



SEASONAL INCIDENCE OF THE COTTON MEALYBUG, *PHENACOCCLUS SOLENOPSIS* TINSLEY (HOMOPTERA: PSEUDOCOCCIDAE) INFESTING TOMATO IN CORRELATION WITH CERTAIN BIOTIC AND ABIOTIC FACTORS

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Abstract

The seasonal incidence of the cotton mealybug, *Phenacoccus solenopsis* Tinsley (Homoptera: Pseudococcidae) on tomato plantations in correlation with certain biotic and abiotic factors was studied at Giza (Atfih) and Qalyubia (Qaha) Governorates during summer 2016 and 2017, and nili 2016 and 2017 growing seasons. The obtained results were summarized as follow:

During summer first season in Atfih, the mean numbers of the mealybug nymphs, adults and total population/sample (100/leaves) during the whole season were 206.72, 67.28 and 274.00 individuals, respectively. In the second season at the same location, the numbers of the pest / sample were 146.61, 50.72 and 197.33 individuals, successively. In Qaha, the mean numbers of nymphs, adults and total numbers/sample during the first season were 137.06, 40.94 and 178.00 individuals, consecutively. During the second season, the mean numbers of nymphs, adults and total population/sample in Qaha were 191.11, 39.39 and 230.50 individuals, respectively. During nili first season in Atfih, the mean numbers of the mealybug nymphs, adults and total population / sample were 777.17, 330.78 and 1107.94 individuals, successively. In the second season at the same location, the mean numbers of nymphs, adults and total population / sample were 940.67, 358.89 and 1299.56 individuals, successively. During the first season in Qaha, the mean numbers of nymphs, adults and total population / sample were 1150.11, 413.50 and 1563.61 individuals, consecutively. In the second season, the mean numbers of nymphs, adults and total population / sample were 1223.06, 376.94 and 1600.00 individuals, respectively.

During this investigation in Atfih (Giza), three hymenopterous solitary endoparasitoids and four predacious species were recorded. The parasitoids were *Aenasius arizonensis* (Girault), *Anagyrus pseudococci* (Girault) and *Acerophagus gutierreziae* Timberlake (Encyrtidae). The predacious ones were *Scymnus syriacus* Mars., *Coccinella undecimpunctata* (L.) (Coleoptera:Coccinellidae), *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae) and *Orius laevigatus* (Fiber.) (Hemiptera: Anthocoridae). In Qalybia (Qaha), three hymenopterous solitary endoparasitoids and four predators were recorded. The parasitoid ones were *Allotropa mecirida* (Walker) (Platygasteridae), *A. gutierreziae* and *leptomastix dactylopii* (Howard) (Encyrtidae). The predacious species were *C. undecimpunctata*, *C. carnea*, *Campylomma* sp. (Hemiptera: Miridae) and *Geocoris* sp. (Hemiptera: Lygaeidae). There were height significant positive correlations between maximum temperature and the populations of the insect pest in Giza during the summer seasons. In Qalyubia, relative humidity showed highly significant correlation during the first nili season and significant correlation during the second summer and nili seasons.

Keywords: Mealybug, *Phenacoccus solenopsis*, tomato plants, biotic and abiotic factors, seasonal abundance, Egypt.

Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crops grown under outdoor and indoor conditions. It becomes an important commercial crop in Egypt so far as the cultivation area production, industrial values and their contribution to human nutrition. The production of Egypt was about 7.943.285 tons in the year of 2016 (Factfish, 2016). The mealybug, *Phenacoccus solenopsis* Tinsley (Homoptera: Pseudococcidae) is a major threat pest to different economic crops in many tropical and subtropical countries. It is polyphagous and infested more than 200 plant species from about 24 countries (Babasaheb and Suroshe, 2015). It is also recorded associated with 28 species of natural enemies including 12 predators and 16 parasitoids. *P. solenopsis* is sucking insect pest and reported in high numbers with aggressive population behavior. The mealybug does not only destroy the host plant by sucking the plant sap, but it is also responsible for transmitting viral diseases. In addition to be excreted honeydew on plant surfaces provides medium for growth of black sooty mold which also disturb the photosynthesis process of plant (Shah *et al.*, 2015).

The effect of abiotic factors (Temperature and relative humidity) on the biology, ecology and population dynamics of any organism was studied (Clark, 2003). Temperature is a

major factor that affect on the abundance of mealybugs (Arai, 1996; Chong *et al.* 2003, 2008; Amarasekare *et al.*, 2008 and Kim *et al.*, 2008) and when the temperature is low, the survival and development of insect pest slows (Jarosiket *et al.*, 2004). Fecundity of an insect pest is affected by RH and temperature as well as life span and development of the mealybug (Kumar *et al.*, 2013). Also the increase in incidence of mealybug population was reported to be positively correlated with the increase in humidity (Anonymous, 2008). Parasitoids and predators are considered the most important biotic factors that affected on the population of *P. solenopsis*. For example the parasitoid, *Aneasius bambawalei* Hayat (Encyrtidae: Hymenoptera) caused 20-70,70 and 20.65% parasitism of *P. solenopsis* according to Tanwar *et al.*, 2008; Ram *et al.*, 2009 and Hanchinal *et al.*, 2010, respectively. The effect of the coccinellid predators on the population of *P. solenopsis* were recorded by Kedar *et al.* (2011).

The aim of this research work is to study the effect of certain biotic and abiotic factors on the population of the mealybug, *P. solenopsis* infesting tomato plantations in two locations in Egypt.

Materials and Methods

The seasonal incidence of the mealybug, *Phenacoccus solenopsis* Tinsley and its associated natural enemies was

conducted during nili and summer seasons of 2016 and 2017 successive years on tomato, *Solanum lycopersicum* L. plantations at Giza (Atfih) and Qalyubia (Qaha) Governorates. Gold stone cv. and Elisa cv. were cultivated in Giza and Qalyubia, respectively. The cultivation dates in summer seasons were during the first and second weeks of March in Giza and Qalyubia, respectively. In nili seasons, tomato was cultivated during the second and third weeks of August in Giza and Qalyubia, respectively. The cultivated area in each location during each summer and nili seasons was about 1050m². Each area was divided into four equal replicates. The tomato plantations received normal agricultural practices and were not subjected to any chemical control application.

Samples of 100 leaves, twenty five ones of each replicate, were taken weekly at random throughout the seasons of the study. The collected samples were packed in paper bags, transferred to the laboratory and examined by the aid of a needle using a stereoscopic microscope at the laboratory of the Scale Insects and Mealybugs Division, Plant Protection Research Institute, Agriculture Research Center. Alive stages (nymphs and adults) of the insect pest and natural enemies were categorized and the counts were recorded. Specimens were enclosed in glass jars (15 cm diameter and 20 cm height). The jars were covered with muslin held in position by a rubber band and checked daily. The predators and parasitoids were separated from the collecting leaves parts during the initial examinations. The predacious and parasitic species were identified by last author of the manuscript. Population fluctuations of the mealybug and its natural enemies (predators and parasitoids) were estimated during the period of investigation.

The main weather factors, maximum temperature (Max. Temp.), minimum temperature (Min. Temp.) and relative humidity (RH %) corresponding to the sampling periods was recorded to determine their effects on the population densities of the mealybug. The weekly records of these weather factors in Giza (Atfih) and Qalyubia (Qaha) Governorates were obtained from Central Laboratory for Agricultural Climate (CLAC), Agricultural Research Center, Dokki, Giza, Egypt.

Simple correlation (r), partial regression (b) and explained variance (E.V. %) values were calculated to obtain information about the relationship between the number of individuals / sample and the mean records of the three tested weather factors. The obtained results were statistically analysed using Costat software program (SAS Institute, 2009).

Results and Discussion

Seasonal incidence of the mealybug, *Phenacoccus solenopsis* Tinsley and its associated natural enemies:

(a) Summer seasons:

(i) In Atfih (Giza)

As shown in Tables (1 and 2), the seasonal abundance of *P. solenopsis* on tomato plantations was evaluated as numbers of the pest (adults and nymphs) per sample (100 leaves).

In the first season (2016), data obtained in Table (1) clear that the infestation began to appear on 3rd April with 13 nymphs and 28 adults/sample. Then, the infestation was

fluctuated with a general tendency to increase. It attained the highest levels of 689 nymphs and 156 adults/sample on 26th June. Thereafter, the population of the pest was decreased gradually to reach 14 nymphs and 12 adults/sample on 31st July. The total number of the pest (nymphs and adults) was increased gradually to reach the highest level of 854 individuals/sample on 26th June. Afterward, the total population of the pest was decreased gradually to attain the lowest level of 26 individuals/sample on 31st July. The mean numbers of nymphs, adults and total population/sample during the whole season were 206.72, 67.28 and 274.00 individuals, respectively.

Three parasitoids and four predators species were recorded during the study (Tables 1 and 2). The parasitoids were *Aenasius arizonensis* (Girault), *Anagyrus pseudococci* (Girault) and *Acerophagus gutierreziae* Timberlake (Hymenoptera: Encyrtidae). All previously mentioned species are solitary endoparasitoids.

The predacious species were *Scymnus syriacus* Mars., *Coccinella undecimpunctata* (L.) (Coleoptera: Coccinellidae), *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae) and *Oruis laevigatus* (Fiber.) (Hemiptera: Anthocoridae). The highest number of *A. arizonensis*, 19 individuals/sample, was recorded on 19th June. *A. pseudococci* reached the highest level of 11 individuals / sample on 8th May. *A. gutierreziae* attained the highest number of 16 individuals/sample on 22nd May. The mean numbers of *A. arizonensis*, *A. pseudococci* and *A. gutierreziae*/sample during the whole season were 5.39, 1.89 and 4.06 individuals, successively.

S. syriacus was the most predominant predator, attained the highest number of 37 individuals/sample on 5th June. *C. carnea* was recorded only during the period from 5th till 19th June, with the highest level of eight individuals/sample on 19th June. *C. undecimpunctata* was found during the period from 1st till 22nd May, with the highest number of nine individuals/sample on 22nd May. *O. laevigatus* was recorded during the period from 1st till 22nd May, with the highest number of nine individuals/ sample on 8th May. The mean numbers of *S. syriacus*, *C. carnea*, *C. undecimpunctata* and *O. laevigatus* / sample during the whole season were 12.78, 1.00, 1.11 and 1.44 individuals, respectively.

In the second season (2017), results in Table (2) indicated that the infestation was observed as in the first season during the period extended from 3rd April till 31st July. The number of nymphs was increased gradually, attained the highest number of 458 individuals/sample on 26th June. Afterward, the population of the nymphs was decreased gradually to record 13 individuals/sample on 31st July. The number of adults was increased gradually to record the highest level of 104 individuals / sample on 26th June. Then, it decreased gradually to record one individual/sample on 31st July. Concerning the total population of the mealybug (nymphs and adults), the highest number of 562 individuals/sample was found on 26th June. Thereafter, the population of the pest was decreased gradually to record the lowest value of 14 individuals/sample on 31st July. The mean numbers of nymphs, adults and total population of the pest/sample during the whole season were 146.61, 50.72 and 197.33 individuals, respectively.

The parasitoid, *A. arizonensis* was recorded during the period from 8th May till 3rd July, with the highest number of

12 individuals / sample on 26th June. *A. pseudococci* was reported only during the period from 24th April till 15th May, with the highest number of eight individuals/sample on 8th May. *A. gutierreziae* was recorded during the period from 8th

May till 19th June, attained its highest level of 17 individuals / sample on 22th May. The mean numbers of *A. arizonensis*, *A. pseudococci* and *A. gutierreziae* / sample during the whole season were 3.50, 0.78 and 3.94 individuals, respectively.

Table 1 : Seasonal abundance of *Phenacoccus solenopsis* Tinsley infested tomato and its associated natural enemies in Atfih (Giza) in summer season during 2016

Date	No. of Population			No. of Parasitoids			No. of Predators				Temp. °C		RH %
	Nymphs	Adults	Total	<i>A. arizonensis</i>	<i>A. pseudococci</i>	<i>A. gutierreziae</i>	<i>S. syriacus</i>	<i>C. carnea</i>	<i>C. undecimpunctata</i>	<i>O. laevigatus</i>	Max.	Min.	
Apr., 3	13	28	41	0	0	0	0	0	0	0	28.5	17.5	54.9
10	24	16	40	0	0	1	0	0	0	0	29.1	18.0	40.7
17	56	20	76	0	0	4	0	0	0	0	29.4	20.0	47.3
24	77	34	111	0	6	5	0	0	0	0	30.5	21.3	41.5
May, 1	86	56	142	1	8	9	7	0	1	4	31.4	23.0	40.6
8	113	61	174	3	11	9	12	0	4	9	31.6	24.1	44.5
15	140	64	204	7	5	14	15	0	6	8	32.2	23.8	37.6
22	185	70	255	8	2	16	27	0	9	5	33.4	21.5	42.5
29	234	82	316	9	1	11	32	0	0	0	35.9	24.8	47.2
Jun., 5	357	91	448	10	1	2	37	5	0	0	38.9	26.1	37.3
12	459	111	570	11	0	1	24	5	0	0	39.8	24.5	41.6
19	568	134	702	19	0	1	23	8	0	0	40.0	24.9	47.1
26	689	156	845	16	0	0	22	0	0	0	41.2	24.9	52.6
Jul., 3	475	101	576	8	0	0	15	0	0	0	41.6	25.0	59.0
10	121	94	215	5	0	0	9	0	0	0	38.6	25.2	59.8
17	65	57	122	0	0	0	4	0	0	0	37.9	25.7	55.1
24	45	24	69	0	0	0	3	0	0	0	38.5	26.1	55.8
31	14	12	26	0	0	0	0	0	0	0	38.1	26.5	58.8
Total	3721	1211	4932	97	34	73	230	18	20	26	636.6	422.9	863.6
Mean	206.72	67.28	274.00	5.39	1.89	4.06	12.78	1.00	1.11	1.44	35.4	23.5	48.0

Table 2 : Seasonal abundance of *Phenacoccus solenopsis* Tinsley infested tomato and its associated natural enemies in Atfih (Giza) in summer season during 2017

Date	No. of Population			No. of Parasitoids			No. of Predators				Temp. °C		RH %
	Nymphs	Adults	Total	<i>A. arizonensis</i>	<i>A. pseudococci</i>	<i>A. gutierreziae</i>	<i>S. syriacus</i>	<i>C. carnea</i>	<i>C. undecimpunctata</i>	<i>O. laevigatus</i>	Max.	Min.	
Apr., 3	9	22	31	0	0	0	0	0	0	0	28.6	18.0	51.1
10	21	17	38	0	0	0	0	0	0	0	29.7	18.8	52.9
17	43	21	64	0	0	1	0	0	0	0	29.9	22.0	50.7
24	55	31	86	0	1	6	0	0	2	0	31.3	22.3	32.6
May, 1	75	45	120	0	4	11	0	0	7	2	31.9	24.0	38.4
8	96	50	146	1	8	12	1	0	10	4	32.4	24.5	42.1
15	110	57	167	4	1	15	4	0	12	5	32.5	24.8	29.3
22	123	59	182	6	0	17	8	0	15	1	33.9	25.1	35.3
29	187	64	251	8	0	6	10	0	5	1	36.4	24.9	30.8
Jun., 5	245	76	321	9	0	1	14	0	3	0	39.1	25.4	34.7
12	256	88	344	9	0	1	16	3	1	0	40.1	26.1	32.1
19	347	93	440	11	0	1	71	4	0	0	40.8	25.8	43.1
26	458	104	562	12	0	0	20	2	0	0	41.5	26.9	44.2
Jul., 3	321	76	397	3	0	0	3	0	0	0	41.7	27.0	44.7
10	210	61	271	0	0	0	1	0	0	0	39.4	26.1	45.7
17	47	42	89	0	0	0	1	0	0	0	38.1	26.4	42.6
24	23	6	29	0	0	0	1	0	0	0	39.0	26.8	49.2
31	13	1	14	0	0	0	0	0	0	0	39.2	26.8	50.0
Total	2639	913	3552	63	14	71	150	9	55	13	645.5	441.7	749.3
Mean	146.61	50.72	197.33	3.50	0.78	3.94	8.33	0.50	3.06	0.72	35.9	24.5	41.6

S. syriacus was found during the period from 8th May till 24th July. The predator reached the highest number of 71 individuals / sample on 19th June. *C. carnea* was recorded only during the period from 12th till 26th June, with four individuals / sample on 19th June. *C. undecimpunctata* was recorded during the period from 24th April till 12th June, recording the highest value of 15 individuals / sample on 22nd May. *O. laevigatus* was observed during the period from 1st

May till 29th May, with five individuals / sample on 15th May. The mean numbers of *S. syriacus*, *C. carnea*, *C. undecimpunctata* and *O. laevigatus* / sample during the whole season were 8.33, 0.50, 3.06 and 0.72 individuals, successively.

The correlations between maximum temperature and total number of the mealybug during the two seasons (Table 9) were positive highly significant where (r) values were

0.699 and 0.681, respectively. Minimum temperature showed positive significant effect on the population of the pest during the second season ($r = 0.513$). The maximum temperature, minimum temperature and relative humidity affected the mealybug populations by 75.95 and 60.74% during the first and second seasons, successively.

(ii) In Qaha (Qalyubya):

During the first season (2016), the infestation with the mealybug was found during the period extended from 5th April till 2nd August (Table 3). The nymphal population was increased gradually to attain its highest level of 350 individuals / sample on 21st June. Then, decreased gradually, recording 27 nymphs / sample on 2nd August. As in nymphal population, the number of adults was increased to reach the highest level of 80 individuals / sample on 21st June. Afterward, the adult population was decreased gradually to record its lowest value of five individuals / sample on 2nd August. The total population of the mealybug reached the highest number of 430 individuals / sample on 21st June. The mean numbers of nymphs, adults and total population of the mealybug / sample during the whole season were 137.06, 40.94 and 178.00 individuals, respectively.

The recorded parasitoid species (Table 3) were *Allotropamecrida* (Walker) (Hymenoptera: Platygasteridae), *A. gutierreziae* and *Leptomastix dactylopii* Howard (Hymenoptera: Encyrtidae). These are solitary endoparasitoids. *Campylomma* sp. (Hemiptera: Miridae), *C. undecimpunctata*, *C. carnea* and *Geocoris* sp. (Hemiptera: Lygaeidae) were recorded as predacious species (Table 3).

A. mecrida was observed during the period from 10th May till 5th July, with the highest number of 17 individuals / sample on 21st June. *A. gutierreziae* was recorded from 19th April to 24th May, attained the highest number of 13 individuals / sample on 10th May. *L. dactylopii* was reported during the period from 26th April till 21st June, recording the highest value of 15 individuals / sample on 24th May. The mean numbers of *A. mecrida*, *A. gutierreziae* and *L. dactylopii* / sample during the whole season were 4.22, 2.17 and 3.56 individuals, successively.

Campylomma sp. was recorded during the period from 3rd May till 12th July, with the highest level of 23 individuals / sample on 21st June. *C. carnea* was reported during the period from 7th June to 12th July, recording the highest number of nine individuals / sample on 28th June. *C. undecimpunctata* was found during the period from 7th June till 12th July, attain the highest number of nine individuals / sample on 28th June. *Geocoris* sp. was recorded from 26th April to 21st June, recording its highest value of eight individuals / sample on 10th May. During the whole season, the mean numbers of *Campylomma* sp., *C. carnea*, *C. undecimpunctata* and *Gocoris* sp./sample were 6.83, 1.61, 3.28 and 1.78 individuals, respectively.

In the second season (2017), the same trend was noticed (Table 4). The infestation occurred during the period from 5th April till 2nd August. The number of nymphs was increased gradually to reach the highest level of 493 individuals / sample on 28th June. Then, the population was decreased gradually to record 34 individuals / sample on 2nd August. The adult population was increased to attain its highest number with 89 individuals / sample on 28th June. Thereafter, the number of the adults was decreased gradually to record nine individuals / sample on 2nd August. Concerning the total number of the mealybug, it increased gradually to reach the highest level of 582 individuals/sample on 28th June. The mean numbers of nymphs, adults and total population of the mealybug / sample during the whole season were 191.11, 39.39 and 230.50 individuals, successively.

The parasitoid, *A. mecrida* was recorded during the period from 10th May to 12th July, with the highest number of 28 individuals on 28th June (Table 4). *A. gutierreziae* was found during the period from 26th April till 7th June, recording the highest number of 11 individuals / sample on 24th May. *L. dactylopii* was reported during the period from 19th April till 28th June, with the highest value of 27 individuals / sample on 24th May. The mean numbers of *A. mecrida*, *A. gutierreziae* and *L. dactylopii* / sample during the whole season were 7.61, 2.72 and 7.11 individuals, respectively.

Table 3 : Seasonal abundance of *Phenacoccus solenopsis* Tinsley infested tomato and its associated natural enemies in Qaha (Qalyubya) in summer season during 2016.

Date	No. of Population			No. of Parasitoids			No. of Predators				Temp. °C		RH %
	Nymphs	Adults	Total	<i>A. mecrida</i>	<i>A. gutierreziae</i>	<i>L. dactylopii</i>	<i>Campylomma</i> sp.	<i>C. carnea</i>	<i>C. undecimpunctata</i>	<i>Geocoris</i> sp.	Max.	Min.	
Apr. , 5	14	35	49	0	0	0	0	0	0	0	30.6	18.0	54.8
12	34	27	61	0	0	0	0	0	0	0	25.3	15.3	44.5
19	50	23	73	0	1	0	0	0	0	0	33.3	17.1	51.2
26	62	29	91	0	5	4	0	0	1	1	40.7	20.0	43.8
May, 3	85	30	115	0	9	10	3	0	6	6	36.9	22.4	44.6
10	106	48	154	2	13	10	7	0	9	8	32.4	19.9	44.6
17	114	53	167	8	7	13	9	0	10	7	34.0	21.5	44.8
24	180	58	238	8	4	15	8	0	13	3	29.5	17.8	39.2
31	192	64	256	9	0	8	12	0	7	3	37.8	20.8	48.3
Jun. ,7	265	42	307	11	0	2	18	1	5	2	42.2	25.1	32.6
14	270	72	342	14	0	1	19	6	4	1	40.5	23.5	42.7
21	350	80	430	17	0	1	23	8	3	1	38.3	24.3	48.8
28	278	72	350	6	0	0	15	9	1	0	35.0	23.9	57.8
Jul. , 5	143	44	187	1	0	0	7	3	0	0	35.7	24.6	59.8
12	161	26	187	0	0	0	2	2	0	0	36.6	24.6	58.3
19	84	21	105	0	0	0	0	0	0	0	34.2	23.1	52.8
26	52	8	60	0	0	0	0	0	0	0	38.3	23.6	54.3
Aug. , 2	27	5	32	0	0	0	0	0	0	0	38.8	25.8	57.3
Total	2467	737	3204	76	39	64	123	29	59	32	640.1	391.3	880.0
Mean	137.06	40.94	178	4.22	2.17	3.56	6.83	1.61	3.28	1.78	35.6	21.7	48.9

Table 4 : Seasonal abundance of *Phenacoccus solenopsis* Tinsley infested tomato and its associated natural enemies in Qaha (Qalyubia) in summer season during 2017

Date	No. of Population			No. of Parasitoids			No. of Predators				Temp.°C		RH %
	Nymphs	Adults	Total	A. mecirida	A. gutierreziae	L. dactylopii	Campylomma sp.	C. carnea	C. undecimpunctata	Geocoris sp.	Max.	Min.	
Apr. , 5	27	38	65	0	0	0	0	0	0	0	31.7	15.5	53.3
12	45	19	64	0	0	0	0	0	0	0	30.0	16.0	55.6
19	56	22	78	0	0	3	0	0	0	0	33.6	15.3	54.2
26	74	24	98	0	3	7	0	0	0	1	31.6	14.1	56.7
May, 3	82	36	118	0	8	14	0	0	0	1	30.6	18.2	48.0
10	112	37	149	3	9	19	1	0	0	3	41.9	19.9	45.3
17	133	40	173	7	10	23	4	0	4	7	34.5	20.0	44.7
24	147	42	189	9	11	27	8	0	9	3	31.3	17.9	48.7
31	201	46	247	11	5	13	10	0	4	2	37.6	23.2	42.5
Jun. ,7	287	53	340	13	3	9	14	1	2	1	40.2	23.5	42.5
14	310	64	374	17	0	7	16	8	0	1	34.0	23.6	45.7
21	380	76	456	24	0	4	71	9	0	0	33.2	21.2	50.4
28	493	89	582	28	0	2	20	6	0	0	37.4	23.1	53.4
Jul. , 5	411	41	452	15	0	0	3	3	0	0	35.9	24.7	54.3
12	347	36	383	10	0	0	1	1	0	0	37.7	25.0	56.3
19	213	25	238	0	0	0	1	0	0	0	37.1	25.4	52.5
26	88	12	100	0	0	0	1	0	0	0	40.0	24.9	58.4
Aug. ,2	34	9	43	0	0	0	0	0	0	0	38.6	24.1	56.7
Total	3440	709	4149	137	49	128	150	28	19	19	636.9	375.6	919.4
Mean	191.11	39.39	230.50	7.61	2.72	7.11	8.33	1.56	1.06	1.06	35.40	20.90	51.10

The predator, *Campylomma* sp. (Table 4) was found during the period from 10th May till 26th July, with the highest value of 71 individuals/sample on 21st June. *C. carnea* was recorded during the period from 7th June till 12th July, recording the highest number of nine individuals / sample on 21st June. *C. undecimpunctata* was noticed during the period from 17th May to 7th June, with the highest value of nine individuals / sample on 24th May. *Geocoris* sp. was detected during the period from 26th April to 17th June, recording the highest number of seven individuals / sample on 17th May. The mean numbers of *Campylomma* sp., *C. carnea*, *C. undecimpunctata* and *Geocoris* sp. during the whole season were 8.33, 1.56, 1.06 and 1.06 individuals, successively.

No significant differences were recorded between the total population of the pest and each maximum and minimum temperature during the two seasons (Table 9). The correlation between the pest population and relative humidity was significant positive only during the second season ($r = 0.470$). The considered abiotic factors affected the mealybug populations by 50.55 and 33.26% during the first and second seasons, respectively.

(b) Nili seasons:

(i) In Atfih (Giza):

As shown in Table (5), in the first season (2016) the infestation occurred during the period extended from 17th September, 2016 till 14th January, 2017. The nymphal population was increased gradually, reaching the highest number of 2001 nymphs / sample on 3rd December. Then, the population was decreased gradually to reach 72 individuals / sample on 14th January. The adult population attained the highest value of 912 individuals / sample on 26th November. Thereafter, the population was decreased gradually, recording 14 individuals / sample on 14th January. The total population of the mealybug attained the highest value of 2634 individuals / sample on 3rd December. The mean

numbers of nymphs, adults and total population of the mealybug/sample during the whole season were 777.17, 330.78 and 1107.94 individuals, respectively.

The parasitoid, *A. arizonensis* was recorded during the period from 15th October till 14th January, recording the highest number of 52 individuals / sample on 10th December. *A. pseudococci* was found during the period from 29th October till 31st December, with the highest number of 16 individuals / sample on 12th November. *A. gutierreziae* was recorded during the period from 24th September to 24th December, reaching the highest value of 40 individuals / sample on 12th November. The mean numbers of *A. arizonensis*, *A. pseudococci* and *A. gutierreziae* / sample during the whole season were 17.83, 4.06 and 14.06 individuals, respectively.

S. syriacus was found during the period from 15th October till 3rd December, recording the highest value of 60 individuals/sample on 10th December. *C. carnea* was recorded during the period from 22nd October till 17th December, with the highest number of nine individuals/sample on 19th November. *C. undecimpunctata* occurred during the period from 1st October till 17th December, attained the highest value of 24 individuals/sample on 12th November. *O. laevigatus* was found during the period from 1st October till 3rd December, recording the highest number of 23 individuals/sample on 5th November. The mean numbers of *S. syriacus*, *C. carnea*, *C. undecimpunctata* and *O. laevigatus*/sample during the whole season were 17.61, 2.17, 6.50 and 5.00 individuals, successively.

Data obtained in Table (6) indicated that the same trend was observed in the second season (2017) as in the first one. The highest number of *P. solenopsis* nymphs was recorded on 3rd December, with 2476 nymphs/sample. Then, the population was decreased gradually to record 101 individuals/sample on 14th January. The adults population attained the highest value of 875 individuals/sample on 26th November. Afterwards, the population was decreased

gradually to reach 22 adults/sample on 14th January. The highest number of the total population occurred on 3rd December, with 3221 individuals/sample. Thereafter, the total population of the mealybug was decreased gradually, attained its lowest value of 123 individuals/sample on 14th January. The mean numbers of nymphs, adults and total population of *P. solenopsis*/sample during the whole season were 940.67, 358.89 and 1299.56 individuals, successively.

The parasitoid, *A. arizonensis* was recorded during the period from 15th October till the end of the season, with the highest value of 40 individuals / sample 10th December. *A. pseudococci* occurred during the period from 29th October till 10th December, recording its highest number of 13 individuals / sample on 12th November. *A. gutierreziae* was found during the period from 15th October till 24th December, with the highest value of 35 individuals/sample on 12th November. The mean numbers of *A. arizonensis*, *A.*

pseudococci and *A. gutierreziae*/sample during the whole season were 14.06 2.22 and 10.61 individuals, consecutively.

S. syriacus was found during the period from 22nd October till 7th January, with the highest number of 54 individuals/sample on 10th December. *C. carnea* was recorded during the period from 15th October till 17th December, recording its highest number of 14 individuals/sample on 5th November. *C. undecimpunctata* occurred during the period from 1st October till 24th December with the highest value of 32 individuals/sample on 12th November *O. laevigatus* was reported during the period from 1st October till 26th November, attained its highest value of 18 individuals/sample on 5th November. The mean numbers of *S. syriacus*, *C. carnea*, *C. undecimpunctata* and *O. laevigatus*/ sample during the whole season were 13.28, 3.83, 7.33 and 3.93 individuals, successively.

Table 5 : Seasonal abundance of *Phenacoccus solenopsis* Tinsley infested tomato and its associated natural enemies in Atfih (Giza) in nili season during 2016.

Date	No. of Population			No. of Parasitoids			No. of Predators				Temp.°C		RH%
	Nymphs	Adults	Total	<i>A. arizonensis</i>	<i>A. pseudococci</i>	<i>A. gutierreziae</i>	<i>S. syriacus</i>	<i>C. carnea</i>	<i>C. undecimpunctata</i>	<i>O. laevigatus</i>	Max.	Min.	
Sep.,17,2016	29	87	116	0	0	0	0	0	0	0	36.1	23.0	57.3
24	61	79	140	0	0	5	0	0	0	0	32.1	22.5	54.8
Oct., 1	185	65	250	0	0	9	0	0	2	4	32.5	23.1	55.3
8	213	90	303	0	0	12	0	0	8	9	32.1	22.0	62.3
15	550	102	652	9	0	17	7	0	10	10	32.0	20.1	60.9
22	860	389	1249	13	0	23	12	1	13	12	31.7	20.0	63.5
29	910	511	1421	17	9	26	15	1	17	19	30.4	20.0	67.2
Nov.,5	1024	589	1613	21	13	32	19	3	19	23	29.5	17.0	66.2
12	1462	742	2204	25	16	40	23	8	24	7	29.1	16.9	60.9
19	1570	856	2426	29	11	34	38	9	11	3	28.7	16.2	65.1
26	1612	912	2524	35	7	29	39	7	7	2	27.1	13.4	61.8
Dec.,3	2001	633	2634	48	6	14	44	6	3	1	25.2	12.7	50.5
10	1645	510	2155	52	4	6	60	3	2	0	23.4	11.5	68.5
17	880	147	1027	37	4	5	21	1	1	0	22.7	11.1	59.2
24	570	114	684	21	2	1	19	0	0	0	21.5	10.8	61.1
31	241	87	328	9	1	0	12	0	0	0	20.6	10.2	55.4
Jan.,7, 2017	104	27	131	4	0	0	6	0	0	0	19.7	9.5	58.3
14	72	14	86	1	0	0	2	0	0	0	19.5	9.2	71.0
Total	13989	5954	19943	321	73	253	317	39	117	90	493.9	289.2	1099.4
Mean	777.17	330.78	1107.94	17.83	4.06	14.06	17.61	2.17	6.50	5.00	27.4	16.1	61.1

Significant positive correlation between the total number of the mealybug and minimum temperature only was obtained in the second season where (r) value was 0.559 (Table 9). Relative humidities showed nonsignificant effects during both seasons. Maximum temperature, minimum temperature and relative humidity affected the pest populations by 30.75 and 39.43% during the first and second seasons, respectively.

(ii) In Qaha (Qalyubya):

Data obtained in Table (7) revealed that the infestation in the first season (2016) occurred during the period from 19th September, 2016 till 16th January, 2017. The nymphal population of *P. solenopsis* increased gradually to attain its highest value of 2981 nymphs/sample on 12th December, Afterward, the population was decreased gradually, recording 145 individuals / sample on 16th January, 2017. The highest number of the mealybug adults was recorded on 5th December, with 987 individuals / sample. Thereafter, the population was decreased gradually to reach its lowest value of 35 adults /sample on 16th January. The total population of

the mealybug was increased gradually to attain the highest value of 3640 individuals on 12th December. Then, the population was decreased gradually to record its lowest value of 180 individuals / sample on 16th January. The mean numbers of nymphs, adults and total population of the pest / sample during the whole season were 1150.11, 413.50 and 1563.61 individuals, consecutively.

The parasitoid, *A. mecrida* was recorded during the period from 10th October till the end of the season, attained the highest number of 89 individuals / sample on 5th December. *A. gutierreziae* occurred during the period from 17th December till 9th January, recording its highest value of 18 individuals / sample on 22nd November. *L. dactylopii* was recorded during the period from 12th December till 9th January, with the highest number of nine individuals / sample on 19th December. The mean numbers of *A. mecrida*, *A. gutierreziae* and *L. dactylopii* / sample during the whole season were 36.33, 5.61 and 1.44 individuals, respectively.

Campylomma sp. was found during the period from 4th October till 2nd January, with the highest number of 22

individuals / sample on 5th December. *C. carnea* was recorded during the period from 10th October till the end of the season, attained its highest number of 69 individuals / sample on 12th December. *C. undecimpunctata* was reported during the period from 7th November till the end of the season, recording the highest value of 25 individuals / sample on 12th November. *Geocoris* sp. was recorded only on 12th, 19th and 26th December and 16th January, with four individuals / sample on 19th December. The mean numbers of *Campylomma* sp., *C. carnea*, *C. undecimpunctata* and *Geocoris* sp. / sample during the whole season were 5.22, 24.22, 4.50 and 0.39 individuals, successively.

In the second season (2017), the same trend was observed (Table 8). *P. solenopsis* nymphs populations were

increased gradually, recording the highest number of 3120 nymphs / sample on 12th December. Then, the number of nymphs was decreased gradually to attain the lowest value of 124 individuals / sample on 16th January, 2018. The adults population was increased to reach its highest number of 856 individuals / sample on 15th December. Thereafter, the population was fluctuated with a general tendency to decrease, recording the lowest value of 12 individuals / sample on 16th January. The total population of the pest was increased gradually to record the highest number of 3830 individuals / sample on 12th December. The mean numbers of nymphs, adults and total population of the mealybug / sample during the season were 1223.06, 376.94 and 1600.00 individuals, respectively.

Table 7: Seasonal abundance of *Phenacoccus solenopsis* Tinsley infested tomato and its associated natural enemies in Qaha (Qalyubya) in nili season during 2016

Date	No. of Population			No. of Parasitoids			No. of Predators				Temp.°C		RH%
	Nymphs	Adults	Total	A. <i>mecrida</i>	A. <i>gutierreziae</i>	L. <i>dactylopii</i>	<i>Campylomma</i> sp.	<i>C. carnea</i>	<i>C. undecimpunctata</i>	<i>Geocoris</i> sp.	Max.	Min.	
Sep.,19,2016	78	110	188	0	0	0	0	0	0	0	35.4	22.3	57.1
26	124	75	199	0	0	0	0	0	0	0	31.4	21.9	51.6
Oct., 3	258	87	345	0	0	0	0	0	0	0	35.4	22.3	56.4
10	541	104	645	10	0	0	0	5	0	0	32.4	22.0	58.4
17	754	199	953	17	2	0	0	8	0	0	31.9	21.4	61.8
24	856	411	1267	26	2	0	1	16	0	0	30.9	20.2	62.3
31	1240	420	1660	42	5	0	2	19	0	0	28.6	19.0	67.6
Nov., 7	1357	580	1937	57	8	0	3	26	1	0	28.8	15.9	62.4
14	1765	650	2415	66	10	0	9	38	2	0	28.6	17.7	64.0
21	1873	745	2618	72	12	0	10	47	4	0	27.5	14.6	66.9
28	1895	823	2718	76	18	0	13	55	9	0	23.6	8.5	59.0
Dec., 5	2478	987	3465	89	14	0	22	61	13	0	23.1	11.5	59.2
12	2981	859	3840	60	10	7	17	69	25	0	21.5	8.4	72.4
19	2110	758	2868	52	9	9	10	40	10	4	19.2	9.0	65.2
26	1210	369	1579	45	7	5	5	23	8	1	18.7	10.2	65.2
Jan.,2,2017	650	175	825	19	3	3	2	17	4	1	18.1	5.0	58.9
9	387	56	443	13	1	2	0	9	4	0	15.1	8.9	60.6
16	145	35	180	10	0	0	0	3	1	1	21.6	10.0	62.9
Total	20702	7443	28145	654	101	26	94	436	81	7	471.8	268.8	1112.0
Mean	1150.11	413.50	1563.61	36.33	5.61	1.44	5.22	24.22	4.50	0.39	26.2	14.9	61.8

Table 8 : Seasonal abundance of *Phenacoccus solenopsis* Tinsley infested tomato and its associated natural enemies in Qaha (Qalyubya) in nili season during 2017

Date	No. of Population			No. of Parasitoids			No. of Predators				Temp.°C		RH%
	Nymphs	Adults	Total	A. <i>mecrida</i>	A. <i>gutierreziae</i>	L. <i>dactylopii</i>	<i>Campylomma</i> sp.	<i>C. carnea</i>	<i>C. undecimpunctata</i>	<i>Geocoris</i> sp.	Max.	Min.	
Sep.,19,2016	56	96	152	0	0	0	0	0	0	0	35.7	23.0	59.2
26	151	66	217	0	0	0	0	0	0	0	34.4	20.9	58.2
Oct., 3	325	81	406	0	0	0	0	0	0	0	32.2	21.5	56.0
10	451	95	546	8	0	0	0	0	0	0	29.2	18.6	55.3
17	682	187	869	12	1	0	0	2	0	0	30.6	16.9	57.5
24	784	425	1209	22	6	0	0	6	0	0	30.7	16.1	61.5
31	1255	433	1688	31	10	0	0	12	0	0	29.0	15.1	53.0
Nov., 7	1450	468	1918	45	11	0	1	15	0	0	27.0	13.6	60.8
14	1684	564	2248	57	14	0	6	18	1	0	27.8	12.4	61.2
21	1866	650	2516	65	21	0	7	23	2	0	21.6	13.6	66.9
28	1980	745	2725	66	25	0	10	46	5	0	24.6	10.3	67.5
Dec., 5	2544	856	3400	71	11	1	16	51	10	0	23.6	15.6	73.5
12	3120	710	3830	46	5	5	19	57	19	6	23.0	9.7	66.0
19	2650	745	3395	36	3	3	7	37	4	5	23.4	16.0	70.4
26	1492	410	1902	26	2	1	2	19	2	3	22.4	9.6	70.6
Jan.,2,2017	950	166	1116	15	1	2	0	14	0	2	20.0	8.8	67.9
9	451	76	527	10	0	0	0	5	0	1	23.5	10.7	65.6
16	124	12	136	8	0	0	0	2	0	1	21.0	8.3	65.6
Total	22015	6785	28800	518	110	12	68	307	43	18	479.7	260.7	1136.7
Mean	1223.06	376.94	1600.00	28.78	6.11	0.67	3.78	17.06	2.39	1.00	26.7	14.5	63.1

The parasitoid, *A. mecrida* was recorded during the period from 10th October till the end of the season, attained the highest value of 71 individuals/ sample on 5thDecember. *A. gutierreziae* was found during the period from 17th October till 2nd January, recording the highest number of 25 individuals / sample on 28th November. *L. dactylopii* was reported only during the period from 5th December till 2nd January, with the highest value of five individuals/sample on 12th December. The mean numbers of *A. mecrida*, *A. gutierreziae* and *L. dactylopii*/sample during the whole season were 28.78, 6.11 and 0.76 individuals, consecutively.

Campylomma sp. was found during the period from 7th November till 26th December, recording its highest value of 19 individuals / sample on 12th December. *C. carnea* was recorded during the period from 17th October till the end of the season, with the highest number of 57 individuals / sample on 12th December. *C. undecimpunctata* was observed

during the period from 14th November till 26th December, showing its highest value of 19 individuals / sample on 12th December. *Geocoris* sp. was recorded during the period from 12th December till the end of the season, with the highest number of six individuals / sample on 12th December. The mean numbers of *Campylomma* sp., *C. carnea*, *C. undecimpunctata* and *Geocoris* sp. / sample during the whole season were 3.78, 17.06, 2.39 and 1.00 individuals, respectively.

The correlation between maximum temperature and the pest population was significant negative only in the second season where (r) value was - 0.504 (Table 9). Relative humidities appeared highly significant and significant positive effects where (r) values were 0.621 and 0.558 in the first and second seasons, respectively. The considered climatic factors affected the mealybug populations by 51.85 and 35.35% during the first and second seasons, respectively.

Table 9 : Simple correlation between total numbers of *Phenacoccus solenopsis* Tinsley on tomato plantations and certain abiotic factors.

Location	Season	Considered weather factor	r	b	E.V %
Giza (Atfih)	Summer 2016	Max. Temp. °C	0.699**	0.00	75.95
		Min. Temp. °C	0.405	0.095	
		RH%	-0.025	0.921	
	Summer 2017	Max. Temp. °C	0.681**	0.002	60.74
		Min. Temp. °C	0.513*	0.030	
		RH%	-0.305	0.219	
	Nili 2016	Max. Temp. °C	0.341	0.166	30.75
		Min. Temp. °C	0.390	0.110	
		RH%	-.0255	0.307	
	Nili 2017	Max. Temp. °C	0.236	0.346	39.43
		Min. Temp. °C	0.559*	0.016	
		RH%	-0.189	0.452	
Qalyubya (Qaha)	Summer 2016	Max. Temp. °C	-0.018	0.945	50.55
		Min. Temp. °C	-0.190	0.450	
		RH%	0.160	0.527	
	Summer 2017	Max. Temp. °C	-0.101	0.690	33.26
		Min. Temp. °C	-0.129	0.610	
		RH%	0.470*	0.049	
	Nili 2016	Max. Temp. °C	-0.324	0.189	51.85
		Min. Temp. °C	-0.440	0.067	
		RH%	0.621**	0.006	
	Nili 2017	Max. Temp. °C	Io9	0.033	35.35
		Min. Temp. °C	-0.376	0.124	
		RH%	0.588*	0.010	

*This difference is considered to be statistically significant.

**This difference is considered to be statistically highly significant.

During the present study it was found that the highest populations of *P. solenopsis* infesting tomato plantations in Atfih and Qaha regions during the summer seasons was recorded at temperatures ranged between 29.5 to 42.2°C and relative humidities of 30.8 to 59.0% RH. During the nili seasons, the highest population of the mealybug occurred at temperatures of 18.1 to 35.4°C and relative humidities of 46.6 to 73.5% RH. Different findings were obtained by several workers. Kumar *et al.* (2013) stated that 35 ± 1°C and 65% RH is the most favorable temperature and relative humidity combination for the optimal growth of *P. solenopsis*. They results also predicts the expansion of this pest to other parts of world in which the average temperature equals to 35°C with 65% RH. The maximum development of

P. solenopsis occurred at 35°C (Amarasekare *et al.*, 2008). Sreedevi *et al.* (2013) studied several experiments designed to investigate the effect of temperature and relative humidity on the development of *P. solenopsis*. They mentioned that at high temperatures, it completes a life cycle approximately twice as fast as compared to lower temperatures. The estimated bioclimatic thresholds and the observed survival rates of *P. solenopsis* indicate the species to be high-temperature adaptive and explained the field abundance of *P. solenopsis* on it host plants. Among mealybug species, *P. solenopsis* could successfully complete its development at 15°C and the survival of *P. solenopsis* was greatly reduced at this lower temperature. According to Nabil (2017), *P. solenopsis* had four and three peaks on eggplant during two

successive seasons. Maximum temperature, minimum temperature and relative humidity showed positive significant relationship with the mealybug population. *P. solenopsis* had three generations in the season. The mealybug preferred the lower leaf surface than the upper one. Abd El-Razzik (2018) mentioned that *P. solenopsis* showed two peaks and presence of three overlapping generations on mulberry trees in both years under field conditions. The favorable time for its abundance on mulberry branches occurred in early and late summer season due to the high temperature, whereas decrease until disappear during the winter season referred to the cold weather. The simple correlation between the mealybug populating and maximum and minimum temperatures was positive and high significant, but RH gave negative and insignificant effect. Nabil and Hegab (2019) revealed that *P. solenopsis* had two to three generations on okra plants during the first and second seasons, respectively. There was significant positive correlation between maximum temperature and the population of mealybug females. Relative humidity showed significant negative effect on the females populations.

In the present work, five parasitoid and six predator species were recorded. The parasitoids were *A. arizonensis* (*A. bambawalei* Hayat), *A. gutierreziae*, *L. dactylopii*, *A. mecrida* and *A. pseudococci*. The predators ones were *Campylomma* sp., *C. carnea*, *C. undecimpunctata*, *Geocoris* sp., *O. laevigatus* and *S. syriacus*. *A. arizonensis* was the most abundant parasitoid species. These findings are in agreement with those of Bharathi and Muthukrishnan (2017). They stated that the solitary endoparasitoid, *A. bambawalei* was found as one of the key regulating factor for the mealybug, despite harbouring 11 different hyperparasitoids. According to Sihet *et al.* (1998), multiple natural enemy species can cause interactions in predators and prey by reducing or increasing risk for the prey. Population of coccinellids was maximum followed when compared to chrysopids. Predators such as coccinellids, *C. carnea*, *Spalgisepius* (Westwood) (Lepidoptera: Lycaenidae) and parasitoids of encyrtids and unidentified eulophid were recorded as natural enemies against *P. solenopsis* in cotton ecosystem of surveyed areas. *C. carnea* has effectively been used and thus has been proved to be a voracious predator of the cotton mealybug (Sattaret *et al.*, 2007). Rabinder *et al.* (2008) reported that larvae of *C. carnea* were found to consume 30 mealybug eggs daily in developmental laboratory test. Rishikumar *et al.* (2009) revealed that the parasitization efficiency of the parasitoid, *A. bambawalei* from field collected mealybugs was 57.2% (range 46-64%) whereas under laboratory conditions, it was 60.6% (range 45-74%). The species of Coccinellidae were the predominant predators, followed by the species of Chrysopidae. Role of Coccinellidae and Chrysopidae in natural biological control of *P. solenopsis* has been widely recognized (Kedar *et al.*, 2011). Khan *et al.* (2012) stated that *C. carnea* and *Cryptolaemusmontrouzieri* predators show strong predatory potential against *P. solenopsis*, being the most ravenous feeder. Moreover, prey stages also had a considerable effect on consumption rate, development and fecundity. Attia *et al.* (2016) surveyed the predators, parasitoids and hyperparasitoids associated with nymphal and adult stages of *P. solenopsis* infesting five ornamental host plants and six weeds. They recorded six predacious species, two endoparasitoids and four hyperparasitoids. The predacious species were *Hyperaspisvinciguerrae* Capra, *S. syriacus*, *Nephus* (*Sides*) *hiekei* Fursch (Coccinellidae),

Dicrodiplosismanihoti Harris (Cecidomyiidae), *C. carnea*, *Symphorobius amicus* Navas (Hemerobiidae) and *Oriusalbidipennis* (Reuter). The primary parasitoids were *A. gutierreziae* and *Chartocerusdactylopii* (Ashmead). Abd El-Razzik (2018) recorded three predacious and two primary parasitoid species associated with the cotton mealybug on mulberry tress. The predators were *H. vinciguerrae*, *D. manihoti* and *S. syriacus*. The parasitoids ones were *A. gutierreziae* and *C. dactylopii*. Nabil and Hegab (2019) recorded *A. arizonensis* as a primary parasitoid of *P. solenopsis* infesting okra plants. Substantially, good deal of natural enemies, both the predators and parasitoids were found associated with the field population of *P. solenopsis*, indicating great potential for environmental friendly natural biological control. It is concluded that *P. solenopsis* population was affected by abiotic factors (temperature and relative humidity) than biotic ones (parasitoids and predators).

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