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Original Article

Resistance Development in *Spodoptera littoralis* (Lepidoptera: Noctuidae) to Conventional and New Insecticides in Egypt

Seham Mansour Ismail*

Insect Population Toxicology Department, Central Agricultural Pesticides Laboratory, Agriculture Research Center, 12618, Giza, Egypt

*Corresponding Author E-mail: dr.sehammansour1@gmail.com

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ABSTRACT

Background: *Spodoptera littoralis* Boisad. (Lepidoptera: Noctuidae) is a serious pest that harms crops all over the world. This pest is frequently treated with insecticides, but in many countries, its resistance impairs field control. The aim of the current study is to determine the resistance evolution to different insecticides in *S. littoralis* for the possibility of detecting susceptibility shifts that lead to poor control.
Methods: Leaf-dip method was used to conduct the pesticides bioassay to determine the resistance stability to several conventional and new insecticides under laboratory settings in field population of *S. littoralis*.
Results: Emamectin benzoate (2.00 ppm) was shown to be the most toxic compound based on LC_{50} values in the first generation, followed by spinosad (8.62 ppm), chlorantraniliprole (79.44 ppm), lambda-cyhalothrin (270.44 ppm), and profenofos (313.96 ppm). After twelve generations, the LC_{50} values for emamectin benzoate, spinosad, chlorantraniliprole, lambda-cyhalothrin, and profenofos decreased 4.88-, 9.91-, 9.42-, 16.52-, and 16.85- times, respectively, in field-collected of *S. littoralis*. The estimated drop in resistance was 17.08, 12.11, 11.96, 10.41, and 9.29 for emamectin benzoate, chlorantraniliprole, spinosad, profenofos, and lambda-cyhalothrin, respectively.
Conclusion: According to the findings, insecticides with novel modes of action had higher reversal rates and less stable resistance to spinosad and chlorantraniliprole.
Keywords: Emamectin benzoate-resistant, Chlorantraniliprole-resistance, Lambda-cyhalothrin-resistant, Profenofos-resistant, Spinosad-resistant.

1. Introduction

One of the most devastating insect pests of cotton and more than 112 other plant species is the cotton leafworm, *S. littoralis* Boisad (Lepidoptera: Noctuidae). Crop losses brought on by *S. littoralis* in Egypt often lead to 26 to 100% yield decreases, depending on the assault intensity [1]. Insecticide resistance has been developed in *S. littoralis* to all insecticide classes and it has become increasingly difficult to control their population in Pakistan [2], Japan, China, Malaysia [3], the United States [4], India [5], Texas [6], Russia [7], and Egypt [8,9]. The problem of resistance is exacerbated in *S. littoralis* because it has multiple generations in one year and each generation is exposed to insecticides, in addition to its high fecundity [7]. Therefore, *S. littoralis* is a good model for insecticide resistance studies.

The rotating use of insecticides that do not exhibit cross-resistance is a crucial aspect of managing resistance [10]. An essential presumption for a successful rotation method is that as an alternative insecticide is used, the frequency of resistant individuals would decrease [11]. When the insecticide is removed from a pest control programme, the insect's susceptibility will return over the course of several generations, allowing the insecticide to be reintroduced. However, in some circumstances, resistance endures for several generations after selection pressure is removed. Such persistent resistance makes it impossible to successfully re-apply insecticide for pest control [11,12]. Designing a successful resistance management program, without specific insecticides or by rotation, requires an understanding of the stability of resistance to insecticides most frequently used to control *S. littoralis*. The current study aims to determine the resistance stability to several conventional and new insecticides under laboratory settings in field population of *S. littoralis*. The information provided will be beneficial for making decisions on how best to handle *S. littoralis'* insecticide resistance in the field, and it can be highly helpful for future research into the pest's insecticide resistance.

2. Materials and Methods

2.1. *Spodoptera littoralis* collection and breeding

S. littoralis egg masses were collected from tomato crop in farmers' fields at Egyptian Governorate (El-Dakahlia) during 2021 and brought to the laboratory. Castor bean (*Ricinus communis* L.) leaves were used without insecticides to rear the larvae and leaves were repositioned every 24 h, pupae were gathered on consecutive days. The emerging adults were kept in oviposition cages, which had two sides covered with muslin cloth to ensure ventilation. The adults were fed a solution containing sucrose (10%) was served on a soaked cotton ball. The cages were supplied with fresh Oleander (*Nerium oleander* L.) leaves to serve as egg laying substrate. Twelve generations of *S. littoralis* were raised without exposure to any insecticides, and all rearing procedures were carried out at a temperature of 25 ±2 °C and a relative humidity of 65 ±5% during a natural photoperiod (16: 8 h light: dark).

2.2. Insecticides

The commercial formulations of insecticides used in this research are: Profenofos (Adwuprof® 72 EC, Bayer Com.), emmamectin benzoate (proclam® 5% SG, Sygenta crop protection Switzerland), lambda-cyhalothrin (Karate® 2.5 EC, Sygenta crop protection Switzerland), spinosad (Tracer® 24% SC, Dow Agro Science), and chlorantraniliprole (Coragen® 18.4% SC, Du Pont).

2.3. Larvae treatment

For toxicological tests on the first, fourth, eighth, and twelfth generations, the second instar larvae of *S. littoralis* were exposed to profenofos, lambda-cyhalothrin, emmamectin benzoate, spinosad, and chlorantraniliprole. The leaf-dip method was used to conduct the pesticides bioassay. Eight replications of each treatment were used in each of the six treatments, including the control, in the experiment. Mortality data were recorded for 72 h for new chemistry insecticides and 48 h for conventional insecticides.

2.4. Statistical analysis

Through the POLO-PC Program (LeOra, 2003) [13], the LC_{50} value for each insecticide was determined using the probit analysis. A resistance factor (RF) was computed using Wearing and Catherine's method [14].

3. Results

3.1. Spinosad

The spinosad LC_{50} value was 8.62 ppm in the first generation of the field-collected population of *S. littoralis*. This value dropped with subsequent generations, reaching a final value of 0.87 ppm in the 12^{th} generation after 72 h of insecticide exposure (Table 1). The rate of decrease in resistance of *S. littoralis* to spinosad was -0.090 and the estimated 10-fold resistance decrease was 11.96 (Table 2). *S. littoralis* had a basal sensitivity rating of 0.87 for spinosad (Table 1).

3.2. Emamectin benzoate

Emamectin benzoate's LC_{50} value for the *S. littoralis* field population was 2.00 ppm for the first generation, and it dropped to 0.41 ppm for the 12^{th} generation after 72 h of exposure (Table 1). Emamectin benzoate resistance decreased at a rate of -0.063, with an estimated 10-fold decline in resistance coming in at 17.08 (Table 2), while *S. littoralis'* initial susceptibility to the emamectin benzoate was 0.41 (Table 1).

3.3. Chlorantraniliprole

After 72 h of exposure, the first LC_{50} value for chlorantraniliprole was 79.44 ppm for the first generation and 8.43 ppm for the 12^{th} generation (Table 1). The rate of *S. littoralis'* insecticide resistance decline was -0.081, and the predicted 10-fold decline of the resistance was 12.11 (Table 2). *S. littoralis's* initial chlorantraniliprole susceptibility score was 8.43 (Table 1).

3.4. Profenofos

The profenofos LC_{50} value of field-collected *S. littoralis* was 313.96 ppm in the first generation and decreased to 18.63 ppm in the twelfth generation after 48 hours of exposure (Table 1). *S. littoralis'* rate of pesticide resistance decline was -0.103, with an estimated 10.41-fold decline in profenofos resistance (Table 2). *S. littoralis* had a profenofos susceptibility rating of 18.63 at the outset (Table 1).

3.5. Lambda-cyhalothrin

The field-collected population of *S. littoralis* had a lambda-cyhalothrin LC_{50} value of 270.44 ppm in the 1^{st} generation, which decreased to 16.37 ppm in the 12^{th} generation after 48 h of exposure (Table I). With an estimated 10-fold decline in resistance of 9.29 for lambda-cyhalothrin, *S. littoralis'* rate of insecticide resistance decrease was -0.102. (Table 2). *S. littoralis'* initial susceptibility to lambda-cyhalothrin was 16.37 (Table 1).

Table 1. Toxicity of various insecticides to different generations of *Spodoptera littoralis* under the lab conditions.

Insecticide	G [a]	n [b]	LC_{50}, 95% confidence limit (ppm)	Slope (± SE)	χ^2 (df)	p	RF [c]
Spinosad	1 st	180	8.62 (4.16-13.75)	1.98 (0.21)	1.20 (4)	0.99	9.91
	4 th	180	5.11 (2.18–12.02)	1.09 (0.18)	0.91 (4)	0.63	5.87
	8 th	180	2.82 (1.13-1.79)	2.11(0 .11)	2.10 (4)	0.45	3.24
	12 th	180	0.87 (0.32–1.52)	1.34 (0.17)	0.24 (4)	0.29	
Profenofos	1 st	180	313.96 (221.294–539.738)	1.37 (0.24)	1.28 (4)	0.88	16.85
	4 th	180	173.59 (126.424–251.635)	1.36 (0.23)	0.65 (4)	0.64	9.32
	8 th	180	78.51 (54.8-111.5)	1.91 (0.32)	2.56 (4)	0.63	4.21
	12 th	180	18.63 (13.6-26.2)	1.60 (0.28)	2.79 (4)	0.14	
Chlorantraniliprole	1 st	180	79.44 (52.8-110.8)	1.44 (0.27)	0.34 (4)	0.98	9.42
	4 th	180	41.89 (27.4-65.3)	1.20 (0.26)	2.02 (4)	0.73	4.68
	8 th	180	15.32 (10.97–21.70)	1.50 (0.16)	3.02 (4)	0.67	1.82
	12 th	180	8.43 (4.16-13.75)	1.98 (0.21)	1.20 (4)	0.99	
Lambda-cyhalothrin	1 st	180	270.44 (142.24–497.79)	1.23 (0.30)	0.57 (4)	0.91	16.52
	4 th	180	98.76 (62.56–181.29)	0.82 (0.33)	0.69 (4)	0.92	6.03
	8 th	180	22.32 (13.38–38.39)	1.52 (0.37)	0.22 (4)	0.71	1.36
	12 th	180	16.37 (9.81–30.16)	1.25 (0.30)	0.46 (4)	0.83	
Emmamectin benzoate	1 st	180	2.00 (1.42–3.82)	1.40 (0.18)	3.05 (4)	0.43	4.88
	4 th	180	1.73 (1.16–2.58)	1.26 (0.20)	4.27 (4)	0.19	4.22
	8 th	180	1.43 (0.52–3.03)	0.77 (0.41)	0.02 (4)	0.92	3.49
	12 th	180	0.41 (0.26-0.56)	1.50 (0.27)	0.40 (4)	0.98	

[a] *Spodoptera littoralis* generation number, [b] Number of *S. littoralis* larvae employed in the bioassay including control, [c] Each generation's resistance factor was obtained by dividing the LC_{50} of the test generation by the LC_{50} of the susceptible generation.

Table 2. Stability of insecticide resistance of *Spodoptera littoralis* against different insecticides

TG [a]	Insecticide	Initial LC_{50} (log)	Final LC_{50} (log)	R [b]	GR [c]
12	Spinosad	8.62 (0.94)	0.87 (-0.06)	-0.091	11.96
12	Profenofos	313.96 (2.50)	18.63 (1.27)	-0.103	10.41
12	Chlorantraniliprole	79.44 (1.90)	8.43 (0.93)	-0.081	12.11
12	Lambda-cyhalothrin	270.44 (2.43)	16.37 (1.21)	-0.102	9.29
12	Emmamectin benzoate	2.00 (0.30)	0.41 (-0.39)	-0.063	17.08

[a] Total generations of *Spodoptera littoralis,* [b] Rate of decline in LC_{50} [log (final LC_{50} – initial LC_{50})/N] where, N is the number of generation populations reared without insecticide exposure, [c] Estimated number of generations needed to reduce LC_{50} by a factor of 10.

4. Discussion

S. littoralis is the most dangerous pest of numerous field crops in Egypt. As a result, it is frequently exposed to insecticides used on numerous afflicted crops. Rapid evolution of resistance may also be influenced by this pest's year-round exposure to various classes of insecticides. This study was done since there was no prior indication of the development of synthetic pesticide resistance in domestic field populations of *S. littoralis*.

This experiment summarized that a population of *S. littoralis* collected from tomato fields in Egypt developed resistance to all five tested insecticides. Previous investigations with populations taken from Pakistan have revealed insecticide resistance in the *S. littoralis* [2], Japan, China, and Malaysia [3], the United States [4], India [5], Texas [6], Russia [7], and Egypt [8,9].

The results of this study show that *S. littoralis* field population had developed resistance to emamectin benzoate in the absence of any selection pressure and were more persistent than the other tested insecticides. Under controlled laboratory conditions, the reversion rate of insecticide resistance in *S. littoralis* was the highest for profenofos (-0.104) and lambda-cyhalothrin (-0.107) and the lowest for emamectin benzoate (-0.063). It is possible that a shared resistance mechanism explains why the rate of decline in insecticide resistance to spinosad and chlorantraniliprole was equal. The extensive use of insecticides in the field for several decades may have led to the high levels of profenofos and lambda-cyhalothrin resistance, which may also reflect numerous resistance mechanisms [15]. Emamectin benzoate has a higher stability of pesticide resistance in *S. littoralis* than other insecticides, which may be the result of a different mechanism of resistance [8,9,16].

5. Conclusion

Based on the findings of the current study, it can be concluded that insecticides (spinosad and chlorantraniliprole) with poorer stability and higher rates of insecticide resistance reversal should be employed for effective management of *S. littoralis* resistance in field conditions. To develop an efficient strategy for managing resistance, further research is needed to better understand the processes through which several insecticides within a single pest species are susceptible to resistance.

Abbreviation

Not applicable.

Authors' contributions

S.M.I. conducted the subject selection, study design, the experiments, paper writing, collecting, interpretation of the data, and performed the statistical analysis. The author read and approved the final manuscript.

Consent for publications

The author agrees to have read the manuscript and authorize the publication of the final version of the manuscript.

Conflict declaration

The authors declare that there is no conflict.

Conflict of interest

None of the authors have any conflict of interest to declare.

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ORCID

Seham Mansour Ismail: https://www.orcid.org/0000-0002-4885-7383

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