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Research Article
Aphytis lepidosaphes (Hymenoptera: Aphelinidae) as an Effective Parasitoid for Controlling the *Lepidosaphes tapleyi* (Williams)

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Abstract

Background and Objective: The guava long scale insect *Lepidosaphes tapleyi* (Williams) (Hemiptera: Diaspididae) is considered one of the main destructive pests of guava around the world. Biological control represents a sustainable alternative for saving control of *L. tapleyi*. The main objective of the present work was to study the seasonal activity and evaluate the impacts of climatic factors on populations of the parasitoid, *Aphytis lepidosaphes*, during two successive years (2017/2018 and 2018/2019) in Esna district, Luxor Governorate, Egypt. **Materials and Methods:** Estimation of the relationship between the population density of *L. tapleyi* and *A. lepidosaphes* activity, by using different models of correlation and regression analyses. The estimate of the effects of climatic factors (daily mean max. temp., min. temp., mean of % relative humidity and mean of dew point) on seasonal activity of the parasitoid, *A. lepidosaphes*, during two successive years (2017/2018 and 2018/2019). **Results:** The results showed that the relationship between the population density of *L. tapleyi* and *A. lepidosaphes* activity was positive during both years. Furthermore, simple regression analysis indicated that the abundance of *A. lepidosaphes* was more highly correlated with the *L. tapleyi* population density in each whole year during the two successive years. The percentages of explained variance EV (%) indicated that all tested variables, i.e. daily mean maximum temperature, minimum temperature, relative humidity and dew point were responsible for 76.26 and 65.40% of the changes in parasitoid, respectively. Furthermore, the dew point was the most effective variable for the change in the parasitoid populations by 33.61 and 18.62%. **Conclusion:** The results showed that *A. lepidosaphes* had three peaks of seasonal abundance over the entire year. As well, the activity of *A. lepidosaphes* was more highly correlated with the *L. tapleyi* population size over the two successive years.

Key words: *Aphytis lepidosaphes*, *Lepidosaphes tapleyi*, seasonal activity, parasitoid, environmental conditions

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Guava trees are subject to infestation by different insect pests, the guava long scale insect *Lepidosaphes tapleyi* (Williams) (Hemiptera: Diaspididae) is considered one of the main destructive pests. This pest injures the shoots, twigs, leaves, branches and fruits by sucking the plant sap, causing deformation, defoliation, drying of young twigs, dieback, impaired blossoming and twig death through the action of their toxic saliva. A characteristic symptom of infestation by this pest is the appearance and accumulation of its scales on the parts of the guava plants that have been attacked[1]. Control of these pests by applying chemical insecticides is a rapid and simple means for reducing their population density. However, the use of pesticides affects their population density. However, the use of pesticides comes with many problems, including toxic effects on humans and other animals as well as beneficial insects. Pesticides also negatively affect the soil fauna through their accumulation in the soil. In Egypt, however, the hard scale insects control (Hemiptera: Diaspididae) mainly relies on the application of the use of pesticides, such as organophosphates or mineral oils, especially during severe infestations in the summer[2,3].

Parasitoids can act as natural enemies in integrated pest management programs for the control of scale insects. *Aphytis* Howard (Hymenoptera: Aphelinidae) develop exclusively as primary ectoparasitoids of armored scale insects and are usually the most abundant and effective natural enemies for the control of these serious pests. Several species of *Aphytis* have been successfully employed for biological control against economically important armored scale insects. The diversity of *Aphytis* has been reported previously[4,5]. *A. lepidosaphes* Compere (Hymenoptera: Aphelinidae) is one of the most important bioagents for controlling the purple scale in different parts of the world[6,7].

The objective of the present study was to investigate the seasonal activity and effects of environmental factors on populations of the parasitoid *A. lepidosaphes* over two successive years (2017/2018 and 2018/2019) in Esna district, Luxor Governorate.

MATERIALS AND METHODS

Study area: Assessing the efficacy of *A. lepidosaphes* for controlling *L. tapleyi* infesting guava trees in a private orchard of about one feddan was carried out in Esna district, Luxor Governorate during two successive years (2017/2018 and 2018/2019).

Population density of *L. tapleyi*: Four guava trees of the balady variety, almost uniform in age, size, shape, height and vegetative growth were selected. Half-monthly samples were taken randomly from different directions and stratums of each tree at a rate of 40 leaves /tree The samples were immediately transferred to the laboratory in polyethylene bags for inspection using a stereo microscope. Live insects on the upper and lower surfaces of the guava leaves were counted and recorded with the inspection date.

Seasonal abundance of *A. lepidosaphes*: *Aphytis lepidosaphes* were examined, identified, counted and recorded based on the half-monthly counts of parasitized scale insects with larvae and pupae of *A. lepidosaphes* for each inspection date (not the emerged wasps). The specimens of scale insects were placed in glass jars and kept at 21-25°C and 60-65% RH to secure any emerging parasitoids. Different stages of parasitoid were identified by the specialists in the Biological Control Research Department, Plant Protection Research Institute, Agricultural Research Centre, Egypt.

The dissected scales were classified as either non-parasitized scale insects or parasitized scale insects. On each collection date, the seasonal activity of *A. lepidosaphes* was recorded and the percentage of parasitism was calculated according to the Eq[8,9]:

$$\text{Parasitism (\%)} = \frac{\text{Number parasitized scale insects}}{\text{Total number parasitized and non-parasitized scale insects}} \times 100$$

Main weather factors may affect the total population of this parasitoid. Therefore, meteorological data (daily mean max. temp., min. temp., mean of % relative humidity and mean of dew point °C) for conditions of Luxor governorate were obtained from the Central Laboratory for Agricultural Climate, Agriculture Research Center, Ministry of Agriculture in Giza. The altitude, latitude and longitude of this region of Luxor were 99 m, 25.67°N and 32.71°E, respectively.

All obtained data were depicted graphically in Microsoft Excel 2010 according to the results of the simple correlation, regression coefficient and the partial regression formula which was adopted to determine the simultaneous effects of tested weather factors on the population density of *A. lepidosaphes* on *L. tapleyi*. The partial regression method, termed the C-multipliers, was adopted according to a method mentioned in a previous study[10]. Statistical analysis was carried out using MSTATC to determine the preferable time for the parasitoid activity[11].

RESULTS

Seasonal abundance of *Aphytis lepidosaphes*: The mean population of *A. lepidosaphes* per *L. tapleyi* leaf was 2.49±0.19 and 2.00±0.17 individuals during 2017/2018 and 2018/2019, respectively. The mean number of larvae per leaf was (1.67±0.14 and 1.32±0.11) individuals and (0.82±0.07 and 0.68±0.07) for the pupae of *A. lepidosaphes* during 2017/2018 and 2018/2019, respectively, Table 1 and 2.

Results also showed that the highest population density of *A. lepidosaphes* was in autumn of 2017/2018 and 2018/2019 for the larval stage (3.03±0.30 and 2.91±0.10 individuals/leaf, respectively), pupal stage (1.19±0.08 and 1.44±0.15 individuals/leaf, respectively) and total mixed population (4.22±0.33 and 4.35±0.21 individuals/leaf, respectively) compared with that in the other seasons.

Results also showed that the total number of *A. lepidosaphes* exhibited four peaks of activity in 2018/2019 namely: Mid-April, mid-August, mid-September and beginning of November, at 1.81±0.16, 3.27±0.25, 4.65±0.38 and 5.58±0.39 individuals per leaf, respectively, Table 1 and Table 2.

Percentage of parasitism: The results shown in Table 1, indicated that four peaks in the percentage of parasitism were recorded in 2017/2018 in mid-April, (12.37%), beginning of July, (15.94%), mid-August, (16.22%) and beginning of January, (15.85%). During 2018/2019 as recorded in Table 1, the highest percentage of parasitism was recorded in mid-April, (6.43%), beginning of July, (7.93%), mid-August, (10.93%), beginning of October, (10.83%) and beginning of January, (8.12%).

Density-dependent relationship: The density-dependent response was determined for *A. lepidosaphes* during spring, summer, autumn and winter over 2017/2018 and 2018/2019. By plotting the abundance of *A. lepidosaphes* against the population density of *L. tapleyi*, the regression analysis indicated that the abundance of *A. lepidosaphes* (Y) was more highly correlated with the population density of *L. tapleyi* (X) during all seasons are presented in Table 3. The density relationship could be represented by the following sub-models:

In the first year (2017/2018):

- Y = 0.77-0.01x EV =1.51% spring
- Y = -1.37+0.19x EV = 37.92% summer
- Y = 1.96+0.06x EV = 11.15% autumn
- Y = 0.27+0.13x EV = 83.46% winter
- Y = -0.0002+0.11x EV = 55.54% whole year

In the second year (2018/2019):

- Y = -0.14+0.05x EV = 55.64% spring
- Y = 0.04+0.08x EV = 49.13% summer
- Y = 0.68+0.09x EV = 84.57% autumn
- Y = -0.80+0.11x EV = 67.95% winter
- Y = -0.84+0.11x EV = 87.37% whole year

Effect of the main climatic factors on the total population density of *A. lepidosaphes*

A-Effect of daily mean maximum temperature: The simple correlation analysis results are shown in Table 4 and indicated a significant positive correlation between the daily mean maximum temperature and *A. lepidosaphes* population in the first year (r = 0.43) and a non-significant positive correlation (r = 0.27) in the second year. The unit effect regression coefficient (b) indicated that an increase of 1°C in the daily mean maximum temperature, would increase the population of *A. lepidosaphes* by 0.12 and 0.07 individuals/leaf in 2017/2018 and 2018/2019, respectively.

The partial regression analysis indicated a significant negative correlation between daily mean maximum temperature and *A. lepidosaphes* population (P. reg. was -0.78) in the first year and a non-significant negative correlation (-0.20) in the second year. Furthermore, the partial correlation values were -0.50 and -0.15 and t-test values were -2.51 and -0.67 when the mean daily minimum temperature, mean relative humidity and the dew point was around their means during the first and second years, respectively (Table 4).

B-Effect of daily mean minimum temperature: Results are presented in Table 4 indicated a significant positive correlation (r = 0.42) between the daily mean minimum temperature and the population density of *A. lepidosaphes* during the first year and a non-significant positive correlation (0.38) in the second year. Furthermore, the calculated regression coefficient (b) for the effect of this factor indicated that every 1°C increase in the daily mean minimum temperature, would increase the population by 0.12 and 0.10 individuals/leaf in 2017/2018 and 2018/2019, respectively.

The precise effect of this factor on the *A. lepidosaphes* population (Table 4) indicated a non-significant positive correlation (P. reg. value was 0.03) in the first year and a non-significant negative correlation (P. reg. was -0.43) in the second year. Furthermore, the values of partial correlation

Table 1: Means of half monthly counts of different stages of the parasitoid, *A. lepidosaphes* parasited on the guava long scale insect, *L. tapleyi* on guava leaves, with climatic factors affecting during 2017/2018 year

		Parasitic stage						Climatic factors			
Season	Date of inspection	Larvae	Pupa	Total	Non parasitized	Total	Parasitism (%)	Max. temp.	Min. temp.	RH (%)	Dew point
Spring	March, 2017										
	1	0.23±0.02	0.06±0.01	0.29±0.03	8.34±0.40	8.63±0.43	3.33	25.86	12.07	41.36	4.64
	15	0.27±0.01	0.12±0.01	0.39±0.01	10.49±0.50	10.89±0.51	3.62	27.21	11.43	30.07	4.36
	April										
	1	0.43±0.04	0.09±0.01	0.51±0.05	15.52±0.75	16.04±0.78	3.21	28.82	15.29	32.41	5.24
	15	1.17±0.07	0.33±0.02	1.49±0.09	10.59±0.51	12.09±0.58	12.37	30.29	16.43	25.14	6.64
	May										
	1	0.47±0.04	0.23±0.02	0.70±0.06	11.54±0.55	12.24±0.60	5.73	34.06	18.13	19.19	6.38
	15	0.46±0.04	0.06±0.01	0.53±0.05	24.93±1.22	25.46±1.25	2.06	35.86	20.5	18.07	7.43
Average		0.50±0.07	0.15±0.02	0.65±0.09	13.57±1.18	14.22±1.17	4.59	30.35	15.64	27.71	5.78
Summer	June										
	1	0.45±0.05	0.20±0.02	0.65±0.07	16.81±0.82	17.45±0.87	3.71	38.41	22.12	18.29	9.35
	15	0.63±0.04	0.44±0.03	1.07±0.07	13.75±0.67	14.82±0.72	7.25	41.07	25.57	17.21	10.86
	July										
	1	2.03±0.11	2.11±0.11	4.14±0.22	21.83±1.05	25.97±1.22	15.94	39.25	24.5	19.56	11.63
	15	1.74±0.12	0.47±0.03	2.21±0.15	28.69±1.40	30.89±1.52	7.14	41.7	25.3	19.79	12.79
	August										
	1	1.24±0.09	1.46±0.10	2.70±0.19	20.24±1.01	22.93±1.16	11.75	41.82	28.18	20.06	13.65
	15	2.17±0.16	2.84±0.22	5.00±0.38	25.84±1.26	30.84±1.56	16.22	40.9	27.7	20.86	14.07
Average		1.38±0.14	1.25±0.21	2.63±0.33	21.19±1.12	23.82±1.35	11.03	40.53	25.56	19.3	12.06
Autumn	September										
	1	4.67±0.44	0.93±0.09	5.61±0.53	32.40±1.61	38.01±2.03	14.75	42.06	27.47	21.71	14.88
	15	3.83±0.32	1.69±0.14	5.51±0.46	34.19±1.69	39.70±2.04	13.89	40.29	24.43	23.64	14.07
	October										
	1	4.27±0.29	1.02±0.07	5.30±0.36	47.98±2.36	53.27±2.63	9.94	39.69	23.81	25.5	14.31
	15	1.55±0.12	0.87±0.07	2.42±0.18	31.94±1.57	34.36±1.71	7.03	38.57	22.64	25.64	13
	November										
	1	1.11±0.08	0.92±0.07	2.03±0.14	32.47±1.59	34.50±1.70	5.88	37.59	21.12	26.94	12.41
	15	2.73±0.08	1.72±0.14	4.45±0.21	52.33±2.57	56.78±2.55	7.84	33	17	33.64	11.71
Average		3.03±0.30	1.19±0.08	4.22±0.33	38.55±1.87	42.77±2.02	9.87	38.53	22.75	26.18	13.4
Winter	December										
	1	3.61±0.26	1.15±0.08	4.76±0.35	38.10±1.90	42.85±2.17	11.1	31.69	16.13	35.88	10.69
	15	2.36±0.18	1.06±0.08	3.42±0.26	18.83±0.94	22.25±1.15	15.39	25.64	10.57	38.5	6.79
	January, 2018										
	1	2.05±0.21	0.70±0.07	2.75±0.28	14.59±0.73	17.34±0.96	15.85	25.24	8.94	39.82	5.06
	15	1.52±0.16	0.87±0.09	2.38±0.25	13.22±0.66	15.60±0.86	15.28	22.07	7.36	48.29	6.21
	February										
	1	0.74±0.08	0.23±0.03	0.97±0.11	8.45±0.42	9.42±0.51	10.31	23.29	8.24	45.88	5.82
	15	0.35±0.04	0.07±0.01	0.42±0.05	7.72±0.38	8.14±0.42	5.21	26.57	12.57	44.36	7.36
Average		1.77±0.23	0.68±0.09	2.45±0.31	16.82±2.16	19.27±2.45	12.72	25.75	10.63	42.12	6.99
Total		40.07	19.64	59.71	540.77	600.48	224.8				
Mean		1.67±0.14	0.82±0.07	2.49±0.19	22.53±1.28	25.02±1.42	9.37				

Table 2: Means of half monthly counts of different stages of the parasitoid, *A. lepidosaphes* parasited on the guava long scale insect, *L. tapleyi* on guava leaves, with climatic factors affecting during 2018/2019

		Parasitic stage						Climatic factors			
Seasons	Date of inspection	Larvae	Pupa	Total	Non parasitized	Total	Parasitism (%)	Max. temp.	Min. temp.	RH (%)	Dew point
Spring	March, 2018										
	1	0.31±0.03	0.08±0.01	0.39±0.04	7.77±0.39	8.16±0.42	4.78	27.79	11	28.86	4.86
	15	0.38±0.01	0.17±0.01	0.55±0.01	11.25±0.55	11.80±0.56	4.66	31	13.57	24.93	6.14
	April										
	1	0.61±0.06	0.17±0.02	0.79±0.08	16.63±0.81	17.41±0.87	4.51	31.94	15.12	24.71	7
	15	1.22±0.11	0.59±0.05	1.81±0.16	26.36±1.28	28.17±1.40	6.43	32.93	16	21.93	6.71
	May										
	1	0.57±0.06	0.06±0.01	0.62±0.07	23.45±1.14	24.07±1.19	2.59	33.38	17.31	19.94	6.94
	15	0.51±0.05	0.07±0.01	0.58±0.05	17.06±0.83	17.65±0.87	3.29	38.5	21.79	16.57	9.14
Average		0.60±0.07	0.19±0.04	0.79±0.10	17.09±1.38	17.88±1.45	4.42	32.59	15.8	22.82	6.8
Summer	June										
	1	0.40±0.04	0.18±0.02	0.58±0.06	15.04±0.74	15.62±0.79	3.71	40.82	23.65	16.35	9.94
	15	0.48±0.03	0.33±0.02	0.81±0.06	12.89±0.64	13.70±0.68	5.9	43	25.64	15.64	11.21
	July										
	1	1.29±0.07	0.44±0.02	1.74±0.09	20.16±0.98	21.90±1.05	7.93	40.06	25	21.88	13.31
	15	1.71±0.12	0.46±0.03	2.17±0.15	38.11±1.84	40.28±1.95	5.38	39.5	25.79	26.21	15.57
	August										
	1	1.09±0.08	1.28±0.09	2.36±0.17	26.28±1.29	28.64±1.42	8.25	39.41	25.12	23.41	14.06
	15	1.41±0.11	1.85±0.14	3.27±0.25	26.62±1.29	29.89±1.48	10.93	40.71	23.5	22.36	14
Average		1.06±0.10	0.76±0.13	1.82±0.20	23.19±1.81	25.01±1.95	7.28	40.59	24.78	20.98	13.02
Autumn	September										
	1	2.49±0.23	0.50±0.05	2.99±0.28	32.28±1.59	35.27±1.80	8.47	39.71	25.59	25.35	15.41
	15	3.17±0.26	1.48±0.12	4.65±0.38	51.11±2.49	55.76±2.78	8.34	38.64	25.64	27.36	15.57
	October										
	1	3.14±0.21	0.75±0.05	3.89±0.26	32.04±1.56	35.94±1.75	10.83	38.75	23.88	28.25	14.88
	15	2.51±0.19	1.41±0.10	3.92±0.29	37.77±1.84	41.69±2.07	9.4	34.36	18.86	30.43	11.93
	November										
	1	3.04±0.21	2.54±0.18	5.58±0.39	54.86±2.67	60.44±2.97	9.24	31.81	17.69	35.56	11.94
	15	3.10±0.09	1.96±0.16	5.06±0.24	48.84±2.40	53.90±2.36	9.39	30.43	15.43	39.36	11.57
Average		2.91±0.10	1.44±0.15	4.35±0.21	42.82±2.06	47.17±2.24	9.22	35.62	21.18	31.05	13.55
Winter	December										
	1	1.58±0.11	0.50±0.04	2.08±0.15	23.39±1.15	25.46±1.27	8.16	28.75	13.69	45.06	11.69
	15	0.88±0.07	0.40±0.03	1.28±0.10	17.06±0.85	18.35±0.92	6.98	24.93	11.64	45.79	9.29
	January, 2019										
	1	0.75±0.08	0.78±0.08	1.53±0.16	17.27±0.87	18.80±0.99	8.12	22.35	7.53	46.18	5.88
	15	0.38±0.04	0.22±0.02	0.60±0.06	16.64±0.84	17.24±0.89	3.48	23.43	8.93	49.07	7.36
	February										
	1	0.34±0.04	0.11±0.01	0.45±0.05	15.48±0.78	15.93±0.81	2.82	25.82	8.41	32.35	4.41
	15	0.28±0.03	0.06±0.01	0.34±0.04	7.65±0.38	7.98±0.41	4.2	25.36	8.79	35.36	5.29
Average		0.70±0.10	0.34±0.05	1.05±0.14	16.25±1.01	17.29±1.12	6.04	25.11	9.83	42.3	7.32
Total		31.65	16.38	48.03	596.02	644.06	157.82				
Mean		1.32±0.11	0.68±0.07	2.00±0.17	24.83±1.36	26.84±1.51	6.58				

Table 3: Different models of correlation and regression analyses for describing the synchronization between *L. tapleyi* population and the parasitoid, *A. lepidosaphes* population in 2017-2019

Year	Tested seasons	Simple correlation and regression values a	r	b	SE	t	Analysis variance F-values	R^2	EV (%)
2017/2018	Spring	0.77	0.12	-0.01	0.04	-0.25	0.06	0.02	1.51
	Summer	-1.37	0.62	0.19	0.12	1.56	2.44	0.38	37.92
	Autumn	1.96	0.33	0.06	0.08	0.71	0.5	0.11	11.15
	Winter	0.27	0.91	0.13	0.03	4.49**	20.18**	0.83	83.46
	Whole year	-0.0002	0.75	0.11	0.02	5.24**	27.48**	0.56	55.54
2018/2019	Spring	-0.14	0.75	0.05	0.02	2.24	5.02	0.56	55.64
	Summer	0.04	0.7	0.08	0.04	1.97	3.86	0.49	49.13
	Autumn	0.68	0.92	0.09	0.02	4.68**	21.92**	0.85	84.57
	Winter	-0.8	0.82	0.11	0.04	2.91*	8.48*	0.68	67.95
	Whole year	-0.84	0.93	0.11	0.01	12.34**	152.21**	0.87	87.37

r: Simple correlation, b: Simple regression, R^2: Coefficient of determination, EV (%): Explained variance, S.E: Standard error, *Significant at $p \leq 0.05$ and **Highly significant at $p \leq 0.01$

were 0.03 and -0.29 and the values of the t-test were 0.14 and -1.34 when the daily mean maximum temperature, mean relative humidity and dew point were around their means in 2017/2018 and 2018/2019, respectively. The results revealed that the daily mean minimum temperature was within the optimum range of *A. lepidosaphes* activity in the first year and around the optimum range of *A. lepidosaphes* population in the second year. This climate factor was the least effective variable for population changes in *A. lepidosaphes* by 0.02% in the first year and was responsible for certain changes in the *A. lepidosaphes* population by 3.26% in the second year.

C-Effect of mean relative humidity: As shown in Table 4, the correlation between relative humidity and the *A. lepidosaphes* population was no significant and negative (r = -0.15) in the first year and no significant and positive (r = 0.14) in the second year. Furthermore, the simple regression coefficient indicated that an increase of 1% in the mean relative humidity would decrease the population of *A. lepidosaphes* by 0.03 individuals/leaf in the first year and would increase the population of the parasitoid by 0.02 individuals/leaf in the second year. The real effect of this factor appeared from the partial regression values, which showed that the effect of relative humidity on *A. lepidosaphes* activity was significantly negative (P. reg. was -0.23) in the first year and no significantly negative (-0.19) in the second year. Furthermore, the partial correlation values were -0.49 and -0.36 and the t-test values were -2.43 and -1.67 when the mean daily maximum temperature, mean daily minimum temperature and dew point was around their means in 2017/2018 and 2018/2019 respectively (Table 4).

D-Effect of mean dew point: The results shown in Table 4 indicate that the effect of mean dew point on *A. lepidosaphes* activity was highly significantly positive (r = 0.72 and 0.69) during 2017/2018 and 2018/2019, respectively. Furthermore, the regression coefficient (b) for the effect of this factor indicated that, for every 1°C increase, the population of *A. lepidosaphes* would increase by 0.37 and 0.30 individuals/leaf in 2017/2018 and 2018/2019, respectively.

The partial regression coefficient values for the effect of mean dew point on the *A. lepidosaphes* population are shown in Table 3 and indicated a highly significant positive correlation (P. reg. values were 1.24 and 1.06) in 2017/2018 and 2018/2019, respectively. Furthermore, the partial correlation values were 0.77 and 0.59 and the t-test were 5.20 and 3.20 when the daily mean maximum temperature, minimum temperature and relative humidity were around their means in 2017/2018 and 2018/2019, respectively (Table 4).

E-Combined effect of the four factors on total population activity of *A. lepidosaphes*: The results showed that the combined effect of these tested factors on *A. lepidosaphes* activity was highly significant where the f-values were 15.26 and 8.98 in 2017/2018 and 2018/2019, respectively (Table 4). The multiple regression analysis revealed that the tested variables together were responsible for the changes in the *A. lepidosaphes* population. The percentages of explained variance (EV%) were 76.26 and 65.40% in 2017/2018 and 2018/2019, respectively. The remaining unexplained variance was assumed to be due to the influence of other unconsidered and undetermined factors that were not included in the present study in addition to the experimental error.

Table 4: Different models of correlation and regression analyses for describing the relationship between main weather factors and the total population of the parasitoid, *A. lepidosaphes* during 2017/2018 and 2018/2019

		Sample correlation and regression values				Partial correlation and regression values						Analysis variance			
Years	Tested factors	r	b	SE	t	P. cor.	P. reg.	SE	t	Efficiency (%)	Rank	F-values	MR	R^2	EV (%)
2017/2018	Max. temp	0.43	0.12	0.05	2.21*	-0.5	-0.78	0.31	-2.51*	7.79	2	15.26**	0.87	0.76	76.26
	Min. temp	0.42	0.12	0.05	2.19*	0.03	0.03	0.21	0.14	0.02	4				
	RH (%)	-0.15	-0.03	0.04	-0.71	-0.49	-0.23	0.09	-2.43*	7.33	3				
	Dew point	0.72	0.37	0.08	4.92**	0.77	1.24	0.24	5.20**	33.61	1				
2018/2019	Max. temp	0.27	0.07	0.05	1.3	-0.15	-0.2	0.3	-0.67	0.8	4	8.98**	0.81	0.65	65.4
	Min. temp	0.38	0.1	0.05	1.95	-0.29	-0.43	0.32	-1.34	3.26	3				
	RH (%)	0.14	0.02	0.03	0.68	-0.36	-0.19	0.12	-1.67	5.06	2				
	Dew point	0.69	0.3	0.07	4.47**	0.59	1.06	0.33	3.20**	18.62	1				

r: Simple correlation, b: Simple regression, R^2: Coefficient of determination, EV%: Explained variance, SE: Standard error, P. cor.: Partial correlation, MR: Multiple correlations, P. reg.: Partial regression, *Significant at $p \le 0.05$ and **Highly significant at $p \le 0.01$

DISCUSSION

During the investigation, it was observed that the parasitoid played an important role in controlling this pest under field conditions during 2017/2018 and 2018/2019 at Esna district, Luxor Governorate. In 2017/2018, the mean total population of *A. lepidosaphes* exhibited four peaks of activity in mid-April, beginning of July, beginning of September and beginning of December, (1.49 ± 0.09, 4.14 ± 0.22, 5.61 ± 0.53 and 4.76 ± 0.35 individuals per leaf, respectively).

These results coincide with findings reported that the ectoparasitoid *Aphytis lingnanensis* had four overlapping activity periods with four peaks when associated with *Aonidiella aurantii*[12,13]. An abundance of *A. lepidosaphes* in the larval stage and autumn may be attributed to the environmental conditions which may be more favourable for *A. lepidosaphes* activity. These results coincide with findings of other researches which observed *A. lepidosaphes* on *Lepidosaphes conchiformis* on fig trees at Burg El-Arab in Egypt in March-April and November-December[14]. Other studies reported that the total population of *Aphytis* sp. parasite on *Pseudaulacaspis pentagona* infesting peach trees in Dakahliya, Egypt, exhibited five peaks. The first started from early February until early April and the second main peak started from early November until mid-January. In the second year of investigation, the parasitoid total population had a curve with six peaks[15,16]. Another study conducted in Iran revealed the same findings[17].

This research also investigated the percentage of parasitism and revealed that percentage of parasitism of *A. lepidosaphes* through the first year was higher (9.37%) in comparison to that in the second year (6.58%), which may due to the influence of favourable factors (such as environmental conditions). However, the highest percentage of parasitism by *A. lepidosaphes* was recorded in winter (12.72%) during the first year and autumn (9.22%) during the second year compared with that in the remaining seasons. These results agreed with the findings of other researches which reported that *P. blanchardi* is controlled by the Parasitoid, *A. phoenicis*[18,19].

A high abundance of the parasitoid *A. phoenicis* was observed on *P. blanchardi* on date palm trees in June, November, January and March[20]. Another study recorded that the rate of parasitism by *A. phoenicis* ranged from 21.4-33.6% in spring, 21.3-36.7% in summer, 35.3-46.8% in autumn and 18.5-39.1% in winter[21]. A study recorded the highest percentage of parasitism by *A. lepidosaphes* in autumn and the lowest in summer[22,23]. A study observed the highest percentage of parasitism in the immature stages of *Aphytis* spp. during winter[24]. These differences in results may be explained by the differences in the prevailing climatic conditions in each study.

In this study, the density-dependant relationship has been investigated for *A. lepidosaphes* during the four seasons through the study period. The results revealed a significant increase in the abundance of *A. lepidosaphes* in the different seasons and over the whole year. The population density of *L. tapleyi increased* by 0.19, 0.06, 0.13 and 0.11 individuals/leaf in summer, autumn, winter and over the whole first year, respectively. Conversely, in spring, the abundance of *A. lepidosaphes* decreased with the increasing population density of *L. tapleyi* by 0.1 individuals/leaf. In 2018/2019, a significant increase in the abundance of *A. lepidosaphes* was shown in the different seasons and over the whole year with increasing population density of *L. tapleyi* by 0.05, 0.08, 0.09, 0.11 and 0.11 individuals/per leaf in the spring, summer, autumn, winter and over the whole year, respectively. This result coincides with the findings of another study which revealed few differences between forecasted and observed dates of the initial appearance of each *C. aonidum* instar in citrus orchards[25].

The effect of climatic factors on the total density of the *A. lepidosaphes* population has been studied. Results showed that the daily mean maximum temperature had significantly changed the *A. lepidosaphes* population in the first year in contrast to the second year of the study where it had an effect variable for population changes in A*. lepidosaphes*. On the other hand, the results indicated that every 1°C increase in the daily mean minimum temperature would increase the population of this pest. This finding coincides with the results of another study which reported that the population density of this pest was observed on samples collected in the southern part of the tree canopy. The temperature had a significant effect on the developmental rate, female needed 625 degree days to complete their development, while male needed 833[25].

Investigation of the effect of the RH on the density of *A. lepidosaphes* showed that the mean relative humidity was above the optimum range of *A. lepidosaphes* population in the first year and around the optimum range of *A. lepidosaphes* activity in the second year. Another study reported that the maximum and minimum temperatures had a significant effect on the population of *L. becki* and its parasitoid *A. lepidosaphes*, whereas the effect of relative humidity was non-significant[26,27].

Results of this research also revealed that the mean dew point was entirely under the optimum range of the *A. lepidosaphes* population in the two years. This climatic factor was the most effective variable for the changes in the *A. lepidosaphes* population in 2017/2018 and 2018/2019. A similar study reported that the dew point was the most effective variable for population changes of the parasitoid *A. phoenicis* on *P. blanchardi* infesting date palm trees[28].

According to the above-mentioned results, it can be concluded that the combined effect of these tested factors on *A. lepidosaphes* activity was highly significant where the tested variables together were responsible for the changes in the *A. lepidosaphes* population. The remaining unexplained variance was assumed to be due to the influence of other unconsidered and undetermined factors that were not included in the present study in addition to the experimental error. These concluded findings coincide with what has been mentioned in another study that investigated the combined effect of multi factors (max. temp., min. temp., relative humidity and dew point) on the total population of *A. phoenicis* on date palm trees during the first year was highly significant whereas it was non-significant in the second year[28].

CONCLUSION

According to the above-mentioned results, it can be concluded that the combined effect of these tested factors on *A. lepidosaphes* activity was highly significant where the tested variables together were responsible for the changes in the *A. lepidosaphes* population. The remaining unexplained variance was assumed to be due to the influence of other unconsidered and undetermined factors that were not included in the present study in addition to the experimental error.

SIGNIFICANCE STATEMENT

This study aimed at the performance of *Aphytis lepidosaphes* (Hymenoptera: Aphelinidae) as an effective parasitoid for controlling the *Lepidosaphes tapleyi* (Williams) under field conditions in Luxor Governorate, Egypt. As well, estimate the effect of some climatic conditions on the seasonal abundance of the parasitoid, *A. lepidosaphes*. This information can aid in the development of an IPM program against *Lepidosaphes tapleyi*.

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