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Field persistence of certain new insecticides and their efficacy against black cutworm, *Agrotis ipsilon* (Hufnagel)

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Abstract

Background: Chemical control is used as a rapid and reliable method for insect control. Still, there is an ongoing need to replace older conventional insecticides with new insecticides to maintain efficacy and environmental protection. Emamectin benzoate, indoxacarb and chlorantraniliprole are broad-spectrum insecticides with a novel mode of actions. The effects of these compounds on some biological aspects of the black cutworm, *Agrotis ipsilon*, and their field persistence residues were estimated.

Results: The results showed that egg hatch was affected by high concentrations (50 and 100 ppm) of the tested compounds. Larvae that hatched from treated eggs were significantly affected at concentrations of 25 ppm and higher. 1st-instar larvae were the most susceptible developmental stage. There was strong suppression of adult formation; 65 and 91% at 25 and 50 mg L⁻¹, respectively. Profoundly affected larvae died before pupation; slightly affected ones reached pupation 2–4 days later, were smaller than larvae in the untreated control, and were sometimes unable to develop into normal adults. Comparatively high concentrations (50 and 100 mg L⁻¹) of the test compounds were necessary to affect adults by ingestion. According to the results, the tested insecticides could be arranged according to their potency descendingly as follows: emamectin benzoate, indoxacarb, and chlorantraniliprole, respectively. Based on the field application, emamectin benzoate proved to be the most effective in initial and residual activity, causing 100% mortality while indoxacarb was least effective. Data also indicated that emamectin benzoate had the longest half-life (Lt₅₀) while indoxacarb recorded the shortest one.

Conclusions: The results obtained in this study indicate that emamectin benzoate, indoxacarb and chlorantraniliprole are potent compounds for controlling *A. ipsilon*. Therefore, these compounds are promising materials that can be used as alternative components in integrated pest management programs to reduce as possible the harmful of using conventional insecticides under field conditions.

Keywords: *Agrotis ipsilon*, Biological aspects, Novel insecticides, Residual toxicity

Background

The black cutworm, *Agrotis ipsilon* (Hufnagel) (Lepidoptera: Noctuidae), is the most destructive pests against many economically important crops, including cotton. At present, broad-spectrum chemical control targeting this pest is the most widely practiced

management tool. However, the intensive use of insecticides has led to the development of widespread and multiple forms of resistance. The aim of recent researches focuses on the development and valuation of various alternative control strategies to reduce dependence on conventional pesticides. Recently, there is an urgent need for effective new insecticides are for continued successful control of *A. ipsilon* in the future. Several insecticides with different modes of action

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(chlorantraniliprole, emamectin benzoate, and indoxacarb) were chosen for this study (Demkovich et al. 2018).

Chlorantraniliprole is a new anthranilic diamide insecticide, which effectively controls pest insects belonging to Lepidoptera, Coleoptera, Diptera, and Hemiptera, is effective against insects that have developed resistance against some conventional insecticides (Bentley et al. 2010). Anthranilic diamides selectively bind to ryanodine receptors in insect muscles resulting in an uncontrolled release of calcium from internal stores in the sarcoplasmic reticulum (Lahm et al. 2005; Cordova et al. 2006), causing impaired regulation of muscle concentration leading to feeding cessation, lethargy, paralysis, and death of target organisms. Anthranilic diamides have very low vertebrate toxicity due to a >500-fold differential selectivity toward insects over mammalian ryanodine receptors (Dinter et al. 2008).

Emamectin benzoate is a novel semi-synthetic derivative of natural product abamectin in the Avermectin family. Avermectins, including emamectin benzoate, is effective against a broad spectrum of arthropod pests (Pienkowski and Mehring 1982). These materials act by interfering with the action of gamma-aminobutyric acid (GABA) (Wright 1984). It blocks post-synaptic potentials of the neuromuscular junction, leading to paralysis.

Indoxacarb represents a new class of insecticides Oxidiazines, with its stomach and contact (Wise et al. 2006). It blocks the movement of sodium ions into the nervous system, resulting in paralysis and death of the pest.

The objectives of this study were to elucidate the effect of chlorantraniliprole, emamectin benzoate, and indoxacarb on the biological aspect of *A. ipsilon*. The study aims also to determine the residues persistence period, Lt_{50} (time required to give 50% mortality) under field conditions.

Methods

Insect rearing

Culture of *A. ipsilon* was reared on castor bean leaves in Department of Insect Population Toxicology, Central Agricultural Pesticides Laboratory, Agriculture Research Center, Dokki, Giza, Egypt, for several generations under reared chamber environments were (25 ± 2 °C and 65 ± 5 % R.H) without any insecticidal contamination and light–dark period was 12 h. Larvae reared in a big glass container with sawdust in the bottom. For adult emergence and oviposition, pupae were put in a ventilated cage. Adults were fed on a 10% sucrose solution soaked in a piece of cotton; laid eggs were collected and kept in glass containers for hatching to be used for the study.

Tested compounds

Commercial formulations of chlorantraniliprole (Coragen[®], 20% SC), and indoxacarb (Steward[®], 15% EC) were supplied by Du Pont Co., and emamectin benzoate (Proclaim[®], 5% S.G) was provided by Syngenta Co.

Immature bioassays

Emamectin benzoate, indoxacarb and chlorantraniliprole against *A. ipsilon* egg mass were determined. The upper layers of each egg mass (0–24 h old) were removed gently with a fine hairbrush. The lower layer in each egg mass was counted by the binocular. The counted egg samples were dipped (5 s) in different aqueous concentrations of the tested formulations, or distilled water as a control. After drying for 2 h at room temperature, the treated eggs were stored in Petri dishes (9 cm in diameter). Three days later, untreated castor bean leaves were added to the Petri dishes for larvae to feeding. Egg hatchability % and larval survival were monitored daily, and the mortality percentages were calculated. Results are based on four replicates of each treatment.

In other assays, 1st-, 3rd- and 5th-instars larvae (10 per each replicate) were exposed to castor bean leaves (*Ricinus communis* L.) treated with a series of aqueous concentrations of the test formulations, or with distilled water as a control. Leaves were dipped for 10 s. in different concentrations of tested compounds, held vertically to allow the excess solution to drip off and dried for 2 h, then offered to larvae for 42 h. After these time intervals, the treated leaves were replaced by untreated ones. Ten 1st-instar larvae were kept in Petri dishes, 3rd- and 5th-instars were held in ventilated wood boxes. The boxes contained sawdust to reduce moisture. Larval mortality recorded after 24 h. Larvae were weighed before exposure to treated leaves and again six days (3rd-instar) or (5th-instar) after exposure. Control 3rd- and 5th-instar larvae, fed untreated leaves, were weighed after similar time intervals. Weight gains of the 3rd- and 5th-instar larvae were determined 24 h, after feeding on treated leaves. Pupation and adult formation of 5th-instars were evaluated after the start of the assay.

Adult bioassays

Effects of ingestion of the tested formulations by adults were studied by allowing adults to fed on a 10% sucrose solution containing 50 or 100 mg L⁻¹ of each test compound, or 10% sucrose solution as a control. Male and female moths were kept in a glass jar containing five individuals each. Mortality was checked daily for five days. Solutions were changed every second day to prevent fungal growth. Results are based on four replicates.

Table 1 Effect of the tested formulations on the % egg-unhatch and larval survival of *A. ipsilon*

Conc. ppm (a.i)	Emamectin benzoate			Indoxacarb			Chlorantraniliprole					
	No. treated eggs	No. eggs-hatch	Eggs-unhatch (%)	Larval survival (%)	No. treated eggs	No. eggs-hatch	Eggs-unhatch (%)	Larval survival (%)	No. treated eggs	No. eggs-unhatch (%)	No. Eggs-hatch	Larval survival (%)
Control	243	236	3.29 ^a ± 0.6	56 ^d ± 1.8	323	314	2.79 ^a ± 1.4	58 ^d ± 1.8	220	1.36 ^a ± 0.6	217	58 ^d ± 1.5
1	204	184	9.8 ^a ± 1.9	35 ^d ± 2.3	268	254	5.22 ^a ± 1.1	38 ^c ± 2.1	216	3.7 ^a ± 1.1	208	37 ^c ± 1.6
10	228	187	17.98 ^b ± 0.2	23 ^c ± 2.3	232	213	8.19 ^a ± 1.5	30 ^c ± 2.3	192	6.25 ^a ± 1.4	180	26 ^b ± 2.3
25	225	166	26.22 ^c ± 1.5	16 ^b ± 1.9	266	226	15.04 ^b ± 0.2	21 ^b ± 1.2	208	11.54 ^b ± 1.2	184	20 ^b ± 1.3
50	206	120	58.25 ^d ± 3.3	5.0 ^a ± 1.3	330	174	47.27 ^c ± 0.9	8.0 ^a ± 0.4	162	30.86 ^c ± 0.96	112	6.0 ^a ± 0.9
100	234	170	87.61 ^e ± 2.5	1.0 ^a ± 0.11	290	203	80.34 ^d ± 3.6	3.0 ^a ± 0.13	170	7.65 ^d ± 2.9	115	2.0 ^a ± 0.12

Means followed by the same letter in the same column are not significantly different according to Tukey's multiple range test at P<0.05

Field experiment and sampling

Application of the tested insecticides was conducted during the cotton-summer season in El-Dakahlia Governorate, Egypt, at Aga district, whereas an area of 2000 m² was selected to be sown on 4th April 2019 with cottonseed var. "Giza 86." The experiments were laid out in Randomized Complete Block Design (RCBD) (four replications). This area was divided into plots size each of 50 m². Four treatments, the three tested insecticides and the check were designed in this area. Application of tested insecticides was done on 26th of June 2019 under field conditions. Irrigation water was used in diluting of the tested insecticides at their field recommended rates/200 L per feddan. Knapsack sprayer (CP3) equipped with one nozzle was used. Unplanted belts (3 m width) were left as barriers between plots to avoid contamination with drifts. Plots received all good recommended agricultural practices without any insecticidal treatments applied during the season. Samples of treated cotton leaves were collected randomly from each treatment immediately after one h from spray (zero time) and then 3, 6, 9, 12 and 14 days' post-spray and transferred directly to the laboratory for feeding *A. ipsilon* by treated leaves with tested insecticides, (100 larvae/treatment/interval) for one day of each interval. Alive larvae were fed for another two days on untreated leaves. Cumulative mortalities were calculated at the end of each interval (three days) and corrected according to Abbott's formula (1925). The cumulative mortalities of the first intervals (samples collected after spraying directly) was considered as initial kill, while the total mean of the cumulative mortality of the other intervals (3, 6, 9, 12 and 14 days from spraying) were considered as residual effects.

Statistical analysis

Data were corrected for control mortality according to Abbott's formula (Abbott 1925). Also, mortality values were analyzed by Probit analysis (LPD line) to determine the LC values and slope for each compound according to a method adopted by Finney (1971). The results were analyzed using one-way ANOVA, significant differences between treatments were determined using Tukey's HSD test in JMP 11.1.1. (SAS Institute Inc. 2013, Cary, NC, USA).

Results

Effect on eggs and young larvae

High concentrations of each compound were required to affect egg-hatch of *A. ipsilon*, Table 1. Inhibition of egg-hatch of 87.61, 80.34 and 67.65% was obtained with 100 ppm concentration for emamectin benzoate, indoxacarb and chlorantraniliprole, respectively. The relatively

high concentrations required for suppression of egg-hatch are probably due to the compound not being able to penetrate the eggshell. Novel insecticides, such as emamectin benzoate, indoxacarb and chlorantraniliprole, are toxic to *A. ipsilon* eggs. Larvae from treated eggs were significantly affected at concentrations of 25 ppm. Effective control of these larvae was only obtained at concentrations of 25, 50 and 100 ppm.

Susceptibility of *A. ipsilon* larvae to tested formulations

First-, 3rd- and 5th-instar *A. ipsilon* larvae were fed on castor bean leaves treated with various concentrations of the test compounds. All larval instars were more susceptible to the tested compounds than the eggs, Table 2. According to LC₅₀ value, 1st-instars are the most susceptible. Increases in mortality of 3rd-instar larvae were seen even after replacing treated leaves with untreated ones; heavily affected larvae were not able to recover and died at a later stage. There is no larva survived with the highest concentrations. The susceptibility of the 5th-instar larvae was lower than that obtained with the 3rd-instar, Table 3.

Effects on weight gain

Larvae that fed on tested compounds-treated leaves weighed less than control larvae, Table 3, the higher the concentration of tested compounds, the lower the larval weight. The weight gains of 3rd-instars exposed to 50 mg L⁻¹ was 96% of the untreated larval weight, while larvae treated with 10 mg L⁻¹ reached only 15% of the untreated larval weight. Fifth-instar larvae exposed to 25 ppm reached 45% of the larval weight of the untreated control, and many of those exposed to 25 mg L⁻¹ experienced weight loss. Larvae of both stages were unable to maintain normal growth when fed on leaves treated with 50 mg L⁻¹, and almost half of the individuals lost weight.

Effect on pupation and adult formation

Pupation and adult formation of 5th-instar larvae were determined after the trial started. There was no significant difference between control larvae and those exposed to 10 mg L⁻¹; approximately 80% of the larvae became adults, Table 4. Suppression of adult formation of 65 and 91% occurred at concentrations of 25 mg L⁻¹ and 50 mg L⁻¹, respectively.

Effect of ingestion on adults

The effect of tested compounds by ingestion on mortality of *A. ipsilon* adult was tested by exposing male and female adults to sucrose solutions containing different concentrations of the tested compounds. A significant effect was observed at concentrations of 50 and 100 mg L⁻¹ resulting in 35 and 60% mortality after three days of

Table 2 LC₅₀ values of tested formulations on different stages of *A. ipsilon*

Compounds	1st-instar larvae		3rd-instar larvae		5th-instar larvae	
	LC ₅₀ (mg L ⁻¹) Confidence limits	Slope	LC ₅₀ (mg L ⁻¹) Confidence limits	Slope	LC ₅₀ (mg L ⁻¹) Confidence limits	Slope
I*	0.259 0.168–0.336	1.51 ± 0.31	0.809 0.53–1.30	1.42 ± 0.19	1.23 1.14–1.53	1.19 ± 0.19
E*	0.0874 0.001–0.07	0.71 ± 0.21	0.164 0.151–0.373	0.96 ± 0.26	0.342 0.235–0.306	1.48 ± 0.27
C*	0.934 0.447–0.389	1.31 ± 0.27	1.284 1.12–1.55	1.13 ± 0.19	2.325 1.63–3.35	1.11 ± 0.18

E*: Emamectin benzoate, I*: Indoxacarb, C*: Chlorantraniliprole

Table 3 Effect of tested formulations on mortality and weight gain of two larval instars of *A. ipsilon*

Conc. (mg L ⁻¹)	3rd-instar			5th-instar		
	Larval mortality (%) ± SE					
	E*	I*	C*	E*	I*	C*
10	30.8 ^d ± 0.2	26.7 ^d ± 1.2	22.2 ^d ± 2.3	20.0 ^d ± 5.2	16.4 ^e ± 1.9	12.3 ^d ± 1.9
25	76.7 ^c ± 2.8	70.0 ^c ± 1.1	66.5 ^c ± 1.4	65.5 ^c ± 1.9	59.9 ^d ± 1.7	55.5 ^c ± 1.4
50	93.3 ^{ab} ± 0.5	86.9 ^b ± 0.8	80.8 ^b ± 0.8	82.3 ^b ± 1.0	77.7 ^c ± 1.5	71.9 ^b ± 1.2
100	100 ^a ± 0.0	100 ^a ± 0.0	95.2 ^{ab} ± 1.5	97.1 ^{ab} ± 0.4	89.8 ^{ab} ± 1.0	84.6 ^{ab} ± 1.2
200	100 ^a ± 0.0	100 ^a ± 0.0	100 ^a ± 0.0	100 ^a ± 0.0	98.1 ^a ± 0.4	92.5 ^a ± 0.6
Mean weight gain (mg/larva) ± SE						
Control	357.9 ^d ± 1.7	355.8 ^e ± 1.3	360.0 ^e ± 1.7	710.5 ^e ± 3.2	714.0 ^f ± 3.6	712.2 ^f ± 2.9
10	203.1 ^c ± 0.2	218.3 ^d ± 1.2	222.6 ^d ± 2.3	506.0 ^d ± 5.2	558.4 ^e ± 1.9	566.1 ^e ± 1.9
25	33.6 ^b ± 2.8	44.7 ^c ± 1.1	48.7 ^c ± 1.4	390.3 ^c ± 1.9	397.0 ^d ± 1.7	385.5 ^d ± 1.4
50	13.7 ^a ± 0.5	16.9 ^b ± 0.8	20.0 ^b ± 0.8	52.3 ^b ± 1.0	63.5 ^c ± 1.5	71.9 ^c ± 1.2
100	–	5.0 ^a ± 0.5	12.2 ^a ± 1.5	7.1 ^a ± 0.4	19.8 ^b ± 1.0	24.6 ^b ± 1.2
200	–	–	–	–	3.1 ^a ± 0.4	5.0 ^a ± 0.6

Means followed by the same letter in the same column are not significantly different according to Tukey's multiple range test at $P < 0.05$

E*: Emamectin benzoate, I*: Indoxacarb, C*: Chlorantraniliprole

Table 4 Effect of the tested formulations on pupation and adult formation of *A. ipsilon*

Conc. (mg L ⁻¹)	Adult formation % ± SE			Pupation % ± SE		
	E*	I*	C*	E*	I*	C*
Control	91 ^c ± 0.2	93 ^c ± 2.1	95 ^c ± 3.5 ^a	81 ^c ± 1.7	83 ± 2.3 ^a	86 ^c ± 1.2
10	86 ^c ± 2.3	87 ^c ± 2.4	88 ^c ± 2.9	78 ^c ± 3.6	80 ± 0.2 ^a	82 ^c ± 1.6
25	36 ^b ± 0.7	38 ^b ± 1.6	41 ^b ± 1.7	32 ^b ± 4.6	35 ± 1.1 ^b	37 ^b ± 2.8
50	15 ^a ± 0.5	18 ^a ± 0.8	22 ^a ± 0.1	10 ^a ± 1.7	13 ± 1.5 ^c	16 ^a ± 0.8

Means followed by the same letter in the same column are not significantly different according to Tukey's multiple range test at $P < 0.05$

E*: Emamectin benzoate, I*: Indoxacarb, C*: Chlorantraniliprole

feeding, and in 93 and 87% mortality after five days of feeding, Table 5.

Persistence of the tested formulations residues

Leaves were collected from cotton field plots sprayed with tested compounds and fed to 3rd-instar *A. ipsilon*. The initial effect of emamectin benzoate proved to be the most effective where caused 100% accumulative

mortalities after 3 days from treatment compared with control while indoxacarb was the least effective (60%). Based on the general mean of residual activity of the tested compounds, emamectin benzoate was superior compound giving 49.013%, followed by chlorantraniliprole 42.12%. On the other hand, indoxacarb (22.488%) was the least effective. Concerning the persistence of the residues of the tested compounds

Table 5 Effect of the tested formulations ingestion on adult of *A. ipsilon*

Conc. (mg L ⁻¹)	Adult mortality (%) ± SE					
	3 days			5 days		
	E*	I*	C*	E*	I*	C*
Control	10 ^a ± 1.1	8.0 ^a ± 0.8	6.0 ^a ± 0.2	15 ^a ± 0.8	13 ^a ± 0.2	11 ^a ± 1.3
50	36 ^b ± 4.6	34 ^b ± 2.8	30 ^b ± 1.7	94 ^b ± 1.2	91 ^b ± 2.3	90 ^b ± 1.6
100	62 ^c ± 4.0	58 ^c ± 5.1	55 ^c ± 1.6	88 ^c ± 0.4	84 ^c ± 1.4	82 ^c ± 1.5

Means followed by the same letter in the same column are not significantly different according to Tukey’s multiple range test at *P* < 0.05

E*: Emamectin benzoate, I*: Indoxacarb, C*: Chlorantraniliprole

on cotton leaves under field conditions with *Lt*₅₀, the results revealed that emamectin benzoate showed significant superior persistence residual activity against 3rd-instar larvae of *A. ipsilon* with *Lt*₅₀ (5.59 days). On the contrary, indoxacarb showed the shortest persistence period recording 1.4 days. No residues could be detected 14 days’ post-treatment for all tested compounds, Table 6.

Discussion

Results obtained from the present study indicate that although the tested compounds have low ovicidal activity yet, it has the highest residual activity against the neonates after 24 h of hatching. It was observed that the larvae of *A. ipsilon* died very soon after treatment probably resulted from their eating the eggshell and contacting the compound at a very young stage. These results are in harmony with in previous studies, Pinela et al. (2000) stated that treatment of 0–24 h eggs at 10 mg a.i/liter or above caused 100% mortality of newly emerged larvae after the first day of hatching. Ioriatti et al. (2009) reported that chlorantraniliprole has an ovicidal activity low.

According to the estimated *LC*₅₀ values, the 1st instar larvae reflected higher level of susceptibility towards all the tested compounds than the 3rd- and 5th-instars, respectively. The obtained results showed the toxicity increased with the increasing of the exposure time and decreased by increasing the larval instars. The present results are confirmed with the results of Lisa 2015; Ismail

2018; Rimpay and Verma 2018, where they reported that emamectin benzoate is the most potent compound followed by indoxacarb, imidacloprid, pyridalyl and chlorantraniliprole against both of *A. ipsilon* and *S. littoralis*.

The results explained that the three newly insecticides significantly reduced biological aspects where weight loss as a result of larvae feeding on castor bean leaves treated with tested insecticides compared with control. Highly affected larvae were unable to increase weight and died before pupation. Slightly affected larvae reached pupation two to four days later than larvae in the untreated control, but pupae were smaller and sometimes unable to develop into normal adults and sometimes pupae can’t complete the molting process and died. Although adults were strongly affected five days after exposure to the compounds, these effects were very mild when compared to effects on the larval stages. The potency of three tested compounds was similar between the sexes of *A. ipsilon* adults. Similar studies have shown that chemicals can have adverse effects on biological parameters, female mating behavior and fecundity of target insects (Xu et al. 2016; Mokbel et al. 2017; Barrania 2019).

Concerning the residue of emamectin benzoate and chlorantraniliprole could be toxic to *A. ipsilon* larvae longer than 7 days with relatively slow activity, but indoxacarb showed low residual toxicity. The rate of the tested compounds residues dissipation in cotton leaves was decreased gradually 3, 6, 9, and 12 days’ post-treatment, and no residues could be detected 14 days’ post-treatment. The present results are in line with Gupta et al.

Table 6 Residual toxicity of tested formulations against 3rd-instar *A. ipsilon* larvae under field conditions

Compounds	Residual effect						Mean of residual effect (%)	<i>Lt</i> ₅₀ (days)
		Z*	3 days	6 days	9 days	12 days		
Emamectin benzoate	100	86.55	64.56	25.50	19.44	–	49.013	5.59
Indoxacarb	60.0	44.59	27.45	12.50	5.41	–	22.488	1.40
Chlorantraniliprole	79.3	76.72	50.70	30.68	10.38	–	42.12	5.56

Z*: initial effect (%) at zero time

(2009) reported that the half-life time of indoxacarb at 70 and 140 g/ha on okra fruit was 0.58 and 1.02 days, respectively, whereas Dake and Bhamare (2019) evidenced the descending relative order of efficacy of insecticides in days was found to be indoxacarb 0.05% (4.74 and 4.93) > chlorantraniliprole 0.005% (4.19 and 4.38) > fenpropathrin 0.01% (3.84 and 3.68) > emamectin benzoate 0.002% (3.00 and 3.21) > flubendiamide 0.007% (2.56 and 2.86) against the nymph of jassid on sunflower leaves receiving first and second application of insecticides, respectively. From the present results, these selected insecticides are good candidates for controlling black cutworm, *A. ipsilon* and can replace hazardous convention insecticides.

Conclusions

The present results concluded that although indoxacarb effective against *A. ipsilon* and significantly reduced biological aspects, it has the lowest persistence period under field conditions. Concerning emamectin benzoate, and chlorantraniliprole caused high toxicity and significantly reduced biological aspects. Also, these compounds had the longest persistence residues and high initial effects under field conditions. Therefore, these compounds with a new mode of action could be used in strategies for controlling *A. ipsilon* and as alternatives of conventional insecticides.

Abbreviations

E: Emamectin benzoate; I: Indoxacarb; C: Chlorantraniliprole.

Acknowledgements

Not applicable.

Authors' contributions

The author contributed to the production and writing of the manuscript. The author read and approved the final manuscript.

Funding

There was no funding for this work.

Availability of data and materials

All data generated during this study are included in this published article.

Ethics approval and consent to participate

The manuscript does not contain any studies involving human participants, human data, or human tissue.

Consent for publication

Not applicable.

Competing interests

The author declares that there are no competing interests.

Received: 26 March 2020 Accepted: 29 December 2020

Published online: 12 January 2021

References

Abbott WS (1925) A method for computing the effectiveness of an insecticide. J Econ Entomol 18:265–267

- Barrania AA (2019) Effects of some insecticides on some biological parameters of cotton leafworm, *Spodoptera littoralis* (Lepidoptera: Noctuidae). Alex Sci Exch J 40:307–313
- Bentley KS, Fletcher JL, Woodward MD (2010) Chlorantraniliprole an insecticide of the anthranilic diamide class. In: Krieger R (ed) Hayes, handbook of Pesticide toxicology. Academic Press, London, pp 2232–2242
- Cordova D, Benner AE, Sacher DM, Rauh JJ, Sopa SJ, Lahm PG et al (2006) Anthranilic diamides: a new class of insecticides with a novel mode of action ryanodine receptor activation. Pestic Biochem Physiol 84:196–214
- Dake RB, Bhamare VK (2019) Bio-efficacy, persistence and residual toxicity of different insecticides against jassids (*Amrasca biguttula biguttula* Ishida) on sunflower. J Entomol Zool Stud 7:1245–1250
- Demkovich MR, Siegel JP, Walse SS, Berenbaum MR (2018) Impact of agricultural adjuvants on the toxicity of the diamide insecticides chlorantraniliprole and flubendiamide on different life stages of the navel orangeworm (*Amyelois transitella*). J Pest Sci 91:1127–1136
- Dinter A, Brugger K, Bassi A, Frost MN, Woodward DM (2008) Chlorantraniliprole (DPX-E2y45, Rynaxypyr) (Coragen 20SC and Altacor 35 WG)—a novel Dupont anthranilic diamide insecticide—demonstrating low toxicity and low risk for beneficial insects and predatory mites. IOBC WPRS Bull 35:128–135
- Finney DJ (1971) Probit analysis, 3rd edn. Cambridge University Press, Cambridge, p 318
- Gupta S, Sharma KR, Gupta KR (2009) Persistence of new insecticides and their efficacy against insect pests of okra. Bull Environ Contam Toxicol 82:243–247
- Ioriatti C, Anfora G, Angeli G, Mazzoni V, Trona F (2009) Effects of chlorantraniliprole on eggs and larvae of *Lobesia botrana* (Denis and Schiffermüller) (Lepidoptera: Tortricidae). Pest Manag Sci 65:717–722
- Ismail SM (2018) Joint action of certain insecticides by sub lethal dose effect on the cotton leafworm *Spodoptera littoralis* (Lepidoptera: Noctuidae) larvae. Egypt J Plant Prot Res 1:43–50
- Lahm GP, Selby PT, Freudenberger TM, Stevenson BJ, Myers G, Seburyamo BK et al (2005) Insecticidal anthranilic diamides: a new class of potent ryanodine receptor activators. Bioorg Med Chem Lett 15:4898–4906
- Lisa BJ (2015) Baseline susceptibility of *Helicoverpa armigera* (Lepidoptera: Noctuidae) to indoxacarb, emamectin benzoate, and chlorantraniliprole in Australia. J Econ Entomol 108:294–300
- Mokbel EMS, Huesien AI, Abdel-Hamid HFM, Osman H (2017) Assessment of resistance risk to emamectin benzoate, indoxacarb and spinetoram in cotton leaf worm, *Spodoptera littoralis* (Boisd.). Egypt Acad J Biol Sci 9:9–18
- Pienkowski RI, Mehring RP (1982) Influence of Avermectin B1 and carbofuran on feeding by alfalfa weevil larvae (Coleoptera: Curculionidae). J Econ Entomol 76:1167–1169
- Pinela S, Budia F, Schneider IM, Gobbi A, Vinuela E (2000) Biological effectiveness of spinosad and methoxyfenozide (RH-2485) IGR on *Spodoptera littoralis* Boisd. (Lepidoptera: Noctuidae) eggs. Boletín de Sanidad Vegetal Plagas 26:483–491
- Rimpy A, Verma SK (2018) Efficacy of novel insecticides against cutworms (Lepidoptera: Noctuidae) infesting cabbage. Int J Chem Stud 6:824–827
- Wise JC, Coombs BA, Vandervoot C, Gut JL, Hoffmann JE, Whalon EM (2006) Use of residue profile analysis to identify modes of insecticide activity contributing to control of plum curculio in apples. J Econ Entomol 99:2055–2064
- Wright JE (1984) Biological activity of avermectine B1 against the bollweevil (Coleoptera: Curculionidae). J Econ Entomol 77:1029–1103
- Xu C, Zhang Z, Cui K, Zhao Y et al (2016) Effects of sublethal concentrations of cyantraniliprole on the development, fecundity and nutritional physiology of the black cutworm *Agrotis ipsilon* (Lepidoptera: Noctuidae). PLoS ONE 11:1–11

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