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ORIGINAL ARTICLE

The impact of insecticides on the cotton mealybug, *Phenacoccus solenopsis* (Tinsley): Efficacy on potato, a new record of host plant in Egypt

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Abstract

The cotton mealybug, *Phenacoccus solenopsis* (Tinsley) (Hemiptera: Pseudococcidae), has become a widespread pest causing serious losses in several economically important crops, articularly cotton. To the best of our knowledge this is the first record of cotton mealybug, *P. solenopsis* as a new pest of potato plants in Egypt. The insect was noticed on potato plants for the first time during the growing season of 2016 (mid-August 2016). Mealybug specimens were collected from infested potato plants and identified as *P. solenopsis*. In an attempt to control this insect pest species, seven insecticides *viz.* sulfoxaflor, abamectin + thiamethoxam, spirotetramat, thiamethoxam, imidacloprid, buprofezin, and pymetrozine, belonging to different chemical groups, were tested for their effect against nymphs and adult females of *P. solenopsis* on potato under field conditions. The obtained results indicated that sulfoxaflor, abamectin + thiamethoxam and spirotetramat had the highest efficacy against *P. solenopsis* recording 80.3–96.05% reduction of the insect population after 21 days of application. Thiamethoxam, imidacloprid, buprofezin and pymetrozine failed to exhibit sufficient *P. solenopsis* control.

Keywords: cotton, mealybugs, neonicotinoid, potato

Introduction

Potato (*Solanum tuberosum* L.) (Solanaceae) is the most important tuber crop in the world, growing in about 150 countries and playing a vital role in the global food system (Low *et al.* 2015). The total world potato production in 2014 was estimated at 381 million tons of fresh tubers from 19.5 million ha (FAOSTAT 2017). Today, Asia and Europe are the world's major potato producing regions, accounting for more than 80% of world production in 2014 (FAOSTAT 2017). In Egypt, from a total cultivated area of 172 thousand ha the total production of potato reached 4.6 million tons in 2004. To meet the food needs in Egypt, the volume of potato imported from Europe in 2013 reached 184.5 thousand tons and cost an estimated US$144.7 million (FAOSTAT 2017). Potato is grown in nearly all parts of the tropical and subtropical world and in warmer areas of temperate regions. Increased temperatures provide suitable conditions for several pests (e.g. insect pests), diseases, nematodes and weeds, to attack potato plants and can cause major production losses (Boydston *et al.* 2008).

Invasive mealybugs (Pseudococcidae: Hemiptera) are one of the most important crop pests in many regions of the world (Mani and Shivaraju 2016); this is especially evident in countries around the Mediterranean Basin (Pellizzari and Porcelli 2014). The genus *Phenacoccus* currently consists of about 180 species and is one of the largest genera in the Pseudococcidae (Ben-Dov 1994). In Egypt, the genus *Phenacoccus* is represented by seven species. Six of them are: *Phenacoccus gypsophilae* Halle, 1927; *P. halli* Ezzat, 1962; *P. parvus* Morrison, 1924; *P. pyramidensis Ezzat,* 1960; *P. solenopsis* Tinsley, 1898 (Halle 1927; Ezzat 1960, 1962; Abd-Rabou *et al*. 2010) and *P. madeirensis* Green, 1923 (Badr and Moharum 2017). An additional species, *P. solani* Ferris, 1918, was recently reported by Dewer *et al.* (2018). Since then, no further records of this species have been reported.

Phenacoccus solenopsis is known as a highly invasive and polyphagous insect pest responsible for serious damage to crops and plants in many countries. It attacks more than 200 plant species including field crops, vegetables, ornamentals, weeds, bushes and trees (Arif *et al.* 2009; Fand and Suroshe 2015). It has been found in more than 35 geographical regions around the world (García Morales *et al.* 2016). This species was initially reported as a pest of cotton in Texas (USA) in 1989 (Fuchs *et al.* 1991). Since 1992, this pest has spread throughout Central America (Williams and Granara de Willink 1992; Ben-Dov 2004) and has subsequently spread to several countries. It has been reported on many different host plants such as sweet pepions in Chile (Larrain 2002), forage crops and soybean in Argentina (Granara de Willink 2003), tomato in Brazil (Culik and Gullan 2005), cotton in Pakistan and Turkey (Hodgson *et al*. 2008; Kaydan *et al*. 2013), *Hibiscus rosa-sinensis* in Nigeria and China (Akintola and Ande 2008; Wang *et al.* 2009), basil and bell pepper in Israel 2008 (Spodek *et al.* 2018) and on sesame in Ethiopia (Gebregergis 2018).

In Egypt, *P. solenopsis* was initially recorded on weeds by Abd-Rabou *et al.* (2010), and subsequently reported as a new invasive pest species on various economically important crops, including tomato, cotton, okra, eggplant, sunflower and some ornamental plants (Ibrahim *et al.* 2015; Beshr *et al.* 2016; El-Zahi *et al.* 2016). It was observed that the thermal requirements for development of the cotton mealybug in Egypt ranged from 20–30°C (Shehata 2017). This study reports the first record of *P. solenopsis* on potato in Egypt, where it is expected to become one of the most important pest species within the next few years because the agroecosystem is nearly ideal for its development and spread. Based on previous and our recent findings on this species to date, this study records a new host plant for the cotton mealybug in Egypt.

Host plant records for *P. solenopsis* were drawn from the ScaleNet database (http://scalenet.info) (García Morales *et al.* 2016). These records were confirmed against the EPPO website (https://www.eppo.int/) in order to determine the proper information about host associations. Generally, potato plants infested by cotton mealybug nymphs and adults feed on the leaves, collars, and roots and cause severe economic losses due to damage to the yield in late season infestations.

The success of cotton mealybug as a devastating pest of crops is due to its ecological adaptability (Hodgson *et al.* 2008). Climatic conditions have a great impact on the population dynamics of cotton mealybug and its distribution over a wide host range (Prasad *et al.* 2012). Therefore, continuous monitoring of the population and dynamics of cotton mealybug is required to avoid severe crop losses with the ongoing changes in climatic conditions. Hence, the surveillance of the pest over large areas needs to be carried out for the development of effective management strategies. Such adaptation to environmental stresses and broad tolerance to climatic conditions make the implementation of an integrated control program difficult. In the same context, recent research reported that *P. solenopsis* developed resistance to organophosphate and pyrethroid insecticides in Pakistan (Ejaz *et al.* 2017).

Several studies and publications on mealybug control are available, but further studies are necessary to improve and develop successful management strategies against this species. Currently, different tactics such as cultural, mechanical, biological, chemical and transgenic approaches are utilized for effective control of mealybugs. Previous studies concluded that mealybug infestations on different plants could be efficiently controlled by using biological control (He *et al*. 2018), botanical extracts (Prishanthini and Vinobaba 2014), and synesthetic insecticides (Lysandrou *et al*. 2012; El-Zahi *et al*. 2016). The recent identification of the female sex pheromone of *P. solenopsis* by Tabata and Ichiki (2016) is likely to aid in this species management. Furthermore, the development of novel approaches to insect pest management using RNA interference (RNAi) could also potentially be incorporated to manipulate *P. solenopsis* populations (Khan *et al*. 2017).

In various parts of the world the management of the cotton mealybug has been able to suppress populations of this species to under threshold levels. Nonetheless, insecticides remain an important component for managing the cotton mealybug because of their efficiency, fast activity, and cost-effectiveness. However, they pose environmental and occupational health concerns. Recent observations that immature stages of cotton mealybugs are more vulnerable and are more likely to be affected by both biotic and abiotic factors are noteworthy due to their management implications (Kumar *et al.* 2013). Therefore, the present study was carried out to (i) register the occurrence of the most recent invasive pest of potato crop in Egypt, *P. solenopsis*; (ii) to assess the effectiveness of different synesthetic insecticides on infested potato plants under field conditions; and (iii) to determine the length of time the applied insecticides are effective.

Materials and Methods

Study location

The experiment was conducted on a private farm located in Abu Hummus, a village of the Beheira governorate, a central area of potato production in the Nile Delta of Egypt. The entire area is located between latitude 31°09'70"N and longitude 30°31'14"E. The research area of the experimental farm is about 4200 m^2 with field conditions of 24.6–35.5°C, 67–85% relative humidity (RH) and 10–12 h daylight.

Sample collection

An overwhelming invasion of the mealybug species was first noticed on potato plants (*Solanum tuberosum* L. cv. Spunta) cultivated through mid-August 2016. During the subsequent potato growing season of 2017, heavy infestations of this pest were also observed in the same area. Mealybug specimens were collected and stored in 95% ethanol at –20°C for morphological identification and molecular analyses. Mealybug specimens were sent to the USDA-ARS Systematic Entomology Laboratory, Beltsville Agricultural Research Center, USA for identification. Specimens were prepared and examined in the same manner as described by Dewer *et al.* (2018). Their identity was confirmed as *P. solenopsis*.

Insecticides

The current study was carried out to evaluate the field performance of seven insecticides in their respective commercial formulations available on the market. The insecticide generic and chemical information is given in Table 1. The concentrations used were based on the recommendations of the Egyptian Ministry of Agriculture for each insecticide to control sucking pest insects under field conditions.

Experimental design and sampling

A field trial was conducted on potato (source: Holland) plants grown on a farm located in Abu Hummus, a village of the Beheira governorate, Egypt, during two consecutive potato seasons (2016 and 2017). Total cultivated area of potato was 4200 m^2 with a general height of approximately 0.4–0.5 m infested with mealybugs. The plot size was 5 × 5 m for each replicate with 0.2–0.25 m inter-plant distance. The infested potato plants with mealybugs were identified, selected and labeled before the application of insecticides. This area did not receive any insecticidal treatments before the start of the experiment. The trial of eight treatments (seven insecticides + untreated control) was laid out in a randomized complete block design with four replicates. A spray was applied with a CP3 knapsack sprayer (Cooper Pegler Co. Ltd., Northumberland, England). The insecticides were used in commercial formulation and the concentrations were prepared using water as a diluent. Insecticides were sprayed in the early morning when the insects are active and the environmental conditions minimize the potential risk of spray drift and evaporation. Five plants were randomly selected from each replicate and inspected for mealybug population. Ten bottom leaves and the collar were observed for the presence of mealybugs from each replicate. Data were recorded on the selected plants before spraying and 1, 3, 7, 14 and 21 days after application. The mean number of nymphs and adult females of cotton mealybugs per potato plant was recorded. The percent reduction of the mealybug population in all treatments compared to the control was calculated according to the Henderson and Tilton formula (Henderson and Tilton 1955):

$$\text{Population reduction} = \left[1 - \frac{\text{Population in treatment after spray}}{\text{Population in treatment before spray}} \times \frac{\text{Population in control before spray}}{\text{Population in control after spray}}\right] \times 100\ [\%].$$

Statistical analysis

The split-plot system in randomized complete block design (RCBD) with eight treatments and four replicates was used following Steel and Torrie (1981). The analysis of variance (ANOVA) was performed using the CoStat program (CoStat program version 6.311, 2005) at 0.05 probability level.

Results and Discussion

The cotton mealybug as a new potato pest in Egypt

The present study represents the first record in Egypt of the cotton mealybug infesting potato (*S. tuberosum* L. cv. Spunta). The mealybug specimens were collected from potato fields in the Beheira governorate (Egypt) during the potato growing season of 2016. The mealybug was identified as *P. solenopsis* Tinsley (Hemiptera: Sternorrhyncha: Coccoidea: Pseudococcidae) at the USDA-ARS Systematic Entomology Laboratory (USA). Different photos of *P. solenopsis*, and photographs of the infestation on potato plants are presented in Figure 1. The cotton mealybug had not been previously reported as a potato pest in Egypt. The occurrence of the mealybug *P. solenopsis* in Egypt was recorded only on weeds by Abd-Rabou *et al.* (2010). In recent years, this pest species became more prevalent, causing damage to the most important crops in the country, including tomato, cotton, okra and eggplant (Ibrahim *et al.* 2015; El-Zahi *et al.* 2016; Beshr *et al.* 2016). Therefore, the present study is the first published record of potato as a new host for *P. solenopsis* in Egypt.

The cotton mealybug infestation attacking potato plants was initially noticed in October 2016. Adults and nymphs of this pest weaken the plants by sucking sap from the leaves, stems and roots of the plant. A magnified view of the mealybug *P. solenopsis*, showing its morphological character is given in Figure 1C and D. Typical *P. solenopsis* specimens can be identified based on the following: they have 9-segmented antennae; the venter of abdominal segments VI–VIII have multilocular disc pores in the median and submedian areas, those on segment VII being at both the anterior and posterior ends of the segment; the femurs have transparent pores; and the circulus is relatively large. *Phenacoccus solenopsis* will also occasionally have a few multilocular disc pores present in the submargin of abdominal segments II–VII (variable in number and position) and small clusters of oral collar tubular ducts in the margins of the last few abdominal segments (fewer than 35 per side) (Hodgson *et al.* 2008; Abbas *et al.* 2009).

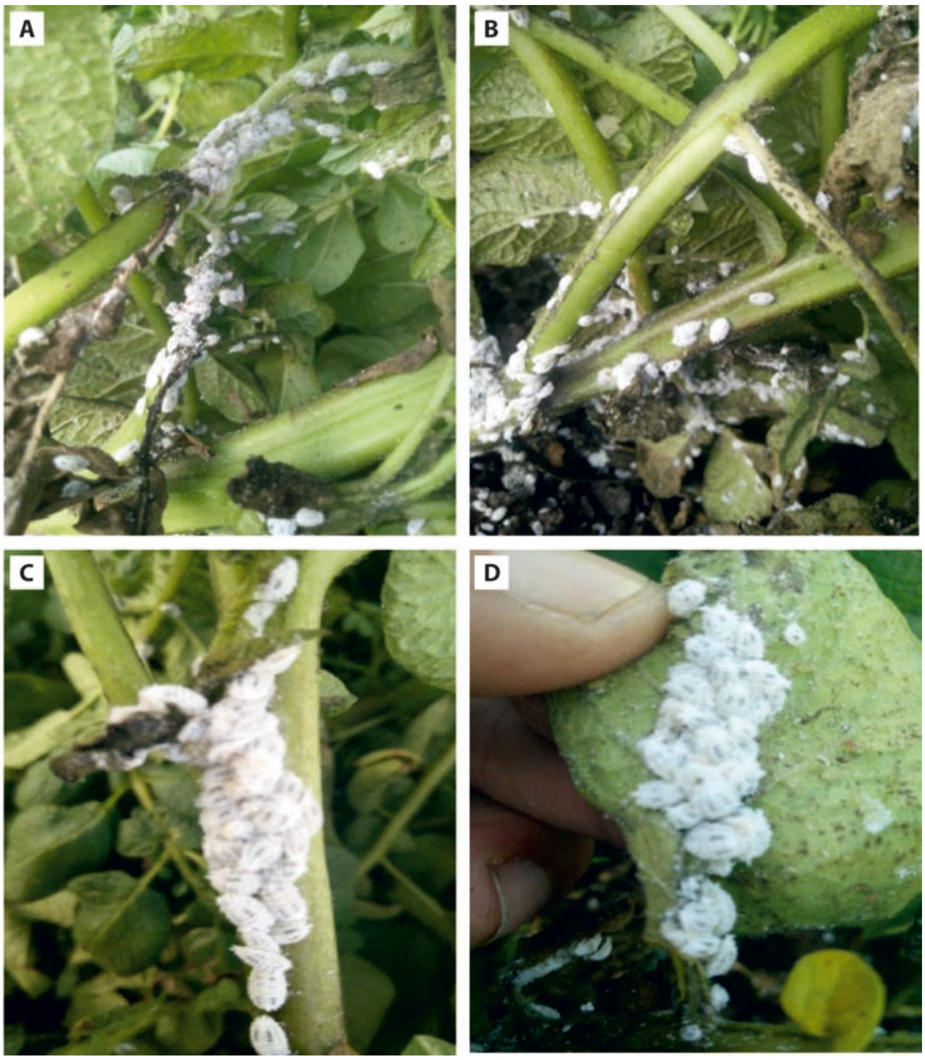

Fig. 1. Photographs showing the infestation of cotton mealybug, *Phenacoccus solenopsis* on different parts of potato plants: A and B – adult females of *P. solenopsis* forming the primary infestation on potato leaves, C and D – stem and potato leaves completely colonized with *P. solenopsis*. Seen are the excreted honey dew on the upper surface of potato leaves and growth of sooty mold causing deformation, distortion and death on infested leaves

The infestation of *P. solenopsis* was observed on all parts of the potato plants during the present study (Fig. 1). The infestation appeared on leaves, stems and sites where the metabolism is accelerated, such as the terminal bud and canopy base (Figs 1A and B). Similar findings were recorded on tomato and cotton plants by Osborne (2005), Culik and Gullan (2005), Silva (2012), Ibrahim *et al.* (2015) and El-Zahi *et al.* (2016). Affected potato plants also exhibit clear symptoms of deformation and distortion of the terminal growth (Fig. 1B). Moreover, noticeable foliar yellowing, leaf wrinkling and puckering were observed (Figs 1B and 1D). Osborne (2005), Silva (2012) and Ibrahim *et al.* (2015) recorded the same injuries on tomato plants during their work. Also, similar symptoms of infestation have been recently recorded on cotton plants growing in Egypt by El-Zahi *et al.* (2016). Growing populations of mealybugs caused severe damage to the plants favoring the growth of sooty molds and causing plant death (Figs 1B and D). The lack of previous records of this insect pest combined with findings of well-established populations on potato plants, indicate that the cotton mealybug *P. solenopsis* may soon become an important insect pest attacking potato plants in Egypt. Therefore, the present study highlights the need for additional surveys and further research on this species and its damage on such an economically important crop. Moreover, the challenge is to develop suitable management programs to suppress the pest population below threshold levels. Such a program for this insect pest then becomes urgently warranted.

Insecticide efficacy against the nymph and adult female of the cotton mealybug

The insecticide efficacy of seven compounds from different chemical groups (Table 1), applied as foliar treatment against the cotton mealybug *P. solenopsis,* was evaluated under field conditions. Data presented in Tables 2 and 3 summarize the effects of the evaluated insecticides, used separately, in suppressing the nymph and adult female populations of *P. solenopsis* on potato plants during two growing seasons, 2016 and 2017. The mealybug populations per potato plant were not the same before application of the tested insecticides. In fact, this is a common problem where the crop is grown under field conditions and infested plants are randomly chosen and sampled (Hanchinal *et al.* 2009; Ahmad *et al.* 2011*)*. Hence, the formula of Henderson and Tilton (1955) was used to calculate the percentage of mealybug population reduction using the mean population pre and post spraying in treated and untreated controls. It is obvious that sulfoxaflor, spirotetramat and abamectin + thiamethoxam induced a fast, initial effect after 1 day of application against nymphs. The reduction in nymph population was 45.25 and 45.46% for sulfoxaflor, and 38.46 and 39.01% for abamectin + thiamethoxam, and 36.64 and 35.44% for spirotetramat in the 2016 and 2017 seasons, respectively. The residual effect of these insecticides extended up to 21 days after the sulfoxaflor treatment (% reduction after 21 days of application was 95.05 and 96.5 during the two seasons). The residual effect extended up to 21 days after the abamectin + thiamethoxam treatment (% reduction after 21 days of application was 91.88 and 92.41 during the two seasons). As for spirotetramat, the percent reduction in the nymph population after 21 days of application was 94.21 and 87.46% during the two seasons. Interestingly, although the percent reduction in the nymph population after 1 day of buprofezin treatment was 11.51 and 13.64%, the effect then increased gradually to reach 96.72 and 95.13% reduction, respectively, after 21 days during the two seasons. Concerning the effect of the same compounds on *P. solenopsis* adult females, as shown in Table 3, the initial effect was 42.86 and 26.02% for sulfoxaflor, 33.75 and 19.87% for abamectin + thiamethoxam, 25.21 and 16.92% for spirotetramat, and 8.54 and 14.15% for buprofezin, in the 2016 and 2017 seasons, respectively. The percent reduction of adult females after 21 days of insecticide application was 88.17 and 89.94% for sulfoxaflor, 80.03 and 85.80% for abamectin + thiamethoxam, 84.57 and 83.54% for spirotetramat, and 71.85 and 55.37% for buprofezin during the two seasons.

The mean population reductions of nymphal and adult female cotton mealybugs after different insecticide treatments on potato plants during two growing seasons (2016 and 2017), are shown in Tables 2 and 3. Data presented in Table 2 elucidate the effects of different insecticides on the mean population percent reduction of nymphs during the 2016 and 2017 potato seasons. Sulfoxaflor was the most effective, causing a 75.13 and 73.39% reduction as the general mean of the effect in 2016, followed by spirotetramat, abamectin + thiamethoxam and buprofezin. The same trend of efficacy on the mean population reduction of nymphs was observed for sulfoxaflor and buprofezin in 2017, while the mean percent reduction of the nymph was higher in abamectin + thiamethoxam than spirotetramat. As for adult females, data in Table 3 indicated the same trend of efficacy where the highest mean values of percent reduction were 68.69 and 62.94% for sulfoxaflor in the 2016 and 2017 seasons, respectively, while spirotetramat gave 61.05 and 53.15% and abamectin + thiamethoxam caused 60.52 and 57.79% reduction as the general means of the effect in the two seasons. In contrast, the lowest mean value of percent reduction was 33.23 and 38.38% for buprofezin in the two seasons compared to other evaluated insecticides against adult females. The results shown in Tables 2 and 3 revealed that the general mean of the percent reduction of nymph and adult populations was higher

Table 1. Common and trade names of tested insecticides, their chemical classes, formulations, basic manufacturers, application rates and mode of actions

Common name	Trade name	Chemical classes	Formulation	Basic manufacturer	Application rate	Target pest	Mode of action
Sulfoxaflor	Closer	sulfoximines	240 SC	Dow AgroSciences, LLC, Indianapolis, IN	100 ml/ feddan	mite, aphid, whitefly, leafhopper, mealybugs	nicotinic acetylcholine receptor (nAChR) agonist (Sparks *et al*. 2013)
Abamectin + Thiamethoxam	Agri-Flex	avermectins + neonicotinoids	18.56% SC	Syngenta Crop Protection, LLC, Greensboro, NC	240 ml/ feddan	tomato leafminer, red spider mite, aphid, armored scale, psyllid	GABA and glutamate-gated chloride channel (GluCl) allosteric modulators, nicotinic acetylcholine receptor (nAChR) agonist (Huang and Casida 1997)
Spirotetramat	Movento	tetramic acid derivative (ketoenole)	10% SC	Bayer CropScience LP, Research Triangle Park, NC	75 ml/100 l	aphid, red spider mite, whitefly, some scales, mealybugs	lipid biosynthesis inhibitor (growth inhibitor) (Ke *et al*. 2010)
Thiamethoxam	Actara	neonicotinoids	25% WG	Syngenta Crop Protection, LLC, Greensboro, NC	25 g/100 l	aphid, termite, boll worm, red palm weevil, leafminer, thrips, jassid	nicotinic acetylcholine receptor (nAChR) agonist (Kayser *et al*. 2016)
Imidacloprid	Best	neonicotinoids	25% WP	Bayer CropScience LP, Research Triangle Park, NC	75 g/100 l	aphid, whitefly, some scales, mealybugs, red spider mite, fruit fly, root-knot nematode, thrips.	nicotinic acetylcholine receptor (nAChR) agonist (Kayser *et al*. 2016)
Buprofezin	Applaud	buprofezin	25% SC	Dow AgroSciences, LLC, Indianapolis, IN	600 ml/ feddan	fruit fly, mealybug, whitefly, thrips, aphid, jassid.	inhibitors of chitin biosynthesis (inhibitor of Homopteran growth regulation) (Uchida *et al*. 1987)
Pymetrozine	Tedo	pyridine azomethine derivatives	50% WG	Syngenta Crop Protection, LLC, Greensboro, NC	20 g/100 l	aphid, whitefly, psyllid, plant hoppers, mealybug	neuroregulation or nerve-muscle interaction (Ausborn *et al*. 2005)

Table 2. Effect of different insecticides applied as foliar treatment against the nymph of cotton mealybug, *Phenacoccus solenopsis* during the late potato seasons of 2016 and 2017

Season	Interval (days)	Mean population of nymph/5 plants ±SD and the percentage of the reduction after different periods of spray														
		control	sulfoxaflor		abamectin + thiamethoxam		spirotetramat		thiamethoxam		imidacloprid		buprofezin		pymetrozine	
		M.N.	M.N.	% R	M.N.	% R	M.N.	% R	M.N.	% R	M.N.	% R	M.N.	% R	M.N.	% R
2016	1	177.0 ± 4.2	91.5 ± 6.9	45.25	100.5 ± 6.9	38.46	105.3 ± 6.3	36.64	111.8 ± 4.6	34.19	113.5 ± 4.4	30.53	151.3 ± 7.4	11.51	121.0 ± 5.5	28.07
	3	173.3 ± 3.9	63.0 ± 3.2	61.45	79.8 ± 7.2	50.11	69.8 ± 3.5	57.05	99.3 ± 6.7	40.39	90.0 ± 4.7	43.76	103.0 ± 1.8	38.43	106.3 ± 3.3	35.42
	7	175.3 ± 5.4	29.8 ± 2.2	82.16	34.8 ± 2.6	78.39	28.3 ± 1.7	82.75	43.3 ± 3.3	74.27	45.8 ± 2.5	71.71	30.3 ± 2.2	82.14	64.8 ± 6.3	61.53
	14	177.3 ± 5.1	13.8 ± 1.3	91.74	18.5 ± 1.3	88.60	15.3 ± 1.7	90.80	28.0 ± 1.8	83.53	30.8 ± 1.7	80.43	10.5 ± 1.3	93.87	25.5 ± 1.3	84.85
	21	180.5 ± 1.9	8.5 ± 1.3	95.03	13.5 ± 1.3	91.88	9.8 ± 1.0	94.21	23.5 ± 1.3	86.44	26.5 ± 1.3	84.09	5.8 ± 1.5	96.72	21.5 ± 1.3	87.47
	Mean	176.7 ± 2.7	41.3 ± 35.2	75.13 a	49.4 ± 38.7	69.49 c	45.7 ± 40.8	72.29 b	61.2 ± 41.4	63.76 e	61.3 ± 38.5	62.10 f	60.2 ± 64.1	64.53 d	67.8 ± 45.4	59.47 e

Table 2. *Continuation*

Season	Interval (days)	Mean population of nymph/5 plants ±SD and the percentage of the reduction after different periods of spray														
		control	sulfoxaflor		abamectin + thiamethoxam		spirotetramat		thiamethoxam		imidacloprid		buprofezin		pymetrozine	
		M.N.	M.N.	% R	M.N.	% R	M.N.	% R	M.N.	% R	M.N.	% R	M.N.	% R	M.N.	% R
2017	1	103.5 ± 3.5	53.0 ± 3.9	45.46	60.0 ± 0.8	39.01	65.0 ± 1.8	35.44	66.5 ± 1.3	29.97	59.5 ± 1.3	35.49	79.3 ± 1.3	13.64	62.0 ± 2.2	35.66
	3	104.8 ± 2.1	39.0 ± 1.8	60.23	49.5 ± 1.3	50.38	54.8 ± 1.7	46.19	57.0 ± 2.2	40.46	53.0 ± 0.8	43.05	72.3 ± 2.5	22.12	53.0 ± 2.2	45.82
	7	106.5 ± 3.3	26.0 ± 2.2	73.91	31.3 ± 1.7	69.20	38.0 ± 2.2	63.32	43.8 ± 2.5	55.31	36.3 ± 2.9	61.72	31.3 ± 1.5	66.92	35.3 ± 1.5	64.57
	14	111.3 ±2 .2	9.0 ± 0.8	91.30	18.5 ± 1.3	79.93	24.5 ± 1.3	77.31	29.5 ± 1.3	71.04	24.3 ± 0.9	75.42	15.5 ± 1.3	84.30	24.5 ± 1.7	76.21
	21	121.0 ± 2.2	4.5 ± 1.3	96.05	8.8 ± 0.9	92.41	14.8 ± 1.7	87.46	17.3 ± 1.7	84.43	13.3 ± 2.2	87.65	5.3 ± 0.9	95.13	13.8 ± 2.2	87.71
	Mean	110.5 ± 7.9	23.0 ± 23.0	73.39 a	30.3 ± 23.5	66.18 b	36.1 ± 23.3	61.94 c	39.6 ± 22.9	56.24 d	34.2 ± 21.8	60.66 c	35.6 ± 35.7	56.42 d	34.6 ± 21.9	61.99 c

M.N. – mean number, % R – percent of reduction: [(M.N. in the control – M.N. in the treatment)/M.N. in the control)] × 100, values across each row having the same superscript letter(s) were not significantly different ($p > 0.05$), $LSD_{0.05}$ values for season 2016 – 0.9915 for insecticides, 0.7169 for interval and 1.8981 for interaction; season 2017 – 1.9 for insecticides, 0.85 for interval, and 2.25 for interaction

Table 3. Effect of different insecticides applied as foliar treatment against the adult female of cotton mealybug, *Phenacoccus solenopsis* during the late potato seasons of 2016 and 2017

Season	Interval (days)	Mean population of adult female/5 plants ±SD and the percentage of the reduction after different periods of spray														
		control	sulfoxaflor		abamectin + thiamethoxam		spirotetramat		thiamethoxam		imidacloprid		buprofezin		pymetrozine	
		M.N.	M.N.	% R	M.N.	% R	M.N.	% R	M.N.	% R	M.N.	% R	M.N.	% R	M.N.	% R
2016	1	92.0 ± 4.1	49.8 ± 0.9	42.86	52.0 ± 2.9	33.75	52.5 ± 6.3	25.21	55.8 ± 10.9	21.25	59.8 ± 1.7	21.06	60.8 ± 7.8	8.54	68.8 ± 2.2	15.81
	3	93.5 ± 3.6	35.3 ± 1.7	60.13	40.0 ± 1.8	49.85	33.8 ± 1.7	52.33	44.5 ±4 .7	37.21	44.0 ± 2.9	42.92	59.8 ± 5.5	11.17	57.3 ± 1.7	30.99
	7	96.0 ± 3.1	26.0 ± 2.1	71.37	29.5 ± 1.2	63.96	24.0 ± 2.1	66.92	31.5 ± 2.0	56.35	32.8 ± 3.0	58.60	55.3 ± 4.3	19.78	41.3 ± 3.8	51.64
	14	96.3 ± 5.6	17.3 ± 1.7	80.95	20.5 ± 1.2	75.02	17.3 ± 1.7	76.24	20.3 ± 1.5	71.56	23.5 ± 1.2	70.19	31.3 ± 2.2	54.72	20.0 ± 1.8	76.53
	21	98.3 ± 2.3	11.0 ± 1.4	88.17	16.8 ± 1.7	80.03	11.5 ± 1.2	84.57	14.3 ± 0.9	80.58	17.0 ± 0.8	79.02	19.8 ± 1.7	71.85	17.0 ± 1.4	80.54
	Mean	95.2 ± 2.5	27.9 ± 15.3	68.69 a	31.8 ± 14.4	60.52 b	27.8 ± 16.1	61.05 b	33.3 ± 17.1	53.39 c	35.4 ± 16.9	54.36 c	45.4 ± 18.7	33.21 d	40.9 ± 22.6	51.10 c
2017	1	42.3 ± 1.7	28.5 ± 1.3	26.02	31.5 ± 1.3	19.87	33.5 ± 0.6	16.92	34.3 ± 0.9	13.81	30.0 ± 2.2	20.61	34.3 ± 3.0	14.15	30.0 ± 0.8	25.42
	3	43.0 ± 1.4	19.5 ± 1.3	50.27	22.0 ± 0.8	45.00	26.0 ± 0.8	36.58	26.3 ± 1.7	35.02	23.5 ± 1.3	38.67	31.0 ± 3.9	24.25	21.3 ± 1.7	48.31
	7	45.3 ± 1.3	13.75 ± 1.0	66.71	17.0 ± 1.4	59.53	20.0 ± 0.8	53.74	20.8 ± 1.3	51.18	18.0 ± 0.8	55.51	23.5 ± 1.3	45.43	17.5 ± 0.6	59.52
	14	48.0 ± 2.2	8.0 ± 0.8	81.75	9.5 ± 1.3	78.62	11.5 ± 1.3	74.97	13.8 ± 0.9	69.64	11.8 ± 1.7	72.65	22.0 ± 1.8	52.72	9.5 ± 1.3	79.21
	21	49.0 ± 2.2	4.5 ± 1.3	89.94	6.5 ± 1.3	85.80	7.8 ± 1.0	83.54	10.8 ± 0.9	76.61	8.0 ± 0.8	81.82	22.3 ± 2.8	55.37	7.8 ± 1.5	83.49
	Mean	46.0 ± 3.5	13.4 ± 10.1	62.94 a	15.8 ± 10.9	57.76 bc	18.1 ± 11.9	53.15 de	19.7 ± 10.5	49.25 e	16.9 ± 9.9	53.85 cd	25.9 ± 5.3	38.38f	15.8 ± 10.1	59.19 ab

M.N. – mean number, % R – percent of reduction: [(M.N. in the control – M.N. in the treatment)/M.N. in the control)] × 100, values across each row having the same superscript letter(s) were not significantly different ($p > 0.05$), $LSD_{0.05}$ values for season 2016 – 2.75 for insecticides, 1.19 for interval and 3.15 for interaction, season 2017 – 2.73 for insecticides, 1.28 for interval, and 3.39 for interaction in 2016 than in 2017 among all treatments. With one exception, pymetrozine exhibited the opposite trend of efficacy where the highest means of percent reduction were 61.99 and 59.19% in 2017 when the percent reduction was 59.47 and 51.10% in 2016 for nymphs and adult females, respectively. The data indicated that sulfoxaflor, abamectin + thiamethoxam and spirotetramat showed the highest efficacy against *P. solenopsis* recording 96.05 to 80.3% reduction of the insect population after 21 days of application. The obtained results are consistent with those of several investigators (Lysandrou *et al.* 2012; Satar *et al.* 2013; Rizvi *et al.* 2015).

The sulfoximines, as exemplified by sulfoxaflor, represent a new class of insecticides. Sulfoxaflor exhibits a high degree of efficacy against a wide range of sap-feeding insects, including those resistant to neonicotinoids and other insecticides. Sulfoxaflor is an agonist of insect nicotinic acetylcholine receptors (nAChRs) and functions in a manner distinct from other insecticides acting at nAChRs. The sulfoximines also exhibit structure activity relationships that are different from other nAChR agonists such as the neonicotinoids (Sparks *et al.* 2013). The precise mode of action of sulfoxaflor, a new nicotinic acetylcholine receptor-modulating insecticide, is unclear. Thus, a detailed understanding of the mode of action, especially in relation to the neonicotinoids, is essential for recommending effective pest management practices (Cutler *et al.* 2013). Previous studies supported our results that sulfoxaflor was the most effective against *P. solenopsis* in Pakistan (Lysandrou *et al.* 2012).

Spirotetramat is used as a phloem-mobile systemic insecticide targeting acetyl-CoA carboxylase, interrupting lipid biosynthesis that reduces fecundity of sucking insects upon foliar application. Rizvi *et al.* (2015) found that spirotetramat proved significantly superior in controlling *P. solenopsis.* Satar *et al.* (2013) also mentioned that spirotetramat reduced the population percentage of the mealybug nymph, *Planococcus citri* after 7 days. In other invertebrates, like plant nematodes, foliar applications of spirotetramat reduced the numbers of nematodes in the rhizosphere soil around plant roots (McKenry 2009). Unfortunately, recent studies reported that *P. solenopsis* has developed resistance to spirotetramat (Ejaz and Ali Shad 2017). But we hope that this information will help to develop a better resistance management strategy for *P. solenopsis*.

The combination of the two active ingredients abamectin and thiamethoxam is designed to provide broad-spectrum insect control, particularly against Asian citrus psyllid, citrus leafminer and citrus rust mite. Combining the active ingredients in this insecticide gives two modes of action since glutamate-gated chloride channel allosteric modulators and nAChR agonist have proven efficacy and reliability in controlling these key destructive pests. Data on the effects of combined abamectin and thiamethoxam on mealybugs or other piercing-sucking insects are still lacking. Thus, the current research provides preliminary data about the field efficacy of abamectin combined with thiamethoxam against mealybugs. In general, there is little peer-reviewed published literature on evaluating the impact of these products against mealybugs.

Conclusions

This study represents the first record of the cotton mealybug, *P. solenopsis* as a new invasive pest attacking potato crops in Egypt. Also, the present study revealed that among all the tested chemicals sulfoxaflor, abamectin + thiamethoxam, and spirotetramat could be recommended for effective management of the cotton mealybug. The obtained results are important in integrated management programs of potato insects, but the assessment of non-targeted effects of the insecticide exhibiting better performance against the cotton mealybug is necessary and yet unavailable.

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