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Efficacy of cinnamon oil and its active ingredient (cinnamaldehyde) on the cotton mealy bug *Phenacoccus solenopsis* Tinsley and the predator *Chrysoperla carnea*

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Abstract

Background: The importance of *Chrysoperla carnea* (Steph.) (Neuroptera: Chrysopidae) as a predator is due to nourishing this predator on some dangerous pests as the cotton mealybug, *Phenacoccus solenopsis* Tinsley, belongs to Hemiptera: Pseudococcidae. So the predator *C. carnea* was used in the management of various pests. The basic aim of this study was the indirect effect of some natural materials against some stages of *C. carnea* through feeding of the predator on the treated prey, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae).

Results: The results showed the comparison between the effectiveness of cinnamaldehyde and cinnamic oil in controlling the pest as soon as ineffectiveness on the predator. Cinnamaldehyde was very save against *C. carnea* which did not effect on the biology of it and the predator completed its life cycle as control (water + tween 80). Thus, the results suggested that cinnamaldehyde could be included in the Integrated Pest Management (IPM) Program without any adverse effect on bio-control agents used in an IPM.

Conclusion: This study may be a great alternative to chemical pesticides in controlling cotton mealybug, *P. solenopsis*, and at the same time, this material is saving to the predator *C. carnea*. This alternative is cinnamaldehyde (the active ingredient of cinnamon oil).

Keywords: *Chrysoperla carnea*, *Phenacoccus solenopsis*, Cinnamic oil, cinnamaldehyde

Background

The cotton mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae), is considered one of the most recent invasive sap-sucking insects in Egypt that is attacking cotton (El-Zahi et al. 2016; Mostafa et al. 2018), vegetables (Ibrahim et al. 2015), and many other field crops of economic importance. This pest feeds on all the green parts of the infested plants which become stunted, weak with distorted and yellow leaves, and die in severe infestations (Culik and Gullan 2005).

Natural products have been recently attracting the attention of some scientists to avoid the problems caused by synthetic compounds (Abou-Yousef et al. 2010; Mostafa et al. 2018).

The application of predators for a successful biological control program could be controversial, due to their potential to prey on other biological control agents and non-target species (Symondson et al. 2002).

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Green lacewing, *Chrysoperla carnea* (Stephens), is a polyphagous predator that is released for pest control in greenhouses and is also very common in many agricultural systems. The previous studies indicate that five larvae *C. carnea* per 100 nymphs of the pest can be used as a biological control against *P. solenopsis* during the management program (Ibrahim 2018). This species is a powerful agent in biological control programs because of an expanded geographical distribution, high compatibility to different systems, high searching ability, and an easy way to rear (Golmohammadi et al. 2009). *C. carnea* larvae are extremely effective predators in the protected or enclosed areas such as greenhouses (Nayar et al. 1976).

The aim of this study was to determine the effect of cinnamon oil and its active ingredient, Cinnamaldehyde, on the cotton mealybug, *Phenacoccus solenopsis*, and apply LC_{50} on *P. solenopsis* individuals to feed the prey *C. carnea* and show the indirect effect of these materials on the control agent.

Methods

Insect rearing

The cotton mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae), was collected from infested cotton plants (*Gossypium barbadense var.* Giza 86) at the field of Aga district, Dakahalia governorate, Egypt. The mealybug was transferred to the laboratory, and sprouting potato tubers were used as a host plant for its rearing. Gravid females of *P. solenopsis* were inserted in sprouting potatoes. Each sprouted potato was infested with an adult female and observed daily (Attia and Ebrahim 2015). From the reared culture, newly hatched crawlers of *P. solenopsis* were placed on each sprouted potato before being confined in a carton cylindrical box of 8-cm long and 12-cm diameter. The carton boxes were kept at 30 °C and 60 ± 5% R.H. Daily examination for the morphological changes were recorded and monitored until adult emergence (Attia and Ebrahim 2015).

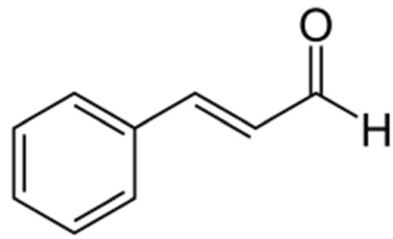
Natural enemy culture maintenance

Larvae of *C. carnea* were obtained from the Bio-Control Laboratory of Plant Protection Research Institute, Dokki, Egypt. They were maintained on *P. solenopsis* at 27 ± 2 °C, 65 ± 5% RH, and 16:8 L:D.

Natural products

Cinnamon oil and its active ingredient, cinnamaldehyde, were used in this study and were bought from Essential oil Extracts Center, National Research Center. Jun-Ran et al. (2015) proved that cinnamaldehyde is the active ingredient of cinnamon oil.

– Cinnamaldehyde, C_9H_8O.



Cinnamaldehyde formula (Vogt 2010)

Preparing the stock solution of the tested materials

The stock concentrations of each tested material (cinnamon oil or cinnamaldehyde powder) were prepared on basis of weight and the volume of the distilled water (w/v) in the presence of tween 80 (0.1%) as emulsifier. Four diluted concentrations for each material were used to draw the LC-P lines. Three replicates were used for each concentration.

Toxicity test

Direct experiment

Toxicity of cinnamon oil and cinnamaldehyde powder was evaluated against adult of *P. solenopsis*. Thirty newly emerged adults, 10 individuals in each replicate, were placed on okra leaves in each Petri dish. Each material had four concentrations, 500, 1000, 5000, and 10,000 ppm, which were sprayed on the individuals. Mortality was recorded for 7 days after treatment. The mortality percentage was estimated and corrected according to Abbott (1925). LC_{50} values were determined using probit analysis statistical method of Finney (1971).

Equation: Sun (1950) (to determine LC_{50} index)

$$\text{Toxicity index for } LC_{50} = \left(\frac{LC_{50} \text{ of the most effective compound}}{LC_{50} \text{ of the least effective compound}}\right) \times 100$$

Indirect experiment

After calculating LC_{50} for each material, each LC_{50} was sprayed on 30 adults of *P. solenopsis*, 10 individuals for each replicate; these individuals were introduced to one larva of the predator, *C. carnea*, after 24 h of direct spraying. Four replicates were used, one prey in each. The results were corrected by control, and the mortality percentage was estimated and corrected according to the analysis of variance (ANOVA) (Analytical software 2005).

Results

Direct experiment

Toxicity studies:

Effect and toxicity index of cinnamon oil and cinnamaldehyde on mortality rate of cotton mealybug, *Phenacoccus solenopsis*

Table 1 Efficiency of cinnamon oil and *cinnamaldehyde* against *Phenacoccus solenopsis* under laboratory conditions 27 ± 2 °C and 65 ± 5% RH

Treatments	Conc.	Total mortality%	LC_{50}	LC_{90}	Slope ± S.D.	Toxicity index LC_{50}	LC_{90}/LC_{50}
Cinnamic oil	**500**	**43.33**	**802.14**	**1,737,321.67**	**0.384 ± 0.122**	**52.78**	**2165.86**
	1000	**56.67**					
	5000	**60**					
	10,000	**66.67**					
Cinnamaldehyde	**500**	**50**	**423.33**	**86,181.21**	**0.555 ± 0.126**	**100**	**203.58**
	1000	**60**					
	5000	**73.33**					
	10,000	**76.67**					

Results obtained in Table 1 showed that mortality rate of the active ingredient, cinnamaldehyde, was high against *P. solenopsis* and more effective than cinnamon oil for all concentrations used. The total mortality was 43.33, 56.67, 60, and 66.67% for 500, 1000, 5000, and 10, 000 ppm, respectively for cinnamon oil, while the total mortality for cinnamaldehyde was 50, 60, 73.33, and 76.67% for 500, 1000, 5000, and 10,000 ppm, respectively.

In addition, LC_{50} of the active ingredient, cinnamaldehyde, was 423.33 ppm and LC_{90} 86181.21 ppm, while cinnamon oil had LC_{50} 802.14 ppm and LC_{90} 1,737, 321.67 ppm. The toxicity index was 100% for cinnamaldehyde, but it was 52.78% for cinnamon oil.

The slope values indicated that cinnamaldehyde had a higher value which was 0.555 while cinnamon oil slope value was 0.384.

LC_{90}/LC_{50} value confirmed that cinnamaldehyde had a lower value, 203.58, than cinnamon oil, 2165.86. Thus, the highest slope value or the lowest ratio LC_{90}/LC_{50} means the steepest toxicity line.

Indirect experiment

In Table 2, the active ingredient, cinnamaldehyde, proved that it was a safety material against the predator *C. carnea* which completed its larval and pupal stages until adult emergence (*C. carnea* feed on *P. solenopsis* individuals sprayed only with water and tween 80), while using cinnamon oil completed the larval stage only of *C. carnea*. Also, the predation efficiency of the predator was higher by using active ingredient cinnamaldehyde than using cinnamon oil. Table 2 also demonstrated the efficiency of *C. carnea* female in laying eggs by percentage 100% in control as soon as in cinnamaldehyde.

Discussion

The active ingredient, cinnamaldehyde, proved its toxicity effect against *P. solenopsis* than cinnamon oil. Similar results were observed by Jun-Ran et al. (2015) who proved effectiveness of cinnamaldehyde and illustrated that cinnamaldehyde was a more active ingredient than other compounds of cinnamic acid which were used in controlling *P. solenopsis*.

Also, cinnamaldehyde is very a useful material for controlling the cotton mealy bug pest, *P. solenopsis*; as soon as it did not cause any harm for the predator, *C. carnea*. Hafiz et al. (2012) proved the effectiveness of *C. carnea* against *P. solenopsis.* Sana et al. (2015) showed that emamectin benzoate had no residual effect on the predator *C. carnea* than neem oil. Pilar et al. (2005) demonstrated that the natural plant extracts, *Trichilia havanensis* (Meliaceae) extracts and *Teucrium viscidum* (Lamiaceae), are nearly innocuous for both natural insects at the conditions tested. El-Wakeil et al. (2006) proved that the chemical products were harmless to adults of *C. carnea*. Kim et al. (2013) and Isman (2000, 2006) illustrated that plant essential oils are potential products for the control of *M. pruinosa* because some of them are selective, biodegrade into nontoxic products, and have less harmful effects on non-target organisms.

Table 2 Effect of different tested materials indirectly on the biological aspects of *Chrysoperla carnea*

Tested materials	Average period of different developmental larval instars (in days)			Total larval stage	Pupal stage	Egg laying %
	1st	2nd	3rd			
Cinnamon oil	**3.17 ± 0.2**	**2.96 ± 0.2**	**3.67 ± 0.2**	**9.8 ± 0.2**	**-------**	**------**
Cinnamaladyde	**3.33 ± 0.3**	**2.98 ± 0.2**	**3.83 ± 0.4**	**10.14 ± 0.2**	**11.67 ± 0.3**	**100**
Control	**3.26 ± 0.2**	**2.83 ± 0.2**	**3.33 ± 0.2**	**9.42 ± 0.2**	**9.67 ± 0.3**	**100**

Conclusion

The cotton mealy bug, *Phenacoccus solenopsis*, is a destructive pest for cotton and some host plants, and one of ways of controlling this pest is biological control. *Chrysoperla carnea* was used for predation of *P. solenopsis* but it dies from using the chemical pesticides, so this study is concerned mainly with maintenance of the predator, *C. carnea*, and at the same time controlling the pest, *P. solenopsis*.

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Authors' contributions
This work was carried out in collaboration between the two authors. GEA designed the study, wrote the protocol, made the statistical analysis, and reviewed the manuscript. NMY applied the whole laboratory work. The two authors read and approved the final version.

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The authors declare that there are no competing interests.

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