Journal of Phytopathology and Pest Management 4(2): 1-12, 2017
pISSN:2356-8577 eISSN: 2356-6507
Journal homepage: http://ppmj.net/

Influence of post treatment temperature on the toxicity of four macrolacton insecticides against *Spodoptera littoralis* (BoisduVal) (Lepidoptera:Noctuidae)

G. A. M. Abdu-Allah*

Plant Protection Department, Faculty of Agriculture, Assiut University, 71526 Assiut, Egypt

Abstract

Temperature is a main ecological factor affect the bioinsecticides toxicity on the destructive larval stage of the cotton leafworm (CLW). The effect of post-exposure temperatures from 13 to 39 °C on the toxicities of two spinosyns (spinosad and spinetoram) and two avermectins (abamectin and emamectin benzoate) toward *Spodoptera littoralis* (BoisduVal) larvae was evaluated using topical and feeding bioassays. Spinosad and spinetoram showed negative temperature coefficient against CLW larvae. The LD_{50} values of spinosad and spinetoram increased by 70.21 and > 81.63 folds when temperature increased from 13 to 39 °C. These two compounds also showed negative temperature coefficient values (-1.71; - 9.92) in the feeding bioassay. On contrast, in feeding application abamectin and emamectin benzoate showed high positive temperature coefficient (27.79 and 194.50) when temperature increased from 19 to 39◦C. The present results ascertain the effect of temperature on the pesticides toxicity. So, spinosyins should be applied in cold weather, whereas, abamectin and emamectin benzoate performed well in relative high temperature.

Keywords: toxicity, spinosad, spinetoram, abamectin, emamectin benzoate, temperature coefficient, *Spodoptera littoralis*.

* **Corresponding author:** G. A. M. Abdu-Allah, Tel. +20882412662, Fax, +20882080384, E-mail: gamalan@aun.edu.eg

Introduction

Temperature is considered a biotic factor affecting biological processes in all living organisms especially on poikilothermic organisms like insects (Fand et al., 2015; Amarasekare & Edelson, 2004; Bale et al., 2002). Also, it is a major factor affecting on insecticide toxicity (DeVrise & Georghiou, 1979). Also, toxicant exposure time, humidity and insecticide formulation affect insecticide toxicity. The relationship between temperature and insecticide efficacy has been varied depending on insecticide molecule, insecticide mode of action, target species, method of application and amount of insecticide ingested or contacted (Kavallieratos et al., 2009; Scott, 1995; Johnson, 1990). The correlation coefficient between insecticide and temperature can be either positive or negative. This coefficient was extensively studied in different species (Khan & Akram, 2014; Glunt et al., 2013; Vassilakos & Athanassiou, 2013; Kowalska, 2008; Mannaa & El-Ghareeb, 1992). The variation between the highest and lowest temperature degree in Egypt through the year is too much. The range of temperature degrees in Egypt is very varied significantly from summer to winter and from day to night. In addition to the economic importance of CLW, *S. littoralis* as one of the most serious injuries insect pests on fields crops as well as horticultural crops in greenhouse or open field not only in Egypt but also on the most Mediterranean countries (Abdu-Allah et al., 2009; El-Gahreeb et al., 2009; Abdu-Allah, 2007). This insect has not any diapauses or/and hibernation or aestivation in Egypt. Consequence, CLW can be adapted in different regions in Egypt and can tolerate the severity temperature. It is recorded from 3 to 46 ◦C in night winter and day summer. The use of insecticides is still the major and familiar method for controlling the CLW. The deposit of insecticide faces the same insect weather in the field. In last decades the new groups of insecticides; like macrolacton group has introduced and recommended for controlling CLW larvae in Egypt (Anonymous, 2016). Macrolactone insecticides are known as microbial bioinsecticides, derived from actinomycetes bacterium species (Copping & Menn, 2000; Putter et al., 1981). Spinetoram and emamectin benzoate are the second generation of spinosad and abamectin. Spinosad is a microbial origin, macrocyclic lacton glycoside, derived from actinomycete bacterium species, *Saccharopolyspora spinosa* Mertz and Ya (Sparks et al., 1998). Emamectin benzoate is a modified fermentation product of the soil microorganism, *Streptomyces avermitilis*. Spinosyn and avermectin insecticides affect the insect nervous system. Abamectin increases the flux of chloride ion at the neuromuscular junction in the nervous system, due to this causes, the arthropods start cessation of feeding and irreversible paralysis (Ishaaya et al., 2002). Spinosad changes the function of GABA-gated chloride channels and nicotinic acetylcholine receptors (Salgado et al., 1997). Although biopesticides have high efficiency and friendly using, they are highly sensitive to the environment (Scott, 1995). In applicable where comparable products from many insecticide classes are ready, temperature should be investigated as a factor in the decision-making steps. Determination of a product temperature coefficient will enable pest managers to select a compatible product that is efficacious under the given environmental conditions. The four tested insecticides are available on the Egyptian market and most of these are recommended for controlling CLW in Egypt (Anonymous, 2016; Abdu-Allah,

2015). The objective of this study to investigate the effect of four post-temperature degrees (13, 19, 29, 39 ◦C) on the toxicity of the four macrolacton using topical and feeding bioassays against the fourth instar larvae of the *S. littoralis* under constant conditions.

Materials and methods

Insects: Strain of CLW, *S. littoralis* used in this study was maintained in Plant Protection Laboratory, Assiut University, Egypt for more than fifteen years without exposure to insecticides. It is reared on castor leaves as described by (Eldefrawi et al., 1964).

Insecticides: Spinosad (Spintor®, SC 24 %, Dow AgroSciences Co.); spinetoram (Radient®, SC12 %, Dow AgroSciences Co); abamectin (Gold®, EC 1.8 %, ELHELB Pesticides & Chemicals Co., Egypt); and emamectin benzoate (Radical®, EC 0.5 %, Agromen Chemicals Co., Ltd.) were used. These insecticides are provided from Experimental Agricultural Research Faculty of Agriculture, Assiut University, Assiut, Egypt except Spintor® which was bought from commercial insecticide market in Egypt.

Bioassay techniques: The topical and feeding bioassays were done at Plant Protection Department Laboratories, Faculty of Agriculture, Assiut University, Egypt according to (Abdu-Allah, 2011). For topical application, spintor® and radient® were dissolved in glacial acetic acid and acetone mixtures (1:1), while acetone solvent was used for gold® and radical®. For feeding bioassay, triton x-100 (0.05%), as detergent, and distilled water as solvent were used. Parts of castor bean leaves were dipped in the pesticide solution for 5 seconds, left until dry. To each replicate, ten selected larvae were fed for 24 h on the treated castor bean leaves, and then the larvae were allowed to feed for 24 h on untreated castor bean leaves. For both bioassays, five to six serial concentrations of each compound was tested against the 4th instar larvae of CLW (the average weight of larvae was 32–36 mg). Separately, to every temperature tested (13, 19, 29, 39 ◦C), the treatments were incubated in adjusted gross chamber in dark and 55± 5% RH for 72 h till recording mortality results. The experiment of each tested compound was duplicable repeated. Percentages of mortality were corrected by Abbot's formula (Abbott, 1925), then pooled and analyzed by probit analysis using the software SPSS (Version 10.0 for windows, SPSS Inc., Chicago, the USA) to determine median lethal concentrations (LC_{50}/ LD_{50}), slope and $\chi 2$ values. According to (Litchfield & Wilcoxon, 1949) the toxicity of bio-pesticides was considered significantly different if the confidence intervals (CIs) at LD_{50}/LC_{50} level did not overlap. Temperature coefficients of each insecticide were recorded at different temperatures according to (Musser & Shelton, 2005).

Results

Data of topical application showed that, both spinosyn insecticides had significantly negative temperature coefficients on for *S. littoralis* at all temperature tested. The LD_{50S} value of

spinosad gradually increased with the increase of tested temperatures. These values were 8.94, 118.64, 314.94 and 627.62 µg a.i. Larvae^{-1} at 13, 19, 29 and 39 ◦C, respectively. This means, the spinosad LD_{50} value that determined at 13◦C was less than that recorded at 19, 29, 39 ◦C by 13.27, 35.23, 70.21 times, respectively. Spinosad showed significant negative temperature coefficient and its toxicity was significantly high at low temperature, and decreased by the increase in temperature degrees. As for spinetoram, the LD_{50S} values took the same trend; these recorded 0.49, 3.04, and 18.35 µg a.i. Larvae $^{-1}$ at 13, 19, and 29 ◦C, respectively. However, at 39 ◦C the tested doses of spinetoram had not any larval mortality. In another words spinetoram have significantly negative temperature coefficient with -37.45, -6.20. Also as in spinosad, spinetoram showed high toxicity at 13 ◦C and the efficiency declined by the increase in temperature, the compound showed no toxicity at 39 ◦C tested (Table 1 & Fig. 1).

Table 1: LD_{50}, slope values of LDP lines of certain bio-insecticides toxicity for *S. littoralis* larvae using topical bioassay.

Bio-insecticide	Temp		LD_{50} (95% CL)	Slope		Temp coefficient [b]				
	(◦C)	n[a]	(µg a.i.larva^{-1})	(±SE)	χ2, (df)	6 ◦C	10 ◦C	16 ◦C	20 ◦C	26 ◦C
Spinosad	13	360	8.94 (0.32-58.93)	0.28 (±0.24)	4.42 (5)	-13.27				
	19	360	118.64 (67.10-138.76)	4.69 (±1.21)	0.64 (5)		-2.65			
	29	360	314.94 (77.83-748.40)	2.67 (±0.78)	0.03 (2)			-35.23		
	39	360	627.62 (NE)	2.06 (±0.81)	0.01 (2)		-1.99		-5.29	-70.21
Spinetoram	13	238	0.49 (0.32-5.89)	0.40 (±0.19)	4.54 (3)	-6.20				
	19	240	3.04 (NE)	1.12 (±0.19)	6.34 (5) [c]					
	29	240	18.35 (8.69-50.80)	1.91(±0.33)	0.70(2)		-6.04		-37.45	
	39	240	>40 (NE)	(NE)	(NE)					
Abamectin	13	210	1.86 (1.56-2.21)	1.23 (±0.15)	0.45(4)	-1.81				
	19	210	3.37 (1.97-7.25)	1.11(±0.17)	4.08(4)		+1.36			
	29	210	2.47 (1.47-4.17)	0.96 (±0.16)	7.15 (4) [c]			-1.33		
	39	210	1.93 (1.13-3.39)	1.00 (±0.19)	11.38(4)[c]		+1.28		+1.75	-1.04
Emamectin	13	210	0.05 (0.03-0.07)	2.98 (±0.51)	1.94 (5)	+1.25				
benzoate	19	210	0.04 (0.02-0.07)	2.22 (±0.68)	0.13 (2)		+2.00			
	29	210	0.02 (0.002-0.04)	3.15 (±0.71)	2.09 (2)			+2.50		
	39	210	0.01 (0.002-0.03)	1.87 (±0.69)	0.98 (2)		+2.00		+4.00	+5.00

[a] Total number of *S. littoralis* tested for each temperature/insecticide treatment. [b] Ratio of higher to lower LD_{50} value for 6–10 ,16-20 and 26◦C differences in temperature. A negative coefficient indicates a higher LD_{50} at the higher temperature. [c] χ2 significantly different from expected ($P < 0.10$), (NE): Confidence limit of LD_{50} not estimated.

In contrast the above mentioned results, abamectin and emamectin benzoate showed significant positive temperature coefficients when used topically on *S. littoralis* larvae. The temperature coefficient values of emamectin benzoate were gradually increased with increasing temperature. Emamectin benzoate has significant temperature coefficient of +5 and + 2.5, required an emamectin dose 5, and 2.5 times lower at 39, and 29, ◦C, respectively than needed at 13 ◦C to get the same control result. From 19- 39 ◦C, the LD_{50} values of abamectin decreased gradually; with 3.37, 2.47, and 1.93 µg a.i. larvae^{-1} at 19, 29 and 39 ◦C, respectively. Abamectin has lower positive temperature coefficient than emamectin benzoate with +1.36 and + 1.75 at 10, and 16 ◦C temperature (Table 1 & Fig.1). The feeding application results data presented in table 2 showed that two spinosyns have negative temperature coefficient in all tested

temperature except for 39 ◦C. The LC_{50} values of spinosad and spinetoram were increased gradually from 13 to 29 ◦C, with 324.72,; 504.36, 553.92 and 125.16, 461.31, 1242.00 mg a.i. liter^{-1} at 13, 19, and 29◦C, respectively. The temperature coefficients of spinosad, and spinetoram were -1.71, - 9.92; and -1.55, - 3.67 at 29, 19 ◦C, respectively. This means to obtain the same mortality at 13 ◦C spinosad and spinetoram concentration should be increased by 1.71, 9.92; and 1.55, 3.67 folds than that at 29, 19 ◦C, respectively.

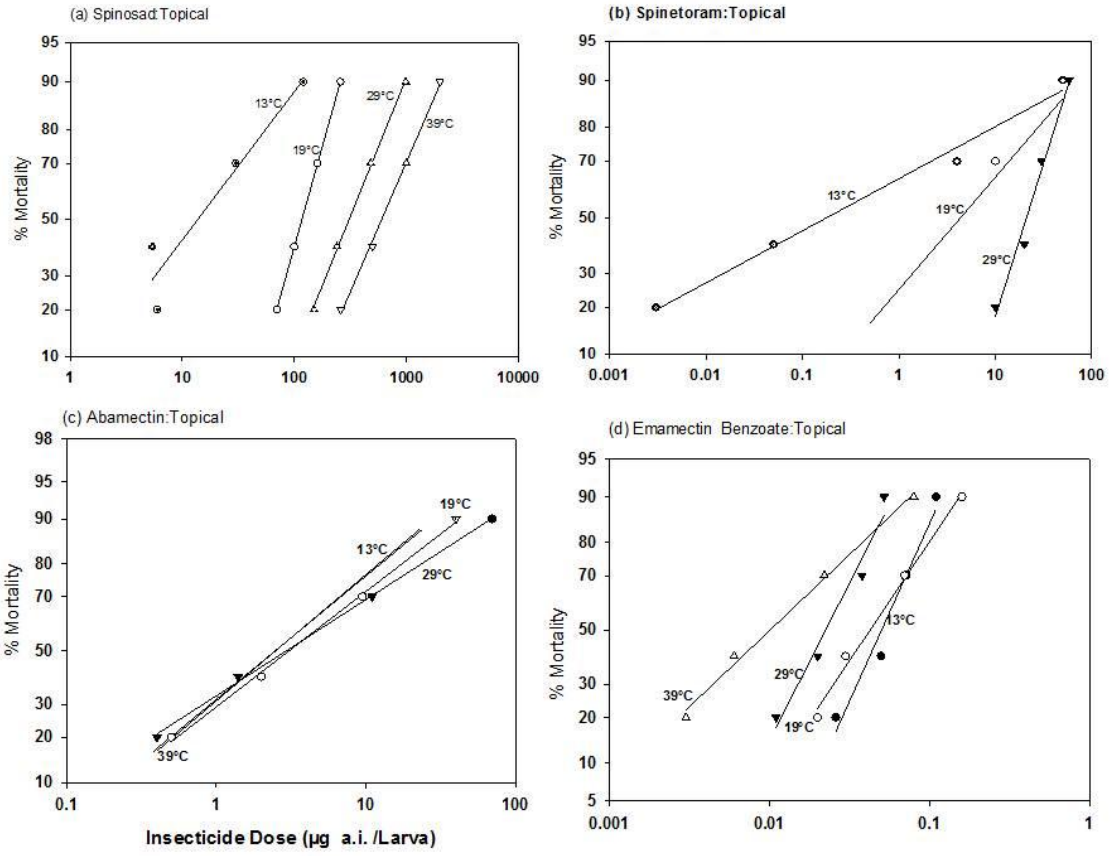

Figure 1: Relationship between log insecticide doses (ug a.i. Larva-1) of spinosad, spinetoram, abamectin, emamectin benzoate and mortality of 4th instar larvae of *S. littoralis*, using topically application method on constant tested temperatures post treatment.

For two avemectin tested the LC_{50} values of abamectin and emamectin benzoate decreased gradually from 13 to 39 ◦C, with 2569, 715.8, 395.02, 185.05, and 3.89; 0.27; 0.14; 0.02 mg a.i. liter^{-1} at 13, 19, 29, and 39◦C, respectively. Emamectin benzoate showed higher significant positive temperature coefficient than that recorded for abamectin. Emamectin benzoate and abamectin with temperature coefficient of +194.50, +13.88; +13.5,+3.87 and +27.79, +6.50, required an emamectin and abamectin concentrations 194.5, 13.88; 13.5, 3.87; and 27.79, 6.50 times lower at 39, 29,19 ◦C, respectively that required at 13 ◦C to get the same larval control level (Table 2 & Fig. 2).

Table 2: LC_{50}, slope values of LCP lines of certain certain bio-insecticides toxicity for *S. littoralis* larvae using feeding bioassay.

Bio-insecticide	Temp		LC_{50} (95% CL)	Slope		Temp coefficient [b]				
	(◦C)	n[a]	(mg a.i. liter^{-1})	(±SE)	χ2, (df)	6 ◦C	10 ◦C	16 ◦C	20 ◦C	26 ◦C
Spinosad	13	300	324.72 (205.42-503.32)	6.87 (±1.90)	2.33 (2)	-1.55				
	19	300	504.36 (264.39-2553.69)	2.98 (±1.33)	0.93 (2)		-1.09			
	29	300	553.92 (272.90-8560.68)	4.02 (±1.67)	1.32 (2)			-1.71		
	39	300	282.89 (201.53-511.81)	5.32 (±1.47)	0.11 (2)		+1.95		+1.78	+1.15
Spinetoram	13	300	125.16 (86.25-172.33)	3.78 (±1.77)	3.52 (2)	- 3.67				
	19	300	461.31 (337.59-790.69)	5.89 (±0.77)	0.49 (2)		- 2.69			
	29	300	1242.00 (571.09-3387.42)	4.46 (±1.53)	0.22 (2)			-9.92		
	39	300	39.68 (15.13-50.44)	7.01 (±2.74)	0.04 (2)		+31.30	+11.63		+3.15
Abamectin	13	300	2569.00 (NE)	4.23 (±3.07)	0.01 (2)	+ 3.59				
	19	300	715.80 (404.65-6718.69)	4.96 (±1.82)	0.02 (2)		+1.81			
	29	300	395.02 (156.33-1416.43)	3.95 (±1.65)	0.15 (2)			+6.50		
	39	300	185.05 (8.82-345.09)	3.55 (±1.68)	0.21 (2)		+2.13		+3.87	+13.88
Emamectin benzoate	13	300	3.89 (2.39-4.74)	1.13 (±0.20)	1.73 (2)	+14.41				
	19	300	0.27 (0.05-0.51)	0.82 (±0.16)	2.69 (2)		+1.93			
	29	300	0.14 (0.02-0.29)	0.93 (±0.16)	1.73 (2)			+27.79		
	39	300	0.02 (0.001-0.03)	1.87 (±0.69)	0.98 (2)		+14.00		+13.50	+194.50

[a]Total number of *S. littoralis* tested for each temperature/insecticide treatment. [b] Ratio of higher to lower LC_{50} value for 6–10 ,16-20 and 26◦C differences in temperature. A negative coefficient indicates a higher LC_{50} at the higher temperature, (NE): Confidence limit of LC_{50} not estimated.

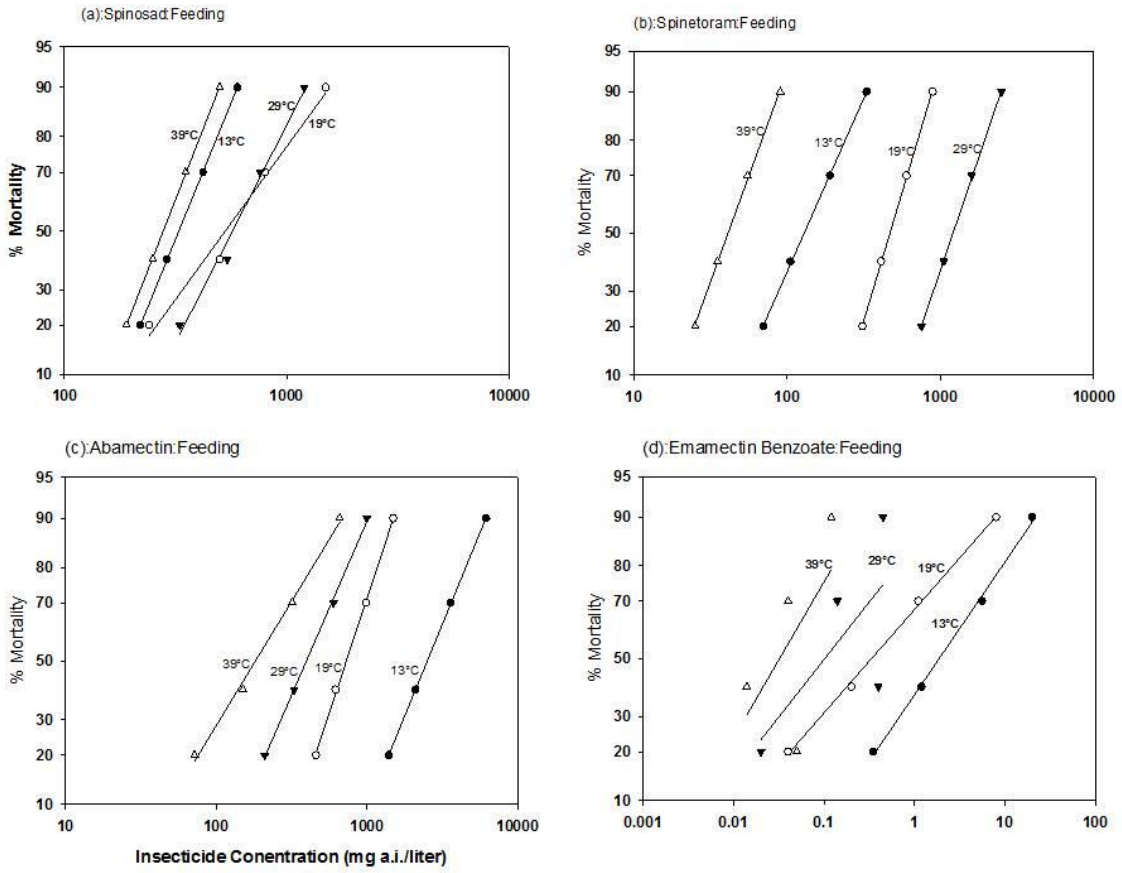

Figure 2: Relationship between log insecticide concentrations (mg a.i.liter^{-1}) of spinosad, spinetoram, abamectin, emamectin benzoate and mortality of 4th instar larvae of *S. littoralis*, using feeding bioassay method on constant tested temperatures post treatment.

The slope values did not significantly differ among tested temperatures for any of the insecticides except for spinosad when tested topically at 13◦C, so that temperature coefficients similar to those reported for LC_{50} could be calculated for all lethal concentrations. The slope values are as steep as frequently encountered in insecticide assays. This was likely due to an observed no repellent effect of the insecticides at the higher doses. In topical application, it was found high significant positive correlation (+0.99) between temperatures tested and the LD_{50} values of spinosad and spinetoram, however there were high negative correlation with emamectin benzoate and no sginificat correlation with abamectin. Converse results were found in feeding bioassay, the significant negative correlation was detected with abamectin and emamectin benzoate (-0.83, 0.74), while spinosad and spinetoram showed no significant correlations (-0.16, +0.07) (Table 3).

Table 3: Correlationship between temperature degrees (13, 19, 29, 39 °C) and LD_{50} or LC_{50} values of spinosad, spinetoram, abamectin and emamectin benzoate tested on the 4th instar larvae of *S. littoralis*.

	Temperature	
	LD_{50}	LC_{50}
Spinosad	$+0.99^{**}$	-0.16^{ns}
Spinetoram	$+0.99^{**}$	$+0.07^{ns}$
Abamectin	$+0.11^{ns}$	-0.83^{*}
Emamectin benzoate	-0.99^{**}	-0.74^{*}

** High significant, * significant, ^{ns} no significant at p=0.05.

Discussion

In the present study the influence of four constant temperatures levels on the effectiveness of different insecticides in CLW larvae was determined under laboratory conditions. Management of this serious injuries larval insect is considered on the field and horticultural crops in Egypt as well as in the most Mediterranean countries (Aydin & Gürkan, 2006; Musser & Shelton, 2005; Kandil et al., 2003). Most recommended insecticides used against CLW larvae usually caused mortality by confusing functions of the nervous system (Khan et al., 2003). Since an insect's body temperature changes with its surroundings, environmental temperature can affect the toxicity of the insecticide (Glunt et al., 2013). Variable metabolic enzymes in insects' body are responsible for the detoxification of insecticides. Natural functioning of the nervous system, is greatly temperature dependent (Montgomery & Macdonald, 1990). In the present results, the spinosyns insecticides exhibited a negative association with surrounding temperatures. Therefore, these could be assumed theoretically to be more toxic in low temperature conditions. The results are in convinced with those reported on spinosyn insecticides in different insect pests (Khan & Akram, 2014; Musser & Shelton, 2005). Conversely to the present results, other studies reported that temperature factor has positively effected on spinosad toxicities such as spinosad against grasshoppers (Amarasekare & Edelson, 2004), *Callosobruchus maculates* (Sadat & Asghar, 2006). This

may be due to the variation in the morphological and physiological characters of insect species. The high potency of spinoad and spinetoram at low temperature can be explained by two suggestions. The first, at low temperature the molecules of these insecticides decreased through the body cuticle so that protection insecticide molecules for intensive exposition to a biological process called biotransformation. Multiple enzymatic activities are responsible for different chemical forms in any xenochemical compound such as spinosad and spinetoram through biotransformation (Harwood et al., 2009). Second suggestion by (Weinzierl et al., 1998) who stated that temperature is an important factor in affecting the effectiveness of microbial insecticides, since spinosad and spinetoram are microbial insecticides which might be a possible factor for decreasing the toxicity at higher temperatures. Being of the view of (Khan & Akram, 2014) further research should be done to understand the phenomenon of decreased potency of spinosad and spinetoram with the decrease in temperature levels. Theoretically, keeping in view the negative relationship between temperature and toxicities of the spinosyns, these insecticides should provide better at low temperatures in the field. Therefore, spinosyins insecticides should be applied in colder winter climates for controlling *S. littoralis* larvae. The tested avermectin insecticides showed positive temperature coefficient against cotton leafworm larvae in both bioassays. The results reported in this study agree with those of (Boina et al., 2009) who reported that abamectin toxicity increased with the increase in temperature from 17 to 37 ◦C in psyllid, *Diaphorina citri* with the Petri dish bioassay. Emamectin benzoate results in present investigation relatively compatible with research reported by (Khan & Akram, 2014) who found that emamectin benzoate has a positive temperature effect against *Musca domestica* L. Penetration and metabolic enzyme activities are partially responsible for detoxification of insecticides. The high penetration of abamectin and emamectin benzoate may be responsible for the high toxicity of these compounds as compared with spinosad and spinetoram. Based on the suggestion of (Harwood et al., 2009) who reported that sodium influx increases due to the stability of open sodium channels at low temperatures, it may be suggest that the activity chloride ion flux at glutamate-gated chloride channel as site of action of abamectin and emamectin benzoate (Ishaaya et al., 2002; Dunbar et al., 1998) is significantly influence by sodium influx. The effect of tested insecticides depends on mode of application and temperatures; this statement is cleared by our presentation, where the temperature coefficients are varied in the same tested temperature at different bioassays. It is generally known that at high temperature, higher amount of the insecticide penetrates the cuticle because the increased chemical solubility or reactivity; however the small amount of the toxicant penetrating the cuticle at low temperature is more active due to decreasing metabolism that gives comparatively high effect at low temperature. This generalization has been realized during the present study because the highest toxicity was recorded

at 13◦C with spinosad and spinetoram but it was the lowest for avermectins. On the other hand, an increase in temperature means also an increase in the activity of CLW larvae consequence the quick touch of the insecticide at the site of action that tends to perform a positive temperature coefficient of mortality. These results insist that there are negative correlation between temperature degrees and toxicity of spinosad and spinetoram, while positive correlation with abamectin and emamectin benzoate. Spinosad and spinetoram showed negative temperature coefficient, so it should be applied at low temperature, in the winter season for controlling CLW larvae. Otherwise for abamectin and emamectin benzoate this showed positive relation with temperature. So to get better control of CLW larva in field by emamectin benzoate and abamectin, it prefers to apply these compounds in the summer season to give a good control result. Knowledge of a product's temperature coefficient will help pest managers to select a product that is effective under the given environmental conditions (Musser & Shelton, 2005). This investigation needs further studies about the effect of changing temperature in the toxicity of tested insecticides.

Acknowledgements

The authors gratefully acknowledge anonymous reviewers for their valuable comments and suggestions. This study was funded by the Faculty of Agriculture, Assiut University, Assiut, Egypt.

References

Abbott WS, 1925. A method of computing the effectiveness of an insecticide. Journal of Economic Entomology **18**: 265–267.

Abdu-Allah G, 2011. Potency and residual activity of emamectin benzoate and spinetoram on *Spodoptera littorals* (Boisd.) African Entomology **19**: 733–737.

Abdu-Allah GAM, 2007. Resistance to spinosad and abamectin in the cotton leafworm, *Spodoptera littoralis* (Boisd.), PhD thesis, Department of Plant Protection, Faculty of Agriculture, Assiut University, Egypt.

Abdu-Allah GAM, El-Gahreeb AM, and Ezz El-Din HA 2009. Resistance stability to spinosad and abamectin in the cotton leafworm, *Spodoptera littoralis* (Bosid.). Resistant Pest Management Newsletter **19**(1): 23–28.

Abdu-Allah GAM, 2015. The effectiveness of some non-traditional materials as pesticides to eggs and larvae of cotton leafworm. Egyptian Journal of Agricultural Research **93**: 157–167.

Amarasekare KG, Edelson JV, 2004. Effect of temperature on efficiency of insecticides to differential Grasshopper (Orthoptera: Acarididae). Journal of Economic Entomology **97**: 595–1602.

Anonymous, 2016. Ministry of Agriculture, Egypt. Program of the Pest Control, Egypt, 311 pp.

Aydin H, Gürkan MO, 2006. The Efficacy of spinosad on different strains of *Spodoptera littoralis* (Boisd.) (Lepidoptera: Noctuidae). Turkish Journal of Biology **30**: 5–9.

Bale J, Masters GJ, Hodkins ID, Awmack C, Bezemer TM, Brown VK, 2002. Herbivory in global climate change research: direct effects of rising temperature on insect herbivores. Global Change Biology **8**: 1–16.

Boina DR, Onagbola EO, Stelinski LL, Salyani M, 2009. Influence of post treatment temperature on the toxicity of insecticides against *Diaphorina citri* (Hemiptera: Psyllidae). Journal of Economic Entomology **102**: 685–691.

Copping LG, Menn JJ, 2000. Biopesticides: A review of their action, application and efficacy. Pest Management Science **56**: 651–676.

DeVrise DH, Georghiou GP, 1979. Influence of temperature on toxicity of insecticides to susceptible and resistant houseflies. Journal of Economic Entomology **72**: 48–50.

Dunbar DM, Lawson DS, White SM, Ngo N, Duggar P, Richter D, 1998. Emamectin benzoate: control of heliothine complex and impact on beneficial arthropods. In "Proceedings, Beltwide Cotton Conferences", CSIRO, San Diego, California, USA, Vol. 2: 1116–1118 pp.

El-Gahreeb AM, Ezz El-Din HA, El-Sayed AMK, and Abdu-Allah GAM, 2009. Monitoring of cross resistance among several insecticides in the cotton Leafworm, *Spodoptera littoralis* (Boisd.). Journal of Agricultural Science Mansoura University **34**: 5473–5485.

Eldefrawi ME, Tappozada A, Mansouer N, Zied M, 1964. Toxicological studies on the Egyptian cotton leafworm, *Prodenia litura*: Susceptibility of different larval instar of P. litura to insecticides. Journal of Economic Entomology **57**: 591–593.

Fand BB, Sul NT, Bal SK, Minhas PS, 2015. Temperature impacts the development and survival of common cutworm, *Spodoptera litura*: Simulation and visualization of potential population growth in India under warmer temperatures though life cycle modelling and spatial mapping. PLoS ONE **10**(4): e0124682.

Glunt KD, Blanford JI, Krijn, PP, 2013. Chemicals, Climate, and Control: Increasing the effectiveness of malaria vector control tools by considering relevant temperatures. PLoS Pathog **9**(10): e1003602.

Harwood ADY, You J, Lydy MJ, 2009. Temperature as a toxicity identification evaluation tool for pyrethoid insecticides: Toxicokinetic confirmation. Environmental Toxicology and Chemistry **28**: 1051–1058.

Ishaaya I, Kontsedalov S, Horowitz A, 2002. Emamectin, a novel insecticide for controlling field crop pests. Pest Management Science **58**: 1091-1095.

Johnson DL, 1990. Influence of temperature on the toxicity of two pyrethoids to Grasshoppers (Orthoptera: Acarididae). Journal of Economic Entomology **83**: 366–373.

Kandil MA, Abdel-Aziz, NF, Sammour EA, 2003. Comparative toxicity of chlorofluazron and leufenuron against cotton leaf worm, *Spodoptera littoralis* (Boisd.). Egyptian Journal of Agricultural Research **2**: 645–661.

Kavallieratos NG, Athanassiou CG, Vayias BJ, Mihail SB, Tomanović Z, 2009. Insecticidal efficacy of abamectin against thee stored-product insect pests: influence of dose rate, temperature,

commodity, and exposure. Journal of Economic Entomology **102**: 1352–1359.

Khan HAA, Akram W, 2014. The Effect of Temperature on the Toxicity of Insecticides against *Musca domestica* L.: Implications for the Effective Management of Diarrhea. PLOS One **9**: e95636.

Khan HAA, Shad SA, Akram W, 2003. Combination of phagostimulant and visual lure as an effective tool in designing house flies toxic baits. PLOS One **8**: e77225.

Kowalska J, 2008. Laboratory studies of the activity of spinosad against *Leptinotarsa decemlineata* (Say) depending on different temperature. In: "16th IFOAM Organic World Congress", Modena, Italy, http://orgprints.org/11780.

Litchfield JT, Wilcoxon F, 1949. A simplified method of evaluating dose effect experiments. Journal of Pharmacology and Experimental Therapeutics **99**: 99–103.

Mannaa SH, El-Ghareeb AM, 1992. Comparative efficacy of variable and constant temperature on the toxicity of certain insecticides against cotton leafworm. Assiut Journal of Agricultural Science **23**: 60–77.

Montgomery JC, Macdonald JA, 1990. Effects of temperature on nervous system: Implications for behavioral performance.American journal of physiology. Regulatory, integrative and comparative physiology **259**: R191–R196.

Musser FR, Shelton MA, 2005. The influence of post- exposure temperature on the toxicity of insecticides to *Ostinia nubilalius* (Lepidoptera:Crambidae). Pest Management Science **61**: 508–510.

Putter I, MacConnel JG, Preiser FA, Haidri AA, Ristich SS, Dybas RA, 1981. Avermectins: Novel insecticides, acaricides and nematicides from a soil microorganism. Experientia **37**: 963–964.

Sadat KM, Asghar PA, 2006. The influence of post-exposure temperature on the toxicity of Spinosad against adults of *Callosobruchus maculatus* Fabricius (Coleoptera: Bruchicadae). In: "Proceedings of the 9th International Working Conference on Stored-Product Protection", ABRAPOS, Passo Fundo, RS, Brazil, 258-262 pp.

Salgado VL, Watson GB, Sheets JJ, 1997. Studies on the mode of action of spinosad, the active ingredient in Tracer insect control. In: "Proceedings Beltwide Cotton Conference", National Cotton Council, New Orleans, Louisiana, USA, Vol. 2 1082-1086 pp.

Scott JG, 1995. Effects of temperature on insecticide toxicity. Reviews in pesticide toxicology. In: "Toxicology communication", INC Research, Raleigh, North Carolina, USA, Vol. 3: 111–135 pp.

Sparks TC, Thompson GD., Kirst HA, Hertlein MB, Larson LL, Worden TV, Thibault ST, 1998. Biological activity of the spinosyns, new fermentation derived insect control agents, on tobacco budworm (Lepidoptea: Noctuidae) larvae. Journal of Economic Entomology **91**: 1277-1283.

Vassilakos TN, Athanassiou CG, 2013. Effect of temperature and relative humidity on the efficacy of spinetoram for the control of thee stored product

beetle species. Journal of Stored Products Research **55**: 73–77.

Weinzierl R, Henn T, Koehler PG, 1998. Microbial insecticides. University of Florida publication ENY-275, Gainesville, Florida, USA.