyridin-2-yloxy)-3, 5-dichlorphenyl urea), a novel benzoyl urea chitin inhibitor, was evaluated along with conventional insecticides and other insect growth regulators for the control of diamondback moth (*Plutella xylostella* L) which has developed resistance to many conventional insecticides both in lowland and highland vegetable growing areas of Malaysia. IKI-7899, formulated as WP and used at 125 to 1000 ppm, was first observed to exhibit excellent insecticidal activity against diamondback moth in 1981 on lowland cabbages. Later tests showed that the EC formulation is superior to the WP formulation. The type of formulation was probably important in the coverage of insecticide on plant surface, and cuticular pick-up and penetration, as well as gut penetration. Numerous trials on lowland and highland cabbages have consistently indicated that IKI-7899 was superior to diflubenzuron and triflumuron. Conventional insecticides fail to control the pest. The optimal rate of IKI-7899 against the diamondback moth appeared to be around 25 ppm spray at weekly or 50 ppm spray at fortnightly intervals. Six days after the fourth weekly spray, cabbage heads had less than 0.01 ppm residues at both 25 and 50 ppm spray regimes whereas kale had 0.37 and 0.78 ppm IKI-7899 residues.

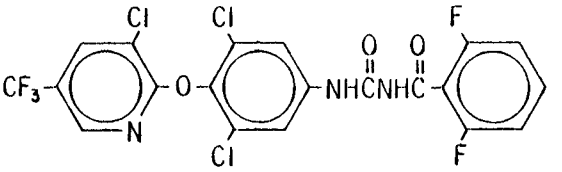
Introduction

Diamondback moth (DBM), *Plutella xylostella* L. (Lepidoptera: Yponomeutidae), is one of the most destructive pests of crucifers throughout southeast Asia. In Malaysia, the only approach hitherto employed by local farmers to control this pest has been the use of insecticides. Although a more integrated approach towards the management of this pest has been recognized and advocated by several workers (Lim 1974, Ooi and Sudderuddin 1978, Sivapragrasam and Lim 1982), the practicability and successes of such as approach have not been convincingly demonstrated. Adoption of this integrated pest management concept by the farmers will also prove to be a difficult extension mission. As a result of a long history of frequent and often excessive usage of insecticides, DBM has become resistant to all groups of conventional chemicals. An annotated record of the use of insecticides ranging from organochlorines to pyrethroids for the control of DBM in the Cameron Highlands and of the insect's resistance to these chemicals was produced by Ooi and Sudderuddin (1978). The pest also exhibits cross resistance to various conventional insecticides (Teh et al 1978).

In recent years, for the need to control this multiple insecticide resistant strain of DBM has resulted in excessive insecticide inputs and has escalated the cost of crucifer production. There is a need, therefore, to explore other means of managing the pest

before cultivation of crucifers ceases to be economically feasible. In a review of the insect pest control situation, Tan (1976) indicated the need for hormonal manipulation of the insect pest as an alternative tool in pest management. However, at the time of this review, he also mentioned that most insect growth regulators (IGRs) were not stable under sunlight. Advancement and progress has since been made in the use of IGRs in insect pest management. We report here results of our trials with a photostable IGR, IKI-7899, for the control of DBM in Malaysia.

IKI-7899 (common name: chlorfluazuron), also known as PP145 and CGA 112, 913, (N-2, 6-difluorobenzoyl-N'-4-(3-chloro-5-trifluoromethyl pyridin-2-yloxyl)-3, 5-dichlorphenyl urea), is a novel benzoyl urea chitin synthesis inhibitor discovered and developed by Ishihara Sangyo Kaisha, Limited of Japan. It has the following chemical structure:



IKI-7899 has a vapor pressure of 10^{-8} mmHg at 20°C. It is sparingly soluble in water (< 0.01 mg/l) but readily soluble in several commonly used organic solvents. It has good photolytic and pyrolytic stability. Its acute oral LD_{50} is >8,500 mg/kg for rats and >7,000 mg/kg for mice and its acute dermal LD_{50} to rats is >1,000 mg/kg. IKI-7899's LD_{50} to the mallard duck is >5,000 mg/kg and its LC_{50} to carp >300 ppm (48 h) and to daphnids >100 ppm (3 h). In a study with worker honeybees, IKI-7899 caused no mortality for up to 72 h after insects were dipped in a 2000 ppm solution. No insect mortality was observed when IKI-7899 at 10 μg/insect was topically applied to the bees. The insecticide does not cause skin irritation in rabbits but irritation can be caused when rabbits are exposed to large dosages of IKI-7899.

IKI-7899 is generally effective on the larvae of Lepidoptera, Diptera and Coleoptera. It is most effective when taken orally although the compound also shows a certain degree of contact toxicity. After ingestion, IKI-7899 disrupts chitin formation, thus killing the insects at ecdysis or when larvae become pupae. Like all other benzoyl urea chitin synthesis inhibitors, it is believed that it acts on an undefined step late in the chitin biosynthesis pathway (Post et al 1974, Marks and Sowa 1976, Duel et al 1978).

Materials and Methods

Field trials against DBM were conducted from 1981 to 1984 in Malaysia at two lowland locations: Malacca (altitude 100 m) and Selangor (altitude 150 m), and at one highland site: the Cameron Highlands (altitude 1200 m).

Trial 1

IKI-7899 5WP was first evaluated at 125, 250, 500 and 1000 ppm spray concentration for DBM control on cabbages (*Brassica oleracea* var *capitala*) in the lowlands. Two conventional insecticides, permethrin at 150 and 200 ppm, and prothiophos at 2000 ppm, were included for comparison.

Trial 2

In this trial WP and EC formulations of IKI-7899 were compared for DBM control on cabbage in the lowlands. IKI-7899 5WP was tested at 62.5, 125 and 250 ppm, while IKI-7899 5EC was evaluated at 31.25, 62.5 and 125 ppm. A mixture of IKI-7899 and permethrin at 62.5 + 50 and 62.5 + 100 ppm were included for comparison. Two conventional insecticides, permethrin at 250 ppm and prothiophos at 2000 ppm, were also included in the trial.

Trial 3

In this test IKI-7899 EC was evaluated at the rates of 6.25, 12.5, 25, 50, 75 and 100 ppm spray on cabbage in the highlands. Two other chitin synthesis inhibitors, diflubenzuron at 250 ppm and triflumuron at 350 ppm, were also included in this trial. Two conventional insecticides, permethrin at 200 ppm and methamidophos at 2000 ppm, were included for comparison.

Trial 4

In this trial IKI-7899 was tested on kale (*Brassica alboglabra*) in the lowland area. The IKI 7899 rates were 6.25, 12.5, 25 and 50 ppm spray. Triflumuron at 350 ppm and permethrin at 200 ppm were also included in the trial.

Trial 5

The frequency of application of IKI-7899 needed to give optimum control of DBM on cabbage in the lowlands was explored in this trial. IKI-7899 at 12.5, 25 and 50 ppm at weekly intervals and at 25 and 50 ppm at fortnightly intervals were evaluated. Triflumuron at 350 ppm, deltamethrin at 30 ppm, and permethrin at 200 ppm at weekly intervals were also included for comparison.

Trial 6

In this trial the persistance of IKI-7899 residues on lowland kale and highland cabbage was studied. IKI-7899 5EC was applied at 50, 100 and 200 ppm on both crops. A total of four applications at weekly intervals were made. The crops were sampled for residue analysis at six days after the last application.

Trial Design

Each treatment was replicated three to four times and plot size consisted of 22 to 30 plants per 4 m x 1 m plot. Treatments were arranged in a randomized complete block design. All insecticides were applied using high volume sprays at 600 to 1500 l/ha according to the growth stages of the crop, smaller plants receiving a lesser spray volume. Assessments were made on the DBM population density (number of larvae per plant) and the damage score (0 to 5 scale) throughout the growth stage of the crop. With the exception of trial 5, the chemicals were applied at weekly intervals.

Results and Discussion

Results on DBM larval population, damage rating, and cabbage yield in the first trial are given in Table 1. The lowest rate of IKI-7899 WP, 125 ppm, was inferior in

Table 1. Efficacy of IKI-7899 against DBM on cabbage in the lowlands (Trial 1)

Insecticide	Rate ppm AI spray	No. DBM larvae/ plant at WAT[bc]		Damage rating[a] at WAT		Yield kg/ plot[d]
		2	4	2	4	
IKI-7899	125	1.14b	0.53a	0.6	0.5	5.74bc
IKI-7899	250	0.70b	0.36a	0.3	0.1	7.35ab
IKI-7899	500	0.85b	0.58a	0.3	0.1	9.14a
IKI-7899	1000	0.78b	0.00a	0.3	0.1	9.73a
Permethrin	125	2.35a	0.52a	1.6	3.1	2.79cd
Permethrin	200	2.05a	0.30a	1.0	2.5	4.70bc
Prothiophos	2000	2.12a	0.10a	1.3	2.9	2.97cd
Control	—	2.27a	0.10a	2.3	3.8	0.32d

[a] Damage rating: 0 = no damage, 1 = slight feeding on leaves, 2 = moderate feeding on leaves, 3 = heavy feeding on leaves, 4 = skeletonizing of plant, and 5 = death of the plant. [b] WAT = weeks after first treatment. [c] Data are means of three replicates. Means in each column followed by the same letter are not significantly different at 5% level according to Duncan's multiple range test. [d] Plot size = 4 × 1 m.

DBM control to the higher rates of 250, 500 and 1000 ppm. The control achieved by IKI-7899 at 125 to 1000 ppm was far superior to permethrin at 100 and 200 ppm and prothiophos at 2000 ppm. These results showed tremendous potential for IKI-7899 as a new tool in DBM management. The compound was able to control strains of DBM resistant to the organochlorine, organophosphorous, carbamate, and synthetic pyrethroid insecticides.

As IKI-7899 is only effective at the moulting stages of the larvae, the kill was initially slower than that achieved by conventional insecticides. DBM larvae poisoned by IKI-7899 were killed at one to three days after treatment depending on the larval instar. Due to the inhibition of chitin synthesis, the IKI-7899 poisoned larvae became spherically expanded and the formation of pupal cases was incomplete or deformed.

Effect of formulation on efficacy of IKI-7899

The results of the comparison of EC and WP formulation are presented in Table 2. EC formulation of IKI-7899 gave better control of DBM than WP formulation. As oral ingestion of IKI-7899 is an important factor contributing to the final kill of insect pests, the coverage of the chemical on the crop is important. EC formulation probably gave better crop coverage than WP. It is also possible that the EC formulation resulted in better cuticular pick-up and gut penetration, thereby giving better DBM control.

There were no differences in control success when permethrin at 50 and 100 ppm were added to IKI-7899 at 62.5 ppm. This was expected as permethrin by alone gave poor DBM control. Permethrin was, however, able to reduce damage caused by the adult flea beetle (*Phyllotreta sinuata*) against which IKI-7899 is not effective.

The two conventional insecticides, permethrin at 250 ppm and prothiophos at 2000 ppm, failed to control DBM in these trials.

Efficacy of IKI 7899 EC on highland cabbages

The lifecycle of DBM differs between the lowlands and the highlands. For example, to complete one lifecycle, it takes 12 to 15 days in the lowlands and 25-30 days in the highlands (Ho 1965, Yunus and Balasubramaniam 1975). The critical period of greatest sensitivity to IKI-7899 and to other chitin inhibitors is at the moulting stages of the insect. Thus, insects with longer instars (or longer lifecycles) will take a longer time to

be affected by chitin synthesis inhibitors, and this results in more damage to the crop than that caused by those with shorter lifecycles. However it was found that IKI-7899 at 12.5 to 100 ppm, which gave good DBM control in the lowlands, also gave excellent control in the highlands (Table 3). The results also revealed that the lowest rate of IKI-7899, 6.25 ppm, did not provide adequate control as did the higher rates. Diflubenzuron at 250 ppm and triflumuron at 350 ppm were inferior to IKI-7899 at 12.5 to 100 ppm. IKI-7899 has been shown to be quite stable inside the larvae of *Spodoptera littoralis*, thereby blocking chitin synthesis more efficiently than diflubenzuron (Neumann and Guyer 1983). This biochemical characteristic of IKI-7899 is probably also true in the case of DBM, hence resulting in better control than diflubenzuron and

Table 2. Effect of formulation of IKI-7899 on the efficacy againt DBM on cabbage in the lowlands (Trial 2)

Insecticide	Rate ppm AI spray	No. DBM larvae/ plant at WAT[bc]		Damage rating[a] at WAT		Yield plot[d]
		1	5	1	5	
IKI-7899 WP	62.5	9.60a	2.73c	1.6	1.7	8.75abc
IKI-7899 WP	125.0	4.20bcd	2.00cd	1.3	1.2	7.85abc
IKI-7899 WP	250.0	3.43cde	1.08de	1.2	0.9	8.85abc
IKI-7899 EC	31.3	0.50de	0.05e	0.9	0.2	8.98abc
IKI-7899 EC	62.5	0.80de	0.00e	0.5	0.2	12.70a
IKI-7899 EC	125.0	0.38de	0.05e	0.8	0.1	12.23ab
IKI-7899 EC + Permethrin	62.5 + 50.5	0.65de	0.05e	0.6	0.1	11.43ab
IKI-7899 EC + Permethrin	62.5 + 100.0	0.48de	0.13e	0.7	0.1	12.65a
Permethrin	250.0	7.68ab	6.90a	1.9	3.6	4.60cd
Prothiophos	2000	5.50bc	5.08b	1.3	3.3	4.03d
Control	—	6.18abc	4.48b	1.5	2.8	4.88cd

[a] Damage rating: 0 = no damage, 1 = slight feeding on leaves, 2 = moderate feeding on leaves, 3 = heavy feeding on leaves, 4 = skeletonizing of plant, and 5 = death of the plant. [b] WAT = weeks after first treatment. [c] Data are means of four replicates. Means in each column followed by the same letter are not significantly different at 5% level according to Duncan's multiple range test. [d] Plot size = 4 × 1 m.

Table 3. Efficacy of IKI-7899 against DBM on cabbage in the highlands (Trial 3)

Insecticide	Rate ppm AI spray	No. DBM larvae/ plant at WAT[bc]		Damage rating[a] at WAT		Yield kg/plot[d]
		1	4	1	4	
IKI-7899	6.3	2.90b	3.57b	1.4	1.8	10.82c
IKI-7899	12.5	2.13bc	2.70b	1.1	1.4	14.44b
IKI-7899	25.0	2.67bc	2.03b	1.3	1.0	15.64b
IKI-7899	50.0	2.20bc	0.87b	1.1	0.4	17.64a
IKI-7899	75.0	1.93bc	0.67b	1.0	0.3	15.08b
IKI-7899	100.0	1.77c	0.17b	0.9	0.2	18.18a
Diflubenzuron	250.0	4.90a	0.28b	2.4	3.7	1.31f
Triflumuron	350.0	4.20a	0.17b	2.1	3.0	8.09d
Methamidophos	2000	4.27a	11.94a	2.1	3.7	6.14de
Permethrin	200.0	4.70a	0.17b	2.3	3.5	3.82e
Control	—	4.57a	2.22b	2.3	3.2	0.25f

[a] Damage rating: 0 = no damage, 1 = slight feeding on leaves, 2 = moderate feeding on leaves, 3 = heavy feeding on leaves, 4 = skeletonizing of plant, and 5 = death of the plant. [b] WAT = weeks after first treatment. [c] Data are means of three replicates. Means in each column followed by the same letter are not significantly different at 5% level according to Duncan's multiple range test. [d] Plot size = 4 × 1 m.

triflumuron. Both the conventional insecticides, permethrin at 250 ppm and methamidophos at 2000 ppm, failed to control the pest.

Due to the severe damage caused by DBM on untreated plots and plots treated with diflubenzuron, triflumuron, permethrin, and methamidophos, there was a general decline of pest infestation on these plots at three weeks after transplanting (WAT). There was also little DBM reinfestation due to the unattractive nature of the badly damaged host plants.

Activity of IKI-7899 EC on lowland kale

Kale in the lowlands is also subjected to the same intensity of DBM destruction as cabbage. Kale is an important lowland cruciferous vegetable and therefore appears to be the most suitable crop to reconfirm the activity of IKI-7899 against DBM. The results of DBM control on kale are shown in Table 4. IKI-7899 at 12.5, 25 and 50 ppm gave excellent DBM control with a consistently low larval count and low foliar damage. Plots treated with triflumuron at 350 ppm exhibited moderate DBM infestation and were inferior to IKI-7899 at 6.25, 12.5 and 50 ppm at 2 and 3 WAT. Permethrin at 200 ppm failed to give satisfactory control.

Table 4. Efficacy of IKI-7899 against DBM on kale in the lowland (Trial 4)

Insecticide	Rate ppm AI spray	No. DBM larvae/ plant at WAT[bc]		Damage rating[a] at WAT		Yield[b] kg/20 plants
		1	3	1	3	
IKI-7899	6.3	0.4c	1.1c	0.4	0.6	2.38cd
IKI-7899	12.5	0.1c	0.9c	0.3	0.4	2.95de
IKI-7899	25.0	0.0c	0.9c	0.0	0.4	2.73cde
IKI-7899	50.0	0.2c	0.5c	0.2	0.3	3.02e
Triflumuron	350.0	0.3c	3.0b	0.3	1.7	2.30c
Permethrin	200.0	2.3a	5.7a	1.0	2.9	1.05b
Control	—	1.5b	8.5a	0.5	3.9	0.32a

[a] Damage rating: 0 = no damage, 1 = slight feeding on leaves, 2 = moderate feeding on leaves, 3 = heavy feeding on leaves, 4 = skeletonizing of plant, and 5 = death of the plant. [b] Data are means of three replicates. Means in each column followed by the same letter are not significantly different at 5% level according to Duncan's multiple range test. [c] WAT = weeks after first treatment.

Frequency of IKI-7899 application

The frequency and timing of application of IKI-7899 were studied in an effort to identify the persistence of the compound in controlling DBM in the lowlands. IKI-7899 at 12.5, 25 and 50 ppm was sprayed at weekly intervals and at 25 and 50 ppm at fortnightly intervals. Results of the larval counts and damage ratings are given in Table 5. There were no differences between the two frequencies of IKI-7899 application. The optimum rate of IKI 7899 which can give effective DBM control appears to be around 25 ppm (weekly applications) and 50 ppm (fortnightly applications). Triflumuron applied weekly at 350 ppm was inferior to IKI-7899 at 12.5 to 50 ppm. There were high DBM larval counts at 1 WAT on plots treated with triflumuron. This initially high DBM population resulted in severe foliar damages to the triflumuron-treated crop at 2 and 3 WAT. Deltamethrin at 30 ppm and permethrin at 200 ppm, both applied at weekly intervals, failed to control the pest.

Table 5. Effect of frequency of IKI-7899 application on the control of DBM on cabbage in the lowlands (Trial 5)

Insecticides	Rate ppm AI spray	Application frequency (weeks)	No. DBM larvae /plant at WAT[a]		Damage rating at WAT[b]	
			1	3	1	3
IKI-7899	12.5	1	4.9	0.5	0.5	0.8
IKI-7899	25.0	1	7.1	0.6	0.3	0.6
IKI-7899	50.0	1	4.7	0.3	0.3	0.8
IKI-7899	25.0	2	3.7	1.5	0.3	1.3
IKI-7899	50.0	2	4.2	0.9	0.3	1.0
Deltamethrin	30.0	1	21.9	4.1	2.2	2.0
Permethrin	200.0	1	21.9	2.3	2.3	2.3
Triflumuron	350.0	1	16.1	1.5	2.7	1.8
Control	—	—	29.0	11.9	2.7	3.9

[a] WAT = weeks after first treatment. [b] Damage rating: 0 = no damage, 1 = slight feeding on leaves, 2 = moderate feeding on leaves, 3 = heavy feeding on leaves, 4 = skeletonizing of plant, and 5 = death of the plant. Data are means of three replicates. Plot size = 4 × 1 m.

Residue levels of IKI-7899

The results of the studies of persistence of IKI-7899 residues on kale and cabbage are shown in Table 6. At six days after four weekly applications of IKI-7899 at 25, 50 and 100 ppm, both the crops showed low residues of IKI-7899. The residue in kale was from 0.37 to 1.76 ppm while in cabbage the residue level was less than 0.01 ppm. The open leaf nature of the kale probably contributed to higher residues on the crop as compared to the close leaf morphology of cabbage.

The low residues of IKI-7899 recovered from both the vegetables, coupled with its low mammalian toxicity, will make this compound an invaluable and safe tool in the management of DBM.

Table 6. Persistence of IKI-7899 residues on kale and cabbage in the lowlands (Trial 6)

Insecticide	Rate ppm AI spray	No. of sprays	Sampling interval (days[a])	Residue (ppm)	
				kale	cabbage
IKI-7899	25	4	6	0.37	< 0.01
IKI-7899	50	4	6	0.78	< 0.01
IKI-7899	100	4	6	1.76	< 0.01
Control	—	—	—	< 0.01	< 0.01

[a] Days between last spray and sampling for residue analysis.

Effectiveness of IKI-7899 against other insect pests

Apart from DBM, IKI-7899 was also highly effective against the early instars of *Spodoptera litura, Hellula undalis* and *Crocidolomia binotalis* on cabbage. However, IKI-7899 was rather slow acting on the later instars of these pests and mortality resulted mainly when the larvae were becoming pupae. Since the late instars of these pests can cause considerable damage due to their voracious feeding habits, it is most important to give the crops a programmed spray after transplanting to prevent such damage.

IKI-7899 is not effective against sucking insects viz aphids, hoppers, and scale insects and has no contact activity against bees. In Peru, IKI-7899 at 25 to 150 g AI/ha has been shown to give excellent control of foliage-feeding Lepidoptera like *Alabama*

argillacea and *Anomis texana* but had no effect on a wide range of beneficial insects including coccinellids and predatory mites and bugs (Collins et al 1984). This selective property of IKI-7899 will play an important role in integrated management of DBM.

Conclusion

IKI-7899 at around 25 ppm applied at weekly intervals or 50 ppm at fortnightly intervals gave consistently excellent control of multiple insecticide resistant strains of DBM in lowland and highland vegetable areas of Malaysia. IKI-7899 at 12.5 to 50 ppm showed superior activity over other chitin synthesis inhibitors such as diflubenzuron at 250 ppm and triflumuron at 350 ppm against DBM. Conventional insecticides failed to give good control of the pest in both lowland and highland vegetable areas of Malaysia. EC formulation was superior to WP.

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