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Cotton mealybug *Phenacoccus solenopsis* (Hemiptera: Pseudococcidae) population density in eggplant and okra plantations and effect of some insecticides

El-Fakharany, S. K. M.

Plant Protection Research Institute, Agricultural Research Center, Dokki, Giza, Egypt.

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Abstract:

The cotton mealybug *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) is a polyphagous sap sucking insect with a wide geographical and host range causing serious losses in several economically important crops. Thus, laboratory and field experiments were conducted at Sakha Agricultural Research Station, Kafr El-Sheikh Governorate during the seasons 2018 and 2019 to study the population density of *P. solenopsis* on eggplant and okra as affected by weather factors and to determine its, efficiency to certain synthetic insecticides. In both seasons, the infestation of *P. solenopsis* started during the early July. The highest population densities were recorded in the third week of August and first of September. The infestation of cotton mealybug was high significantly and positively correlated with the maximum and minimum temperature, while populations had insignificant negative correlation with relative humidity. Based on the multiple regression analysis and the coefficient of determination values (R2), the maximum and minimum temperature and the relative humidity were responsible for the changes in the insect population by 47.5 to 65.3%. Thiamethoxam was the most effective insecticide (LC_{50}= 3.19 and 3.46 mg AI L-1) against the third instar nymphs of *P. solenopsis* using the leaf-dip method, while buprofezine was the least toxic one with LC_{50} value of 121.79 and 146.14 mg AI L-1 on eggplant and okra. In an attempt to control this pest, seven toxic materials viz., imidacloprid, acetamiprid, spirotetramat, buprofezin, dinotefuran, thiamethoxam, and abamectin + thiamethoxam, belonging to different chemical groups, were tested for their influence against *P. solenopsis* on eggplant and okra under field conditions. Abamectin + thiamethoxam, imidacloprid, thiamethoxam, and acetamiprid showed the highest efficacy against *P. solenopsis* recording 91.05 to 81.50% reduction of the insect population. Spirotetramat was the least in this pest control.

Introduction

Vegetable crops are economic agricultural products in Egypt and allover the world. Both eggplant (*Solanum melongena* L.), family Solanaceae and okra (*Abelmoschus esculentus* L.) (Moench), family Malvaceae are an economically important vegetable crop grown in tropical and sub-tropical parts of the world (Nwangburuka *et al.*, 2011). Eggplant is a major fruit vegetable with world production exceeding 31 million tonnes (Mt),Egypt (1Mt) (Daunay *et al.*, 2007).

The cotton mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) is a polyphagous pest, feeding on a wide variety of host plants including such as Malvaceae, and Solanaceae. It attacks more than 166 plant species including field crops, vegetables, ornamentals, weeds, bushes and trees (Nagrare *et al.*, 2012; Fallahzadeh *et al.*, 2014 and Abdel-Razzik *et al.*, 2015). The order of importance of hosts of *P. solenopsis* from the documented families was Malvaceae> Solanaceae > Astaracea > Euphorbiaceae > Amaranthaceae > Portulaceae (Harde *et al.*, 2018). It causes economic damage mainly to cotton, brinjal, okra, tomato, sesame, sunflower and china rose (Arif *et al.*, 2009 and Fallahzadeh *et al.*, 2014). Most *P. solenopsis* hosts belonging to families Solanaceae, Malvaceae and Cucurbitaceae, accounting for 48 % of the reported host plants (Fallahzadeh *et al.*, 2014 and Abdel-Razzik *et al.*, 2015).

P. solenopsis infestations on different hosts could be effectively controlled using synthetic insecticides, plant extracts, mineral oils and biological control agents (El-Zahi *et al.*, 2016; Seni and Naik, 2017; Mostafa *et al.*, 2018 and Rezk *et al.*, 2019). The present investigations were planned to study the population density of *P. solenopsis* on eggplant and okra as affected by weather factors and to determine its, efficiency to certain synthetic insecticides under laboratory and field conditions.

Material and methods

Field experiments were conducted during 2018 and 2019 seasons at the experimental farm of Sakha Agricultural Research Station, Kafr El-Sheikh Governorate and laboratory of Vegetable Pest Research Department, Sakha Agricultural Research Station.

1. Population density of *Phenacoccus solenopsis* in eggplant and okra:

The survey for *P. solenopsis* on infestation eggplant (*Solanum melongena* L. var. Black Beauty) and okra (*Abelmoschus esculentus* L. var. white velvet) crops were conducted at the farm of Sakha Agricultural Research Station, Kafr El-Sheikh Governorate, during 2018 and 2019 seasons. An area of 1000 m^2 was divided into four equal plots and considered as four replicates arranged in a complete randomized block design. On May 5, okra seeds and eggplant seedlings were sown or transplanted in both seasons. Inspection started 30 days after sowing or transplanting and continued weekly till harvesting. At each examination, 40 apical twigs of the same age were randomly chosen from this area (5 twigs from each corner plus 5 from the center/replicate) to count the adult females and nymphs of the mealybug.

2. Climatic factors:

Daily mean temperature and relative humidity were obtained from the Meteorological Department of Sakha Agricultural Research Station. The correlation (r) values were calculated between the climatic factors and *P. solenopsis* on using the SPSS statistical software package 16.0 (SPSS Inc., Chicago, IL, USA).

3. The tested compounds were:

The current study was carried out to evaluate the laboratory and field performance of seven insecticides in their respective commercial formulations available on the market. Imidacloprid (Magknock 70% WG, Jiangsu, Aijin, Agrochemical Co., Ltd, China), acetamiprid (Mosprid 20%SP,Indogulf Crop Sciences Ltd), spirotetramat (Movento 10% SC, Bayer Crop Science, Germany), buprofezine (Hank 25%SC, Shandong, Sino- Agri United Biotechnology Co., Ltd), dinotefuran (Oshin 20% SG, Mitsui Chemicals Agro Inc. Japan), thiamethoxam (Medal 25%WG, Barigat and Estries Pvt. Ltd. India) and abamectin 3.32% + thiamethoxam 15.24% (Agri-Flex 18.56% SC, Syngenta Agroswissra). 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.

Table (1): Common and trade names of tested insecticides, their chemical classes and application.

Common name	Trade name	Chemical classes	Application rate/100L
Imidacloprid	Magknock	Neonicotinoid	70 g
Acetamiprid	Mosprid	Neonicotinoid	25 g
Spirotetramat	Movento	Tetramic acid derivative (ketoenole)	75 ml
Buprofezin	Hank	Buprofezin	150 ml
Dinotefuran	Oshin	Neonicotinoid	125 g
Thiamethoxam	Medal	Neonicotinoid	30 g
Abamectin 3.32%+thiamethoxam15.24%	Agri-Flex	Avermectin + neonicotinoid	120 ml

4. Laboratory assessments:

4.1. Insect colony:

To establish a culture of *P. solenopsis,* infested eggplant and okra plants were collected from plants in fields those do not have any previous exposure to pesticides. Adult females were separated and inoculated on eggplant and okra plants , potted under laboratory conditions of 30±2^{oc}, 65±5 RH. Two days later, the females settled on plant leaves and stems and started egg laying. The newly moulted third instar nymphs were used in the laboratory experiments

4.2. Toxicity of tested compounds to *Phenacoccus solenopsis:*

Leaf-dip method: A serial of concentrations was prepared from each insecticide using tap water for dilutions. Fresh eggplant and okra leaves with petioles were washed thoroughly with tap water and shad dried. Five leaves were dipped in each concentration for 20 seconds and in the tap water only for the control, and then shade dried. Circular openings were created in nine cm diameter plastic Petri dishes. A filter paper was put underneath each leaf to absorb any water vapor. Twenty newly moulted third instar nymphs of *P. solenopsis* were transferred to each Petri dish using a fine camel hair brush, representing one replication. Five replications were made for each concentration and the control. A binocular microscope was used to distinguish dead insects from live ones. Number of dead insects and the percentages of mortality were recorded after 24, 48 and 72 h of the treatment. Mortality was corrected according to Abbott's Formula (1925). Data were plotted on log dosage-probit papers and statistically analyzed according to Finney (1971).

5. Field assessments:

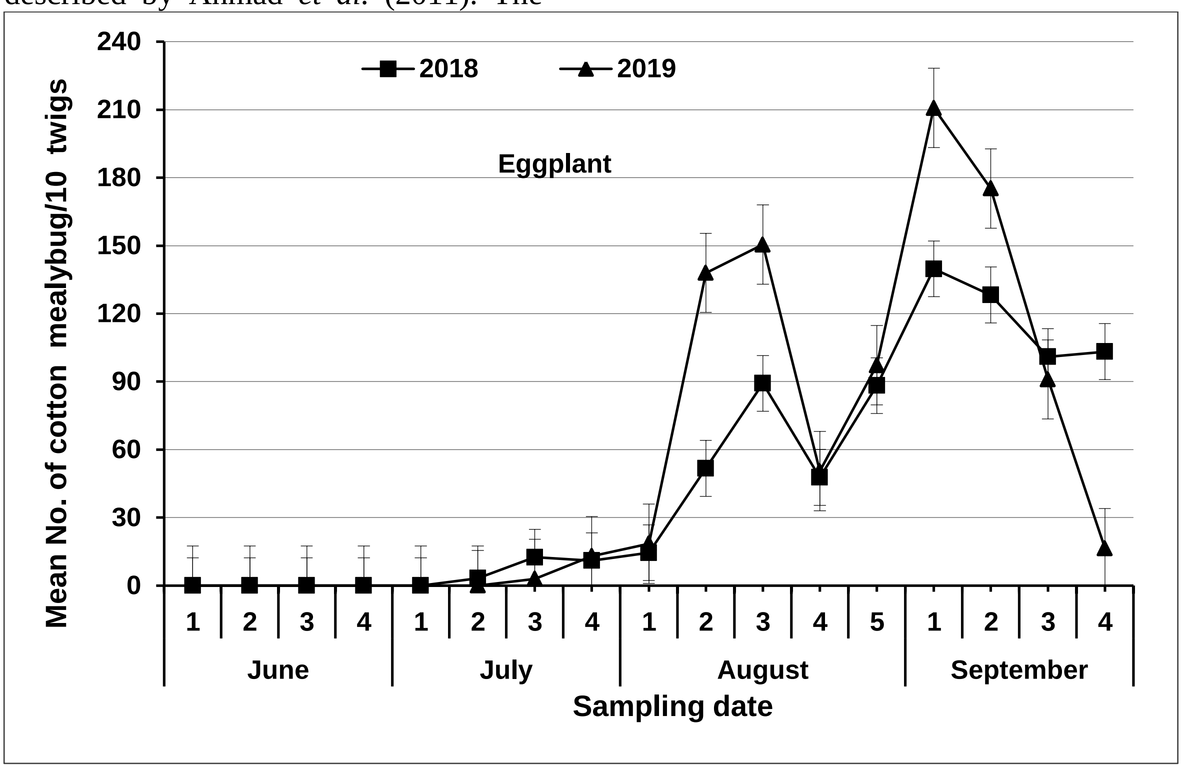
Field experiments were conducted

during September, 2018 and 2019 seasons at the experimental farm of Sakha Agricultural Research Station, Kafr El-Sheikh governorate. An area of 1000 m^2 planted with eggplant (*Solanum melongena* L. var. Black Beauty) and okra (*Abelmoschus esculentus* L. var. White velvet) was divided into plots 42 m^2 each treatment and infested with *P. solenopsis* on. This area did not receive any insecticidal treatments before the start of the experiment. Seven insecticides + control were tested in a arranged in a complete randomized block design with four replicates. The tested compounds were applied at recommended rates using a motor knapsack sprayer, tap water was used for dilutions. Ten eggplant and okra plants were randomly chosen from each replication to count the cotton mealybug population. According to the method described by Ahmad *et al.* (2011). The chosen plants were examined before spraying and 3, 7,10, 14 and 21 days post spray. The mean number of *P. solenopsisper* per eggplant and okra plant was recorded. Percentage of infestation reductions in mealybug population among treatments in relation to control was calculated according to Fleming and Retnakaran (1985) equation.

Results and discussion

1. Population density of *Phenacoccus solenopsis:*

During the seasons, 2018 and 2019, the infestation of *P. solenopsis* on eggplant and okra plants at Sakha Agricultural Research Station, Kafr El-Sheikh governorate started at low density in July (Figures, 1 and 2), the population increased gradually and the highest peaks of *P. solenopsis* were recorded in the third week of August and first week of September.



Figure(1): Population fluctuations of *Phenacoccus solenopsis* on eggplant plants at Sakha Agricultural Research Station farm in 2018 and 2019 seasons.

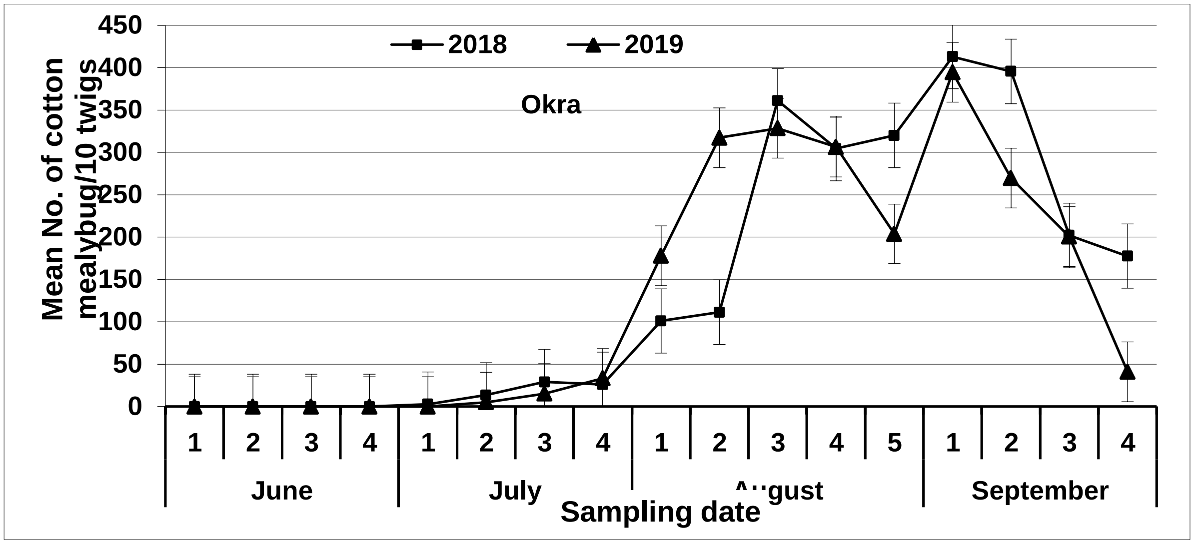


Figure (2): Population fluctuations of *Phenacoccus solenopsis* on okra plants at Sakha Agricultural Research Station farm in 2018 and 2019 seasons.

The present results are in parallel with Sahito *et al*. (2011) who observed the highest infestation of *P. solenopsis* on cotton during September and october, while Shahid *et al.* (2012) recorded the peak of the mealybug population in August and September. The highest this pest population was observed during the second half of September (Shah *et al.*, 2015). Singh and Kumar (2012) showed that *P. solenopsis* population is higher in october on cotton and okra whereas maximum population of mealybug were seen in February on tomato and potato host plants. *P. solenopsis* was recorded on eggplant during growing summer plantation 2016 from July till September, at Fayoum Governorate, infected with a few numbers of this pest and its was recorded one peak in the second week of August (Abd El-Wareth, 2016). The highest peaks the infestation this pest on eggplant plants were observed in June, July, August and September (Nabil, 2017). Also, El-Zahi and Abd-Elsalam (2017) found that the infestation of *P. solenopsison* cotton plants started at low density in June, the population increased gradually and its highest peak was observed in September. Nabil and Hegab (2019) found the infestation with *P. solenopsis* females started on the fourth week of July and the first week of August during 2017 and 2018 seasons, respectively. The population of females had two peaks, the first one occurred in August and the second peak recorded in September on okra plant.

2. Relationship between temperature, relative humidity and cotton mealybug populations

The population of *P. solenopsis* was high significantly and positively correlated (Table, 2) with the maximum (r = 0.624, 0.735, 0.797 and 0.663) and minimum (r = 0.658,0.735, 0.630 and 0.608) temperatures in 2018 and 2019 on eggplant and okra, respectively. Cotton mealybug populations had insignificant negative correlation with relative humidity on eggplant and okra all two growing seasons (Table, 2).

Table (2): Correlation (r) and regression (b) coefficients between some weather factors and *Phenacoccus solenopsis* per population on eggplant and okra twigs.

Season	Variable	Eggplant		Okra	
		r	% R^2	R	% R^2
2018	Maximum temperature (c^o)	0.624**	51.7	0.797**	64.1
	Minimum temperature (c^o)	0.658**		0.630**	
	Mean R.H (%)	-0.356^{NS}		-0.212 ^{NS}	
2019	Maximum temperature (c^o)	0.735**	65.3	0.663**	47.5
	Minimum temperature (c^o)	0.735**		0.608**	
	Mean R.H (%)	-0.288 ^{NS}		-0.095 ^{NS}	

** Highly significant, P ≤ 0.01 — * Significant, P ≤ 0.05 — ^{NS} Not significant

According to the coefficient of determination values (R^2) of this study, the maximum and minimum temperatures and the relative humidity were responsible for the change in the population density of *P. solenopsis* by 51.7, 65.3, 64.1 and 47.5% during 2018 and 2019 on eggplant and okra, respectively. The obtained results of correlation and regression analysis clearly showed that weather factors play important role in the development of *P. solenopsis* population.

Singh and Kumar (2012) found that *P. solenopsis* population was showing positive correlation with higher temperature, whereas negative correlation with lower temperature and humidity. Also, the infestation of *P. solenopsison* cotton was positively correlated with the maximum and minimum temperature (Babu and Meghwal, 2014), and showed a positive correlation with the relative humidity (Hameed *et al*., 2014). El-Zahi and Abd-Elsalam (2017) found that the population of *P. solenopsis* was significantly and positively correlated with the maximum and minimum temperatures. The correlation between the relative humidity and the population was positive and insignificant. Nabil (2017) found that maximum and minimum temperature (˚C) and relative humidity showed positive significant relationship with the cotton mealybug population. Nabil and Hegab (2019) found that significantly positive correlation between maximum temperature and the population females of this insect whereas, a significant negative correlation was found with mean of relative humidity.

3. Toxicity of tested compounds to *Phenacoccus solenopsis* in laboratory:

Thiamethoxam was the most toxic compound to *P. solenopsis* nymphs (3.19 and 3.46) followed by imidacloprid with LC_{50} values of 12.67 and 14.98 mg AI L^{-1} after 72 hours, on eggplant and okra respectively. The LC_{50} was 14.97 and 15.76 mg AI L^{-1} for abamectin + thiamethoxam followed by dinotefuran with LC_{50} value of 27.92 and 27.34 mg AI L^{-1} on eggplant and okra, respectively (Table, 3). Buprofezine was the least toxic compound to *P. solenopsis* third instar nymphs.

The field rates of thiamethoxam and imidacloprid applied in the laboratory resulted in 95.2 and 81.6% mortality, respectively in the 2^{nd} instar nymphs of *P. solenopsis* (Rashid *et al.,* 2011). Ujjan *et al*. (2015) found that lambda-cyhalothrin was highly effective with 50% lethal concentration followed by acetamiprid and Imidacloprid. Seni and Naik (2017) found that lamda cyhalothrin was the most toxic followed by chlorpyriphos , imidacloprid and thiacloprid. El-Zahi and Abd-Elsalam (2017) found that thiamethoxam was the most effective insecticide against the third instar nymphs of *P. solenopsis* using the leaf-dip method, while lufenuron was the least toxic. Methomyl, acetamiprid and imidacloprid showed insignificant differences among them.

Table (3): Laboratory evaluation of tested compounds against *Phenacoccus solenopsis* (Third-instar).

Compound	LC_{50}[a] 95%CL[b]	LC_{90}[a] 95%CL[b]	Slope	LC_{50}[a] 95%CL[b]	LC_{90}[a] 95%CL[b]	Slope
	Eggplant			Okra		
Imidacloprid	12.67 10.92-14.52	48.65 39.79-63.12	2.19	14.98 8.82-23.42	72.12 54.36-234.26	1.88
Acetamiprid	38.95 33.61-44.83	163.20 130.57-218.54	2.06	42.15 36.32-48.67	184.92 146.11-252.28	1.99
Spirotetramat	88.72 76.98-103.94	352.88 264.27-507.99	2.14	96.94 83.91-114.19	383.27 290.02-559.63	2.15
Buprofezine	121.79 107.27-139.59	409.47 327.58-548.75	2.43	146.14 125.22-174.59	649.83 476.79-995.29	1.98
Dinotefuran	27.92 17.39-47.76	97.58 81.04-330.18	2.36	27.34 24.13-31.02	92.27 75.61-119.10	2.43
Thiamethoxam	3.19 2.76-3.64	11.71 9.64-15.04	2.27	3.46 3.01-3.94	12.59 10.36-16.20	2.28
Abamectin + thiamethoxam	14.97 13.52-16.54	34.03 29.51-10.86	3.59	15.76 14.28-17.37	34.68 30.19-41.41	3.74

[a]LC_{50} and LC_{90} are expressed in mg AI L^{-1}--[b]95%CL Confidence limits

4. Field assessments:

The insecticide efficacy of seven compounds, from different chemical groups presented in Table (4) and (5) were evaluated under field conditions for their efficacy against *P. solenopsis* infesting eggplant and okra plants at Sakha, Kafr El-Sheikh Governorate during two growing seasons, 2018 and 2019. The mealybug populations per eggplant and okra plant were not the same before application of the tested compounds. In fact this is a common problem where the crops are grown under natural field conditions and infested plants are randomly chosen and sampled (Ahmad *et al.,* 2011). Hence, the formula of Fleming and Retnakaran (1985) was used to calculate the percentage of mealybug population change using the mean population pre and post sprays in treated and control plots.

It is obvious that abamectin +thiamethoxam (90.38 and 90.78%), imidacloprid (89.16 and 89.52%), thiamethoxam (86.69 and 87.75%) and acetamiprid (83.28 and 84.63%) were the most potent compounds in reducing the population density of cotton mealybug in eggplant plants. It was followed by dinotefuran, buprofezine and spirotetramat (Table,4).

Table (4): Potency of tested compounds in reducing *Phenacoccus solenopsis* populations on eggplant plants at Sakha Agricultural Research Station farm, Kafr El-Sheikh Governorate

Compound	Used* conc. [mg a.i.l^{-1}]	Aver. No. pre- treat./5 plants	% Reduction					
			Initial effect %	Residual effect after indicated days				Grand average
				7	10	14	21	
2018								
Imidacloprid	489.51	150.5	75.66	86.29	91.56	95.33	96.98	89.16
Acetamiprid	50.0	140.75	61.44	82.57	88.34	92.05	92.07	83.28
Spirotetramat	75.0	133.0	55.93	76.20	85.57	86.31	34.45	67.69
Buprofezine	375.0	155.0	56.39	75.79	79.25	77.84	88.54	75.56
Dinotefuran	250.0	183.0	59.60	80.27	85.25	84.36	92.61	80.42
Thiamethoxam	75.0	210.25	73.0	84.27	89.93	92.58	94.69	86.69
Abamectin+thiamethoxam	222.63	233.0	76.85	88.12	92.50	96.37	98.05	90.38
Control(No.)	-	83.25	125.0	177.5	157.25	160.0	201.5	-
2019								
Imidacloprid	489.51	85.0	76.96	86.56	92.10	95.84	96.13	89.52
Acetamiprid	50	111.5	63.76	83.75	90.43	92.07	93.16	84.63
Spirotetramat	75	91.5	57.02	78.87	89.53	87.85	30.71	68.80
Buprofezine	375	123.0	57.03	76.25	80.73	75.35	89.12	75.70
Dinotefuran	250	109.75	59.78	79.99	84.16	82.04	93.69	79.93
Thiamethoxam	75	181.0	75.27	84.95	91.49	91.90	95.14	87.75
Abamectin + thiamethoxam	222.63	199.25	77.69	89.14	93.46	96.20	97.41	90.78
Control(No.)	-	71.5	115.0	162.75	181.0	141.5	152.25	-

*** the used concentrations were determined based on the recommendations of Egyptian Ministry of Agriculture**

Table (5): Potency of tested compounds in reducing *Phenacoccus solenopsis* populations on okra plants at Sakha Agricultural Research Station farm, Kafr El-Sheikh Governorate

Compound	Used* conc. [mg a.i.l-1]	Aver. No. pre- treat./ 5 plants	% Reduction					
			Initial effect %	Residual effect after indicated days				Grand Average
				7	10	14	21	
2018								
Imidacloprid	489.51	75.5	70.30	83.13	92.73	94.36	95.19	87.14
Acetamiprid	50.0	105	50.87	81.07	90.44	92.70	92.44	81.50
Spirotetramat	75.0	99.75	58.57	79.88	89.78	85.27	26.79	68.06
Buprofezine	375.0	115.5	55.62	74.52	79.91	77.51	90.77	75.67
Dinotefuran	250.0	111.0	65.22	77.75	83.48	81.78	95.39	80.72
Thiamethoxam	75.0	133.0	70.97	82.59	91.75	90.40	96.59	86.46
Abamectin+thiamethoxam	222.63	141.0	75.01	88.64	93.77	95.17	97.83	90.08
Control(No.)	-	66.0	103.0	171.0	105.25	77.5	145.5	-
2019								
Imidacloprid	489.51	212.0	68.32	81.30	95.15	97.28	97.77	87.96
Acetamiprid	50.0	92.5	58.46	79.87	91.83	92.69	92.79	83.13
Spirotetramat	75.0	140.0	66.62	78.27	92.19	86.92	24.79	69.76
Buprofezine	375.0	227.25	60.09	73.22	80.34	71.91	91.40	75.39
Dinotefuran	250.0	347.0	66.88	76.92	85.18	86.50	98.35	82.77
Thiamethoxam	75.0	227.25	69.46	80.44	90.10	89.38	98.53	85.58
Abamectin+thiamethoxam	222.63	336.0	74.76	87.79	96.17	97.15	99.38	91.05
Control(No.)	-	56.25	81.25	140.5	175.0	85.25	210.75	-

*** The used concentrations were determined based on the recommendations of Egyptian Ministry of Agriculture**

Abamectin +thiamethoxam and imidacloprid were the most effective compounds in reducing cotton mealybug in okra plants, with reduction of (90.08 and 91.05%) and (87.14 and 87.96 %) respectively in 2018 and 2019. It was followed by thiamethoxam and acetamiprid with reductions of (86.46 and 85.58 %) and (81.50 and 83.13 %), respectively (Table 5). It was followed by dinotefuran, buprofezine, while spirotetramat was the least in this pest control.

Rizvi *et al.* (2015) found that spirotetramat proved significantly superior in controlling *P. solenopsis*. El-Zahi *et al.* (2016) found that imidacloprid and thiamethoxam showed the highest efficacy against *P. solenopsis* recording 89.2 and 84.6% reduction of the insect population while emamectin-benzoate failed to exhibit sufficient *P. solenopsis* control. Unfortunately, recent studies reported that *P. solenopsishas* developed resistance to spirotetramat (Ejaz and Ali Shad, 2017). Sulfoxaflor, abamectin+thiamethoxam, spirotetramat, thiamethoxam, imidacloprid, buprofezin, and pymetrozine 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 (Rezk *et al.*, 2019)

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