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RESEARCH ARTICLE

Damage status and seasonal occurrence of the mealybug *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) on roselle plants

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Abstract

The *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae), known as the cotton mealybug, has been one of the most important pests attacking roselle plants (*Hibiscus sabdariffa* L.) in recent years. The current study was conducted in a private roselle field of Balady cultivar at Esna district, Luxor Governorate, South Egypt, during the two growing seasons (2022 and 2023) to monitor the incidence of the pest. It also evaluated the influence of weather conditions and plant growth stages on the abundance of *P. solenopsis*. The data suggests that around May 13th, roselle plants were infested by the mealybug individuals which are the 7th week after sowing and the 20th standard meteorological week. The infestation continued to fluctuate until the 43rd SMW (crop maturity) in both seasons. In addition, the general averages of *P. solenopsis* individuals during the second cropping season were higher than those in the first cropping season. In both seasons, *P. solenopsis* abundance increased steadily in roselle in July and August. The seasonality and population fluctuations of mealybugs in roselle were influenced by weather conditions and plant stages. These effects were highly significant, and the variables changed from season to season. Additionally, the explained variance coefficients for the two cropping seasons were 93.41% and 90.29%, respectively. The population of mealybugs in the field during both seasons was most influenced by the average daily minimum temperature. This study can help develop efficient pest control strategies to minimize mealybug infestations in roselle crops, leading to improved yield, economic benefits, and environmental sustainability.

Keywords: Abundance; Phenacoccus solenopsis; plant evolution; roselle plants; seasonal occurrence

1. *Introduction*

Roselle (*Hibiscus sabdariffa* L.) is one of the plants in the Malvaceae Family. It is a medicinal plant with high levels of vitamin C, oxalic, malic, citric, and tartaric acids, as well as hibiscin (delphinidin) and gossyperin (cyanidin), two different forms of anthocyanin. It positively impacts how the stomach works; by removing harmful bacteria and microorganisms, they decrease blood pressure and relax the rest of the body's muscles. In addition, anthocyanin, a red pigment, is utilized in the culinary sector to produce sauces, tea pies, and sweets (Hassan 2009; El-Dissoky *et al*. 2020; Ismail *et al*. 2020). Roselle plants are damaged by infestations of piercing-sucking insect pests (Abdel Moniem and Abd El-Wahab 2006). Among them, the mealybug (MB), *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae), which is a highly polyphagous pest and is regarded as a deleterious pest on roselle plants (Vennila, *et al*. 2011). It feeds on the phloem sap of the host and then attacks the soft shoots, twigs, leaf veins, branches, and fruits. This pest attacks all stages of plant growth from the beginning of germination until harvest(Hodgson *et al*. 2008; Aheer *et al*. 2009).The feeding damage by MB to the leaves, branches, and fruits causes

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significant sap loss, resulting in chlorosis, distorted leaves, death of growth tips, early leaf drop, dryness, dwarfing, wrinkles, stunted development, deformation, leaf reduction, and death of plants (Babasaheb and Suroshe 2015; Shehata 2017; Bakry *et al*., 2024). Long-term nutrient limitation has a detrimental impact on plant development and roselle productivity as a consequence of severe damage (Ibrahim *et al*., 2015; Saad 2021). It infests the roselle plants, and because it feeds directly on the sap from the plant leaf, consumes huge quantities of phloem sap, and excretes a substantial quantity of honeydew, it leads to the spread emerging and activity of ants. This is because the plant's vitality, growth, and output are decreased by the insect's large numbers, decreased movement, and concentrated consumption of nymphs (Sahayaraj *et al*., 2014). All insect pests heavily depend on normal climatic conditions, including temperature, relative humidity, and precipitation to develop and spread (Aheer*et al*. 1994). These MBs exhibit irregular behavior as a result of the unpredictable environment. The development of pest management techniques is aided by an understanding of pest seasonal occurrence, crop phenology, and population dynamics (Sadek *et al*., 2023). It is essential to continually monitor the insect pests infesting roselle to establish the best integrated control strategies. In this context, the current study was conducted to look into the seasonal frequencies, peak activity, and correlation of climate variables, and plant development with *P. solenopsis* population throughout the roselle growing season. The results on pest monitoring will be helpful developing effective pest management practices for roselle.

2. Materials and Methods

To describe the population density of pests, researchers have used a variety of entomological parameters using insect counts, percentages of damaged leaves, and infestation progression.

2.1. Population studies

2.1.1. Occurrence of the mealybug,P. solenopsis on roselle plants

Throughout the two growing seasons (years 2022 and 2023), weekly inspections were executed in a planted area of private roselle (Balady cv.) (25º24'40" N, 32º31'59" E) at Esna District, Luxor region, Egypt, to assess the population density of *P. solenopsis* per 10 leaves. The seeds were sown in the first week of April for every season in a field measuring approximately 4200 square meters. Pest monitoring started at ten in the morning. The agricultural practices in growing roselle plants were followed except the use of insecticides. Sampling began as soon as germination was noticeable on the layer of soil and continued every week until the roselle plant was harvested. Observations of *P. solenopsis* attacking the roselle plants were estimated at weekly intervals [Standard Meteorological Week (SMW)]. The first detectable mealybug infestation in the study region was identified on 13th May, *i.e*., through the 20th (SMW), which corresponds to the 7th week olds after planting (WAS) and extends to the date of roselle harvest. The total estimates of mealybugs were calculated on forty roselle leaves randomly selected for two seasons and from the different levels of roselle plants (ten leaves per replicate). The pest was stored in tubes filled with 90% alcohol and brought to the Plant Protection Research Institute, Agricultural Research Center in Giza, Egypt for insect identification. These leaves were gathered, packaged in different polythene bags, and transported to the lab. Under a stereo binocular microscope, the total count of *P. solenopsis* (nymphs and adults) on both sides of the leaves were counted and estimated to display seasonal fluctuations. To discuss the seasonal occurrence of *P. solenopsis* based on the average number of populations per 10 leaves, this was discussed through weekly records on roselle plants, plus or minus (±) the standard error (SE), which was used to assess population estimates. We obtained a total of 1920 leaves, *i.e*., 48 different observation periods, throughout the two cropping seasons. Ten leaves × four replicates × twenty-four times × two seasons were employed for the sampling. There were 960 leaves per season. A direct examination of mealybugs was carried out at the same time as the weekly monitoring as mentioned (Bakry and Arbab 2020; Bakry *et al.*, 2023 a).

2.1.2. Damaged leaf percentages by P. solenopsis

The *P. solenopsis* counts on roselle leaves were estimated, while its percentages of damaged leaf were assessed according to Bakry and Abdel-Baky (2023b).

$$A = (n / N) \times 100$$

Where, A = Percentage of damaged leaves

n = The number of damaged leaves in the examined sample.

N = The total number of observed leaves (undamaged + damaged) over each investigation date.

2.1.3. Infestation Progression (IP)

The progression of the infestation shows how quickly the infestation of mealybugs was growing year after year. The frequency distribution curve of the population was smoothed using the following formula according to Abd El-Moaty (2013), which was used to estimate the data:

$$IP = \{(2 \times \text{the present count}) + \text{the preceding count} + \text{the following count}\} / 4$$

2.2. Calculation of the mealybug-days and the cumulative mealybug-days

To ascertain mealybugs infestation by measuring the overall number of individual mealybugs at weekly sample periods in the field. The calculation of the mealybug-accumulated numbers, mealybug-days, and cumulative mealybug-days were estimated.

2.2.1. Mealybug-days (MD)

Overall counts of mealybugs are how many would have been observed if samples had been taken each day and results were totaled. The following formula was used to compute this metric using the mealybug-days parameter (Bakry and Fathipour 2023).

$$MD = [7 \times (C_1+C_2) / 2]$$

In this formula, MD refers to the Mealybug-days, C_1 and C_2 refers to the mealybug counts in the present and preceding sample intervals, respectively.

2.2.2 Cumulative mealybug-days (CMD)

The current cumulative total mealybug days are the mealybug days from the previous assessment plus the mealybug days from the present assessment for each sampling period and add them up.

2.3. Rate of Variation (RV)

To estimate the rate of variation (R.V.) in population estimates, percentage of leaves damaged and progression of infestation in weekly inspection variations, this was calculated by dividing the mean of the numbers found on the present investigation date by those found on the previous investigation date (Bakry and Fathipour 2023).

2.4. The polynomial relationships between P. solenopsis abundance and percentage of damaged leaves, and the progression of infestation:

To estimate the nonlinear relationships between the *P. solenopsis* abundance as an independent factor and the percentage of leaves damaged and the progression of infestation represented as dependent variables.

These statistical relationships are shown by a third-degree polynomial equation. This procedure was previously used by Bakry and Abdel-Baky (2024).

2.5. Impacts of the weather parameters and biotic variable on P. solenopsis abundance attacking roselle plants**:**

In order to evaluate the effect of abiotic variables (meteorological parameters) and biotic factor (plant growth, *i.e*., periods in weeks after sowing,), on the abundance of *P. solenopsis* throughout the two seasons (2022 and 2023). The weather data, viz., maximum temperature, minimum temperature, and mean percentage of relative humidity, were obtained from the Central Laboratory for Agricultural Climate, Agricultural Research Center, Ministry of Agriculture at Giza. The daily records of these parameters were recalculated to obtain daily averages over 7 days of *P. solenopsis* estimation. The plant growth development was evaluated at the date of mealybugs estimation. This relationship was calculated by the third-order nonlinear model, according to Bakry and Abdel-Baky (2023a) using this technique. The different correlation and regression analyses of the data were worked out weekly to find the relationships between them using the MSTAT-C software program (Freed 1991). The simple correlation values between tested variables were plotted using R software (R Core Team 2019). All the data in the tables and figures shown was estimated and calculated using Microsoft Excel 2017.

3. Results

The infestation symptoms of mealybug, *P. solenopsis*, led to distortions in the roselle plants. The damage includes all parts of the plant, as shown in Figure 1.

Figure 1. Photographs showing the infestation symptoms of mealybug, Phenacoccus solenopsis Tinsley (Hemiptera: Pseudococcidae), led to distortions in the roselle plants: The damage includes all parts of the plant (Source: Samples taken from a field of the infested roselle plants by Dr. Moustafa M.S. Bakry, September 2022).

3.1.1. Population studies

The weekly estimates of *P. solenopsis* that attacked roselle plants (cv. 'Balady') at Esna district, Luxor Governorate, over two cropping seasons in 2022 and 2023 are presented in Tables 1 and 2 and Figures 1 and 2. These include weekly averages of weather variables and plant characteristics during the two growing seasons. The impacts of the weather variables and plant growth of roselle plants on *P. solenopsis* abundance were calculated based on the average counts of nymphs and adult individuals per leaf on successive inspection dates. According to the observations during the two seasons, *P. solenopsis* appeared on the roselle plants on May 13th, which coincides with (7th WAS, *i.e*., 20th SMW) and infestation fluctuated and continued until the 43rd SMW (time of crop maturity) per season.

3.1.2. Population fluctuation of P. solenopsis

A. Seasonal occurrence during the first-year cropping season of 2022

Initial mealybug populations exhibited on May 13th were consistent with the 7th week after sowing (*i.e*. 20th SMW), reached 1.10 ± 0.11 individuals per leaf and reached their (first) peak on June 10th, as compatible with the (11th WAS, *i.e*., the 24th SMW), being 13.85 ± 1.35 individuals/leaf of *P. solenopsis*, when the maximum, minimum temperatures, and relative humidity were 37.59 °C, 23.96 °C, and 28.23%, respectively. Then, the population decreased gradually until June 24th, which corresponds to (13 WAS, *i.e*., 26th SMW), and then reincreased gradually to reach a second peak on July 22nd (17th WAS, *i.e*. 30th SMW), being

(26.75 ± 2.74 individuals per leaf) at (40.40 °C, Max. temp.; 27.98°C Min. temp. and 30.63% R.H.). After that, the population dropped on July 29th (18th WAS, *i.e*. 31st SMW), and then increased again to reach the third peak on August 26th as compatible with (22nd WAS, *i.e*., 35th SMW), being (30.95 ± 3.07 individuals per leaf) at (41.04 °C, Max. temp.; 27.41°C Min. temp. and 30.29% R.H.). Thereafter, the number of mealybugs decreased gradually and continuously during the crop maturity period until it reached October 22 (30th WAS, *i.e*. 43rd SMW), as shown in Table, 2 and Figure 1.

B- Seasonal occurrence during the second-year cropping season of 2023

On May 13th, of the second year of the investigation initial mealybug populations were consistent with the 7th week after sowing (*i.e*., in the 20th SMW) and reached 1.00 ± 0.09 individuals per leaf. Afterthat, they reached their first peak on June 10th, which was in line with the 11th week after sowing (*i.e*., the 24th SMW), with a population of 13.68 ± 1.08 individuals/leaf of *P. solenopsis*. This peak occurred when the maximum and minimum temperatures were 39.74°C and 25.28°C, respectively, and the relative humidity was 29.81%. Following this peak, the population gradually decreased until June 24th (13 WAS, *i.e*., 26th SMW). Then, it began to increase again, reaching a second peak on July 22nd (17th WAS, *i.e*., 30th SMW), with a population of 32.75 ± 2.26 individuals per leaf. This peak occurred when the maximum and minimum temperatures were 42.72 °C and 29.54 °C, respectively, and the relative humidity was 32.36%. The population decreased again on July 29th (18th WAS, *i.e*., 31st SMW) and continued to August 5th (19th WAS, *i.e*., 32nd SMW), and then gradually increased to reach a third peak on August 26th, which was in line with the 22nd week after sowing (*i.e*., the 35th SMW). The population at this peak was 38.13 ± 2.78 individuals per leaf, with maximum and minimum temperatures of 43.40 °C and 28.95 °C, respectively, and a relative humidity of 31.99%. After this third peak, the number of mealybugs decreased gradually and continuously until October 22nd (30th WAS, *i.e*., 43rd SMW), as indicated in Table 2 and Figure 1.

The findings indicated that there was a higher number of *P. solenopsis* on roselle plants in the second growing season (2023) compared to the first growing season (2022). The average count of *P. solenopsis* per leaf was 16.60 ± 18.00 and 19.39 ± 4.61 individuals in the first and second growing seasons, respectively. The analysis of variance revealed highly significant differences in the total estimates of *P. solenopsis* in different investigation dates in each season (F values were 98.59 and 190.19; the L.S.D values were 2.56 and 2.25 for the two seasons respectively. Likewise, the coefficients of variation ratios reached 10.98 and 8.32% in the two seasons, respectively (Tables 1 and 2). It was also observed that there were highly significant differences in the total numbers of the pests population between the two growing seasons (F values were 99.69, the L.S.D. values were 0.55 and the coefficient of variation percentage was 10.77%).

***3.1.3. Percentages of leaves damaged by* P. solenopsis**

The percentages of leaves damaged by *P. solenopsis* varied with the progress in the examination dates of the roselle plants during the two successive study seasons (Tables 1 and 2; Figures 2 and 3).

Table 1. Number (mean ± standard error) of mealybug individuals, % damaged leaves, progress of infestation, and mealybug-days of *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) invasion in roselle plants as affected by to weather conditions at Esna district, Luxor region throughout 2022 cropping season

Inspection date		SMW	WAS	No. of individuals per leaf ± S.E.	% No. mealybugs of total counts	Cumulative numbers	% Cumulative No.	Mealybug-Days	Cumulative mealybug-days	% Damaged leaves	Progress of infestation	Max. temp.	Min temp.	% R.H.
May, 2022	13	20	7	1.10 ± 0.11	0.28	1.10	0.28	3.85	3.85	12.50 ± 2.50	1.38	35.79	20.95	30.42
	20	21	8	3.33 ± 0.35	0.83	4.43	1.11	15.49	19.34	20.00 ± 4.08	3.28	36.71	21.96	27.95
	27	22	9	5.35 ± 0.57	1.34	9.78	2.45	30.36	49.70	25.00 ± 2.89	5.61	37.92	22.12	29.25
June	3	23	10	8.40 ± 0.86	2.11	18.18	4.56	48.13	97.83	30.00 ± 4.08	9.00	41.03	27.25	31.56
	10	24	11	13.85 ± 1.35	3.48	32.03	8.04	77.88	175.70	32.50 ± 4.79	11.96	37.59	23.96	28.23
	17	25	12	11.73 ± 1.15	2.94	43.75	10.98	89.51	265.21	35.00 ± 2.89	11.33	41.04	25.65	27.34
	24	26	13	8.00 ± 0.82	2.01	51.75	12.99	69.04	334.25	27.50 ± 4.79	10.43	42.72	27.57	24.08
	1	27	14	14.00 ± 1.43	3.51	65.75	16.50	77.00	411.25	32.50 ± 6.29	13.97	40.56	26.13	28.47
July	8	28	15	19.89 ± 2.00	4.99	85.64	21.50	118.62	529.87	35.00 ± 6.45	19.68	41.46	25.50	27.67
	15	29	16	24.95 ± 2.53	6.26	110.59	27.76	156.94	686.81	37.50 ± 6.29	24.14	41.04	26.69	24.36
	22	30	17	26.75 ± 2.74	6.71	137.34	34.48	180.95	867.76	40.00 ± 4.08	25.36	40.40	27.98	30.63
	29	31	18	23.00 ± 2.37	5.77	160.34	40.25	174.13	1041.88	35.00 ± 2.89	23.36	41.28	27.90	29.07
August	5	32	19	20.70 ± 2.04	5.20	181.04	45.44	152.95	1194.83	32.50 ± 4.79	22.73	42.53	29.80	32.09
	12	33	20	26.50 ± 2.66	6.65	207.54	52.10	165.20	1360.03	35.00 ± 6.45	25.93	42.64	28.94	27.37
	19	34	21	30.00 ± 2.88	7.53	237.54	59.63	197.75	1557.78	42.50 ± 4.79	29.36	42.16	28.22	29.38
	26	35	22	30.95 ± 3.07	7.77	268.49	67.40	213.33	1771.11	40.00 ± 4.08	30.35	41.04	27.41	30.29
Sept.	2	36	23	29.50 ± 2.97	7.41	297.99	74.80	211.58	1982.68	45.00 ± 8.66	28.39	40.01	26.54	31.00
	9	37	24	23.60 ± 2.37	5.92	321.59	80.73	185.85	2168.53	42.50 ± 4.79	23.89	42.80	28.62	27.92
	16	38	25	18.85 ± 1.92	4.73	340.44	85.46	148.58	2317.11	32.50 ± 2.50	19.76	41.76	27.82	33.63
	23	39	26	17.75 ± 1.74	4.46	358.19	89.91	128.10	2445.21	27.50 ± 2.50	17.14	42.72	28.14	34.12
Oct.	1	40	27	14.20 ± 1.39	3.56	372.39	93.48	111.83	2557.03	22.50 ± 2.50	14.38	39.59	23.77	29.91
	8	41	28	11.36 ± 1.11	2.85	383.75	96.33	89.46	2646.49	20.00 ± 4.08	11.57	39.71	24.06	31.90
	15	42	29	9.38 ± 0.94	2.35	393.13	98.68	72.57	2719.06	17.50 ± 4.79	8.84	38.24	23.48	34.80
	22	43	30	5.25 ± 0.52	1.32	398.38	100.00	51.19	2770.25	17.50 ± 2.50	4.97	36.10	20.88	32.98
Total				398.38	100.00			2770.25			396.79			
General average				16.60 ± 18.00						30.73 ± 4.86	16.53 ± 1.79	40.29	25.89	29.77
F value				98.59						3.81				
L.S.D. at 0.05 level				2.56 **						12.82 **				
C.V.%				10.98						29.66				

Where: SMW refers to the standard meteorological week; WAS refers to the weeks after sowing; S.E. = Standard error; L.S.D. = Least significant difference; * Significant at P ≤ 0.05, ** Highly significant at P ≤ 0.01; C.V. = Coefficient of variation.

Table 2. Number (mean ± standard error) of mealybug individuals, % damaged leaves, progress of infestation, and mealybug-days of Phenacoccus solenopsis Tinsley (Hemiptera: Pseudococcidae) invasion in roselle plants as affected by to weather conditions at Esna district, Luxor region throughout 2023 cropping season

Inspection date		SMW	WAS	No. of individuals per leaf ± S.E.	% No. mealybugs of total counts	Cumulative numbers	% Cumulative No.	Mealybug-Days	Cumulative mealybug-days	% Damaged leaves	Progress of infestation	Max. temp.	Min temp.	% R.H.
May, 2023	13	20	7	1.00 ± 0.09	0.21	1.00	0.21	3.50	3.50	10.00 ± 4.08	1.33	37.83	22.09	32.14
	20	21	8	3.30 ± 0.24	0.71	4.30	0.92	15.05	18.55	22.50 ± 2.50	3.30	38.81	23.17	29.51
	27	22	9	5.60 ± 0.48	1.20	9.90	2.13	31.15	49.70	27.50 ± 4.79	5.68	40.08	23.34	30.89
June	3	23	10	8.23 ± 0.61	1.77	18.13	3.89	48.39	98.09	30.00 ± 4.08	8.93	43.38	28.78	33.34
	10	24	11	13.68 ± 1.08	2.94	31.80	6.83	76.65	174.74	35.00 ± 2.89	11.68	39.74	25.28	29.81
	17	25	12	11.15 ± 0.79	2.40	42.95	9.23	86.89	261.63	32.50 ± 4.79	11.75	43.40	27.08	28.87
	24	26	13	11.03 ± 0.75	2.37	53.98	11.60	77.61	339.24	30.00 ± 7.07	11.74	45.18	29.12	25.41
	1	27	14	13.78 ± 1.02	2.96	67.75	14.56	86.80	426.04	32.50 ± 4.79	15.61	42.89	27.59	30.06
July	8	28	15	23.85 ± 1.68	5.12	91.60	19.68	131.69	557.73	37.50 ± 2.50	22.97	43.84	26.92	29.22
	15	29	16	30.40 ± 2.14	6.53	122.00	26.21	189.88	747.60	45.00 ± 6.45	29.35	43.40	28.18	25.70
	22	30	17	32.75 ± 2.26	7.04	154.75	33.25	221.03	968.63	42.50 ± 4.79	30.98	42.72	29.54	32.36
	29	31	18	28.03 ± 2.04	6.02	182.78	39.27	212.71	1181.34	40.00 ± 4.08	28.35	43.65	29.46	30.71
August	5	32	19	24.60 ± 1.77	5.29	207.38	44.55	184.19	1365.53	37.50 ± 2.50	27.15	44.98	31.47	33.90
	12	33	20	31.38 ± 2.28	6.74	238.75	51.30	195.91	1561.44	40.00 ± 4.08	30.96	45.10	30.56	28.90
	19	34	21	36.48 ± 2.64	7.84	275.23	59.13	237.48	1798.91	42.50 ± 2.50	35.61	44.59	29.80	31.03
	26	35	22	38.13 ± 2.78	8.19	313.35	67.32	261.10	2060.01	37.50 ± 2.50	36.49	43.40	28.95	31.99
Sept.	2	36	23	33.23 ± 2.43	7.14	346.58	74.46	249.73	2309.74	35.00 ± 2.89	32.79	42.30	28.02	32.75
	9	37	24	26.58 ± 1.96	5.71	373.15	80.17	209.30	2519.04	32.50 ± 7.50	27.09	45.27	30.22	29.48
	16	38	25	21.98 ± 1.17	4.72	395.13	84.89	169.93	2688.96	30.00 ± 4.08	23.04	44.16	29.37	35.54
	23	39	26	21.63 ± 1.52	4.65	416.75	89.54	152.60	2841.56	27.50 ± 2.50	20.63	45.18	29.71	36.06
Oct.	1	40	27	17.30 ± 1.21	3.72	434.05	93.26	136.24	2977.80	25.00 ± 2.89	17.52	35.21	21.15	27.63
	8	41	28	13.84 ± 0.97	2.97	447.89	96.23	108.99	3086.79	22.50 ± 4.79	13.98	37.46	22.12	29.60
	15	42	29	10.95 ± 0.79	2.35	458.84	98.58	86.77	3173.56	20.00 ± 4.08	10.59	36.48	21.88	32.47
	22	43	30	6.60 ± 0.48	1.42	465.44	100.00	61.43	3234.98	17.50 ± 2.50	6.04	34.10	18.63	30.67
Total				465.44	100.00			3234.98			463.54			
General average				19.39 ± 4.61						31.35 ± 4.82	19.31 ± 2.21	41.80	26.77	30.75
F value				190.19						4.20				
L.S.D. at 0.05 level				2.25 **						11.81 **				
C.V.%				8.32						27.05				

Where: SMW refers to the standard meteorological week; WAS refers to the weeks after sowing; S.E. = Standard error; L.S.D. = Least significant difference; * Significant at P ≤ 0.05, ** Highly significant at P ≤ 0.01; C.V. = Coefficient of variation.

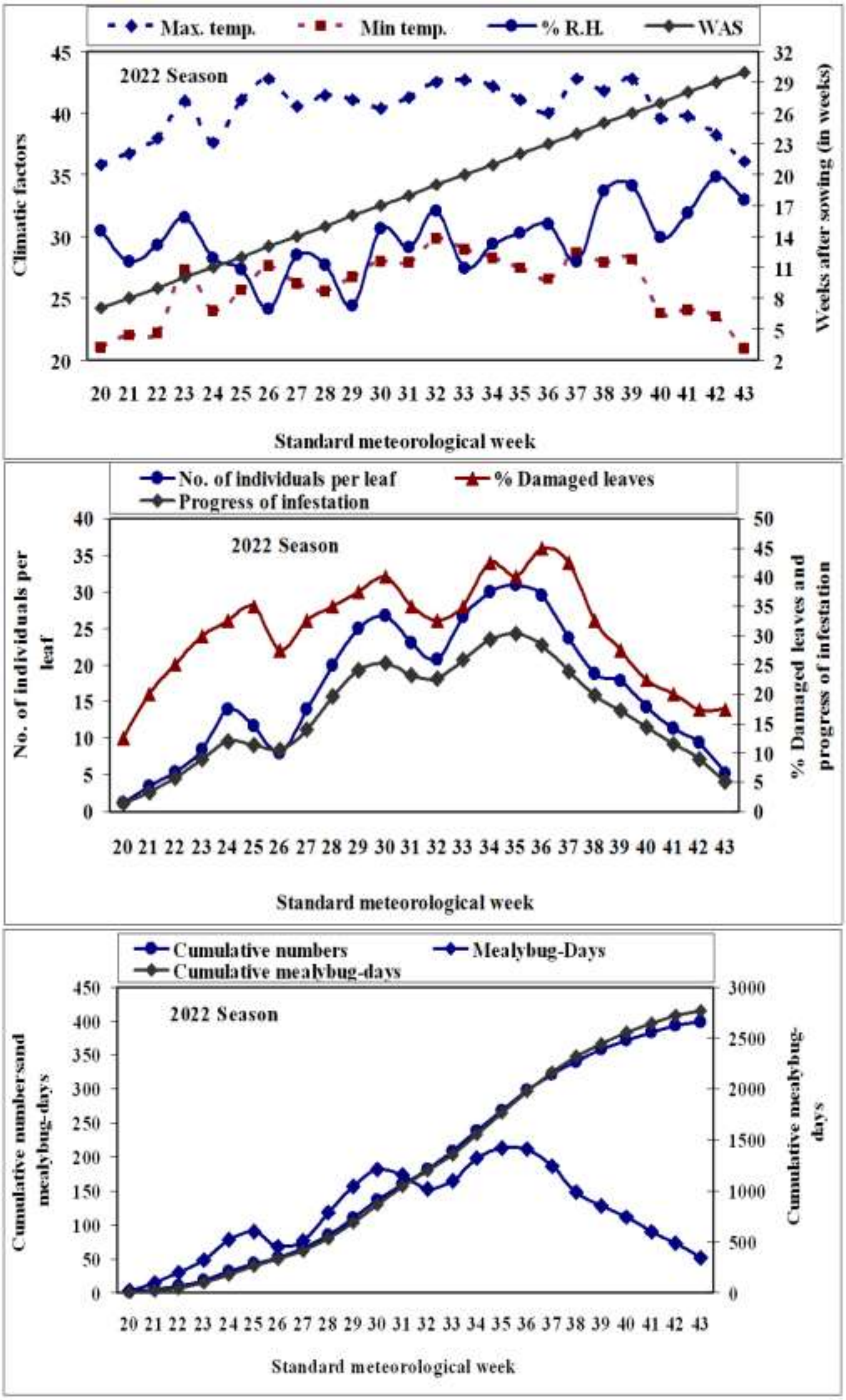


Figure 2. Average numbers of *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae), % damaged leaves, progress of infestation, and mealybug-days of *P. solenopsis* infesting roselle plants to weather conditions at Esna site, Luxor region throughout 2022 cropping season

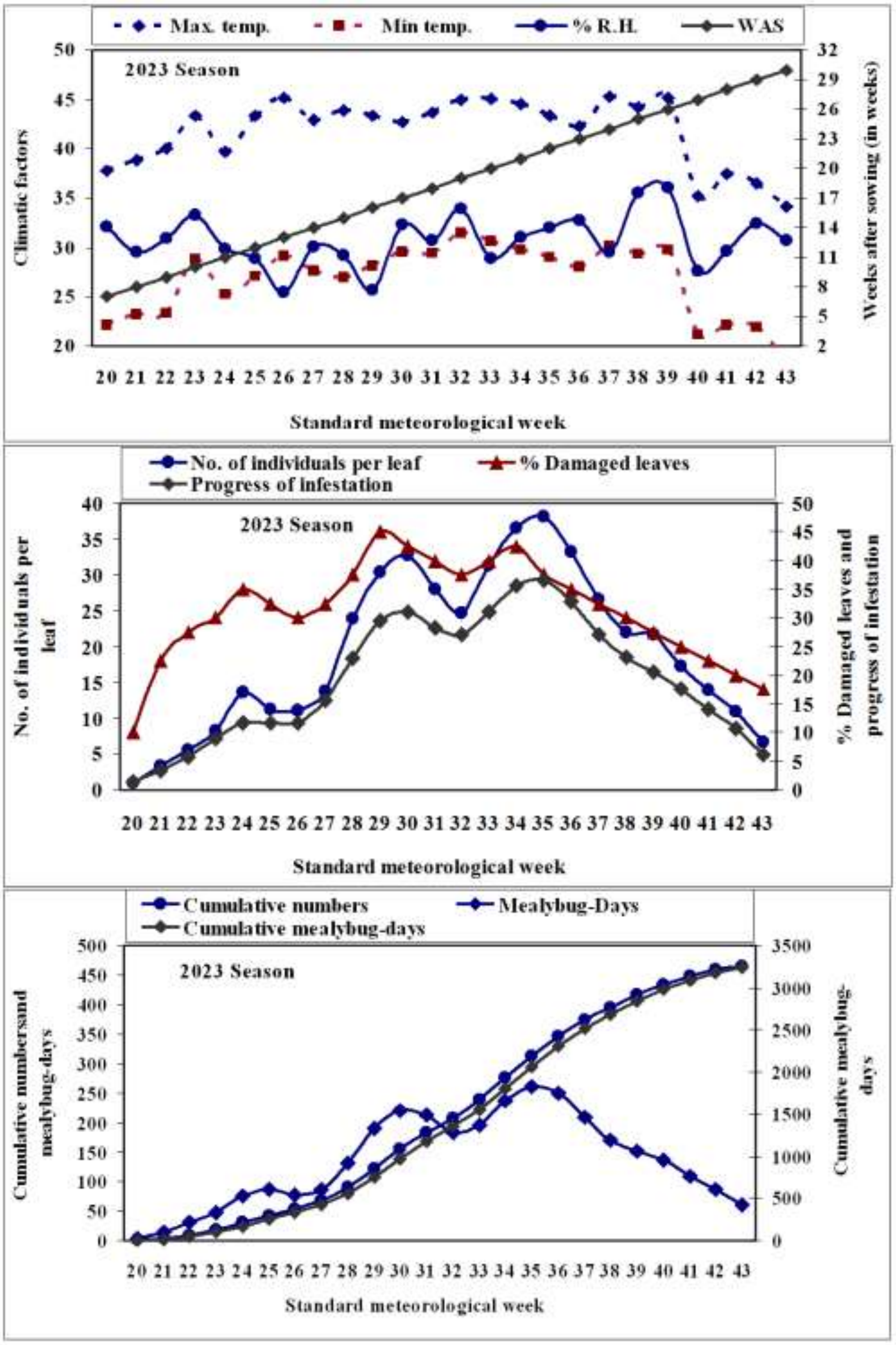


Figure 3. Average numbers of Phenacoccus solenopsis Tinsley (Hemiptera: Pseudococcidae), % damaged leaves, progress of infestation, and mealybug-days of Phenacoccus solenopsis infesting roselle plants to weather conditions at Esna site, Luxor region throughout 2023 cropping season

The percentages of damaged leaves by *P. solenopsis* had three seasonal peaks for each year. The peak recorded in June 17th (12th WAS, *i.e*., 25th SMW), July 22nd (17th WAS, *i.e*., 30th SMW), and September 2nd (23rd WAS, *i.e*., 36th SMW) in 2022 season and in June 10th (11th WAS, *i.e*., 24th SMW), July 15th (16th WAS, *i.e*., 29th SMW), and August 19th (21st WAS, *i.e*., 34th SMW) in 2023 season, as shown in Tables (1 and 2) and Figures (2 and 3). As for the mean percentages of damaged leaves, they were 30.73 ± 4.86 and 31.35 ± 4.82% over the two growing seasons, respectively. The increment in the percentages of damaged leaves in the second season compared to the first one was approximately 1.02 times, Tables 1 and 2. Significant differences were found between the percentages of damaged leaves examined at different examination dates at each season (the F value was 3.81 and 4.20; the L.S.D values were12.82 and 11.81) for both seasons respectively. The coefficients of variation ratios reached 29.66 and 27.05 % over both seasons, respectively, as presented in Tables (1 and 2). Conversely, there was no significant variation in the percentages of damaged leaves between both cropping seasons.

3.1.4. Infestation progression

The cycle of *P. solenopsis* infestation had three peaks that were exhibited on June 10th (11th WAS, *i.e*., the 24th SMW), July 22nd (17th WAS, *i.e*. 30th SMW) and August 26th (22nd WAS, *i.e*., 35th SMW) in 2022 cropping season and June 10th (11th WAS, *i.e*., the 24th SMW), July 22nd (17th WAS, *i.e*., 30th SMW) and August 26th (22nd WAS, *i.e*., the 35th SMW) in 2023 cropping season, as presented in Tables (1 and 2) and Figures (2 and 3). The infestation of *P. solenopsis* increased slowly during the first season compare to the second season (from 16.53 ± 1.79 individuals/leaf in 2022 to 19.31 ± 2.21 individuals/leaf in 2023). The increase in the progression of *P. solenopsis* infestation in the second season compared to the previous season was approximately 1.17 times. Thus, time of control application of *P. solenopsis*on roselle plants is imposed, season after season. As for the activity of *P. solenopsis* across each season based on the data obtained, the highest total population density and infestation development of *P. solenopsis* were also recorded on August 26th (22nd WAS, *i.e*., 35th SMW) during each experimental season. The highest percentages of leaves damaged by *P. solenopsis* were recorded on September 2nd (23rd WAS, *i.e*., 36th SMW) during both seasons.

3.2. Mealybug-accumulated numbers and cumulative mealybug-days:

To confirm mealybug infestation, the estimates of the total number of individual mealybugs at weekly sampling intervals were done. As shown in Tables 1 and 2 and illustrated in Figures 2 and 3, the mealybug-accumulated numbers, mealybug-days and cumulative mealybug-days for *P. solenopsis* on roselle plants, shows the overall effect of insect individuals that continually evolve. In terms of cumulative numbers, the two seasons had 398.38 and 465.44 individuals of *P. solenopsis* per season, respectively. Moreover, the data shows that the impact of *P. solenopsis* numbers on roselle plants was greater in the second season (3234.98 cumulative mealybug-days) than in the previous season (2770.25 cumulative mealybug-days), as shown in Tables 1 and 2.

3.3. Rate of variation in P. solenopsis counts

The rate of variation (RV) in *P. solenopsis* estimates, percentage of leaves affected and progression of infestation on roselle plants were calculated in weekly monitoring intervals (Table 3). This model is an indicator of the favorable time for insect activity, expressed as the week that shows the difference in insect activity over the season. When R.V. >1 expresses increased activity this week, <1 expresses a decrease in activity this week, and equal to 1 expresses no change in activity (Bakry and Abdel-Baky 2024). The huge increase in total counts of *P. solenopsis* and progression of infestation appeared at the 7th (WAS) and continued to the 11th WAS, from the 14th week and continued until the 16th week, and from the 20th week and continued till the 22nd week WAS, over each season, which the variation rates were higher than 1. The suitable times for weekly increase for the damaged leaf percentages occurred in the 7th WAS and continued to the 12th WAS, from the 14th week and continued until the 16thWAS, and from the 20thWAS and continued till the 21st WAS in the 2022 cropping season, which the variation rates listed higher than one.

Table 3. The rate of variation (R.V.) in the mean number of Phenacoccus solenopsis Tinsley (Hemiptera: Pseudococcidae), % damaged leaves, and progress of infestation on roselle plants at Esna site, Luxor region throughout 2022 and 2023 cropping seasons

Inspection date		SMW	WAS	2022 season			2023 season		
				Mealybug numbers	% Damaged leaves	Progress of infestation	Mealybug numbers	% Damaged leaves	Progress of infestation
May	13	20	7	—	—	—	—	—	—
	20	21	8	3.02	1.60	2.37	3.30	2.25	2.49
	27	22	9	1.61	1.25	1.71	1.70	1.22	1.72
June	3	23	10	1.57	1.20	1.61	1.47	1.09	1.57
	10	24	11	1.65	1.08	1.33	1.66	1.17	1.31
	17	25	12	0.85	1.08	0.95	0.82	0.93	1.01
	24	26	13	0.68	0.79	0.92	0.99	0.92	1.00
	1	27	14	1.75	1.18	1.34	1.25	1.08	1.33
July	8	28	15	1.42	1.08	1.41	1.73	1.15	1.47
	15	29	16	1.25	1.07	1.23	1.27	1.20	1.28
	22	30	17	1.07	1.07	1.05	1.08	0.94	1.06
	29	31	18	0.86	0.88	0.92	0.86	0.94	0.92
August	5	32	19	0.90	0.93	0.97	0.88	0.94	0.96
	12	33	20	1.28	1.08	1.14	1.28	1.07	1.14
	19	34	21	1.13	1.21	1.13	1.16	1.06	1.15
	26	35	22	1.03	0.94	1.03	1.05	0.88	1.02
Sept.	2	36	23	0.95	1.13	0.94	0.87	0.93	0.90
	9	37	24	0.80	0.94	0.84	0.80	0.93	0.83
	16	38	25	0.80	0.76	0.83	0.83	0.92	0.85
	23	39	26	0.94	0.85	0.87	0.98	0.92	0.90
Oct.	1	40	27	0.80	0.82	0.84	0.80	0.91	0.85
	8	41	28	0.80	0.89	0.80	0.80	0.90	0.80
	15	42	29	0.83	0.88	0.76	0.79	0.89	0.76
	22	43	30	0.56	1.00	0.56	0.60	0.88	0.57

Where: SMW refers to the standard meteorological week; WAS refers to the weeks after sowing.

Similarly, in the 2023 cropping season, the favorable times for the percentages of damaged leaf took place at the 7th WAS and continued to the 11th WAS, from the 14th week and continued until the 16th week and from the 20th WAS and continued till the 21st WAS in the 2022 cropping season, which the variation rates being higher than 1. It was clear that an increase in *P. solenopsis* counts, percentage of damaged leaves, and progression of infestation by weekly sampling, which were higher than one, indicated that climatic parameters were more suitable for the growth and activity of *P. solenopsis*.

3.4. The polynomial relationships between the abundance of P. solenopsis percentages of damaged leaves and progression of infestation

Mathematical equations of the nonlinear regression method were calculated to establish the correlation between the abundance of *P. solenopsis* counts as an independent variable (X_1) and the percentage of leaves damaged (Y_1) & progression of infestation (Y_2) as dependent variables, we used a third-degree nonlinear equation, as shown in Figure 4.

3.4.1. On percentages damaged leaves (Y_1)

P. solenopsis population (X_1), when modeled using a three-degree polynomial exhibited a high correlation with the percentage of damaged leaves (Y_1). The explained variance was 76.86 and 68.09% during the two seasons, respectively (Figure 4). The *P. solenopsis* population model is the most effective in predicting the percentage of damaged leaves on roselle plants. The polynomial regression equations are:

First season (2022):

$$Y_1 = 0.0011 X_1^3 - 0.0595 X_1^2 + 1.7873 X_1 + 12.972 \quad (R^2 = 0.7686)$$

Second season (2023):

$$Y_1 = 0.0004 X_1^3 - 0.0376 X_1^2 + 1.5102 X_1 + 14.369 \quad (R^2 = 0.6809)$$

3.4.2. On the progression of infestation (Y_2)

P. solenopsis population (X_1), when modeled using a three-degree polynomial, showed a high correlation with the infestation progression (Y_2). The explained variance was 98.99 and 99.23%

during the two seasons, respectively (Figure 4). The predicted progression of infestation was calculated through the statistical equations in Figure 4. The polynomial regression equations are:

First season (2022):

$Y_2 = -0.0002\ X_1^3 + 0.0067\ X_1^2 + 0.9195\ X_1 + 0.4414$ ($R^2 = 0.9899$)

Second season (2023):

$Y_2 = -0.0002\ X_1^3 + 0.0059\ X_1^2 + 0.9496\ X_1 + 0.2035$ ($R^2 = 0.9923$).

3.5. Impacts of weather parameters and biotic variable on **P. solenopsis** *abundance:*

3.5.1. Effect of certain abiotic variables (meteorological parameters):

A- Effect of the daily mean maximum temperature (X_1):

The results of the statistical analysis in Table (4) and Fig. (5) exhibit highly significant and positive correlations between the daily maximum temperature and the abundance of *P. solenopsis* (*r*-values; +0.65 and +0.65) throughout the two growing seasons, respectively. Furthermore, the estimated regression for the impact of this variable indicates that every 1˚C increase in the daily maximum temperature would increase the numbers of *P. solenopsis* individuals by 2.72 and 1.87 individuals per leaf during the two seasons, respectively. The actual impacts of daily maximum temperature on the abundance of *P. solenopsis* are presented in Table 4. These showed a significantly negative relation (*P. reg.* value was -3.92) in the 2022 season and an insignificantly negative effect in the 2023 season (*P. reg.* value was -2.58). In this context, the values of partial correlation were (-0.49 and -0.33) and the values of the t-test were (-2.46 and -1.51) during the two growing seasons, respectively. The maximum temperature was responsible for certain changes in the *P. solenopsis* abundance by 8.56 and 3.43% per season, respectively (Table 4).

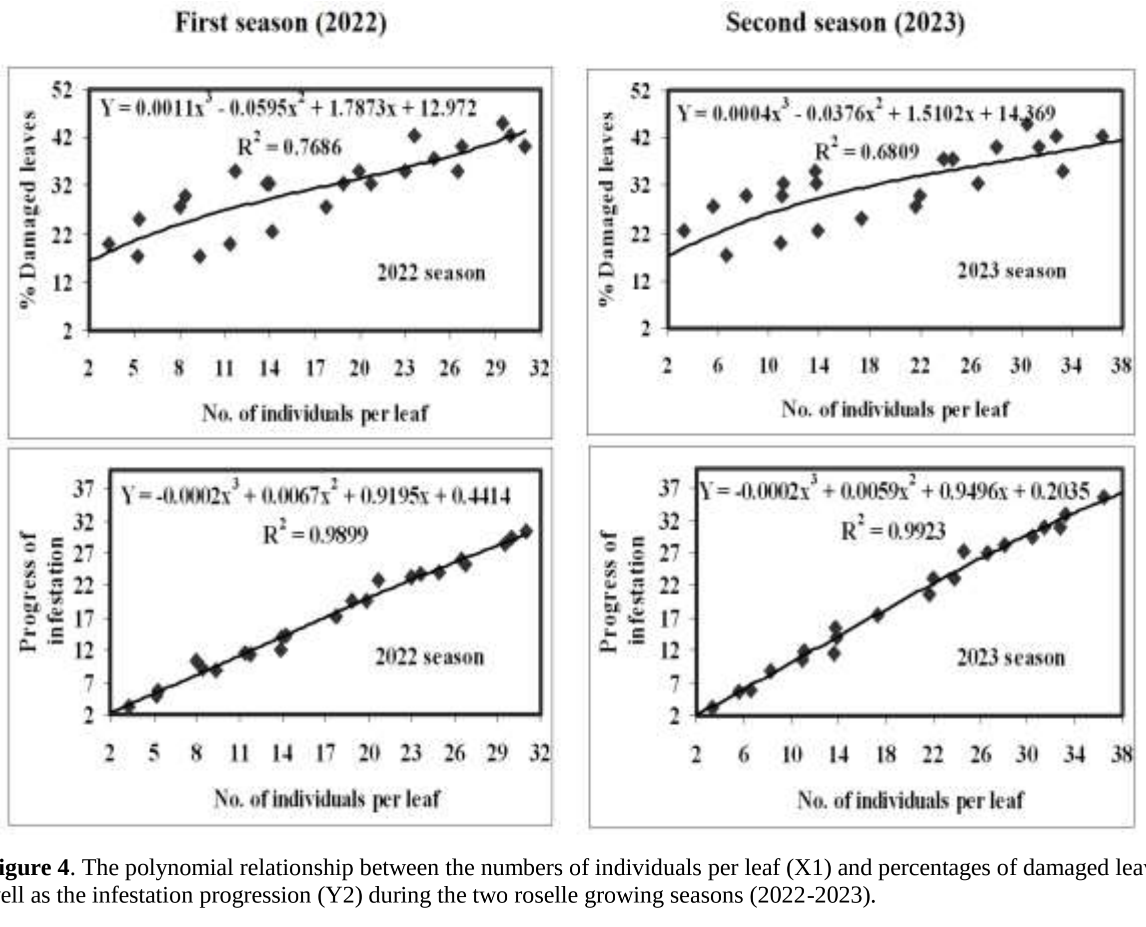


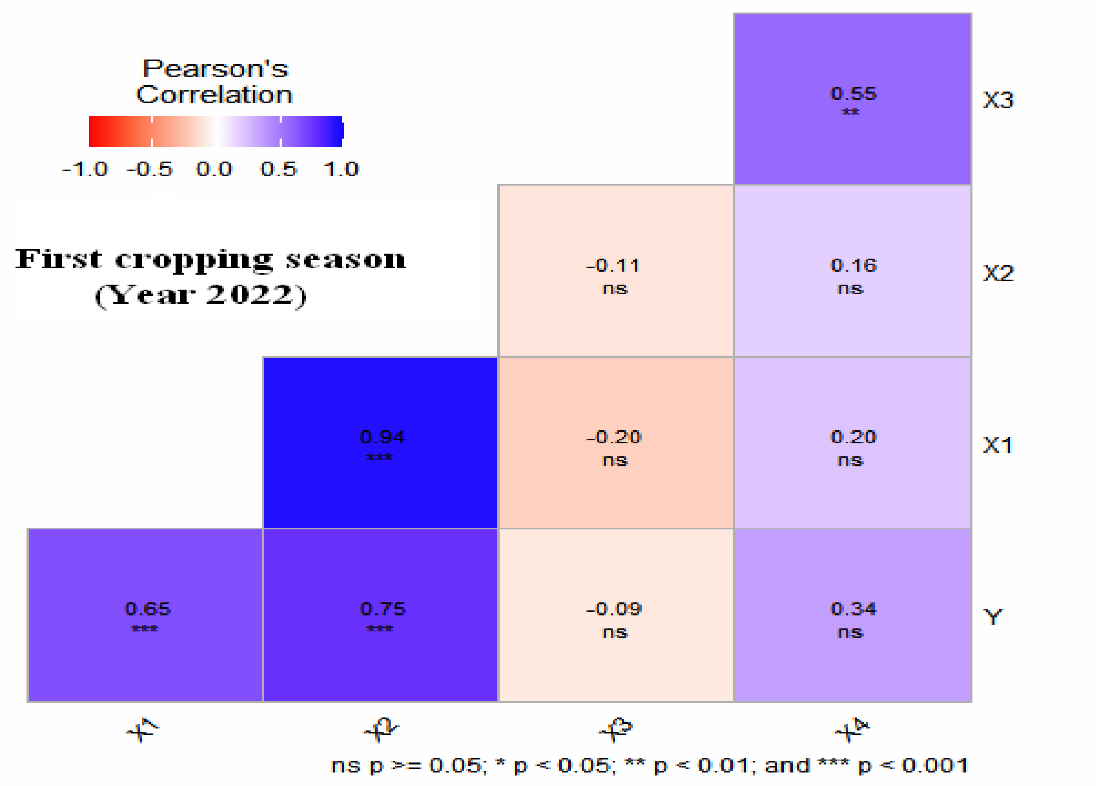
Figure 4. The polynomial relationship between the numbers of individuals per leaf (X1) and percentages of damaged leaves (Y1), as well as the infestation progression (Y2) during the two roselle growing seasons (2022-2023).

B- Effect of daily mean minimum temperature

The results of the statistical analysis of simple correlation (Table 4 and Fig. 5) showed highly positive significant correlations between the daily mean minimum temperature and the numbers of mealybugs for the two growing seasons (*r*-value; +0.75 and +0.68), respectively. According to the regression coefficient, an increase of 1°C in the daily minimum temperature would increase numbers by 2.59 and 2.10 individuals per leaf, during the two seasons, respectively. The partial regression analysis revealed a highly significant positive impact of daily mean minimum temperature during both seasons, with partial regression values of (5.18 and 4.72) in the two seasons. Similarly, the partial correlation coefficients were +0.69 and +0.56 for the two seasons, respectively. The t-test values were 4.18 and 2.92 for the first and second seasons, respectively. The minimum temperature was the most effective variable for the variance in mealybug numbers by 24.76% and 12.76% in the 2022 and 2023 seasons, respectively.

C- Effect of the mean relative humidity:

As shown in Table (4) and Fig. (5), revealed a weak negative insignificant correlation between the daily mean relative humidity and the number of mealybugs (*r*-value = -0.56) in the 2022 cropping season and an insignificantly positive (*r*-value = +0.08) in the 2023 cropping season. Additionally, the calculated regression coefficient (b) for the effect of this variable indicated that for every 1% increase, the population would decrease by 0.31 individuals/leaf in the 2022 season and increase by 0.35 individuals/leaf in the 2023 season (Table 4).



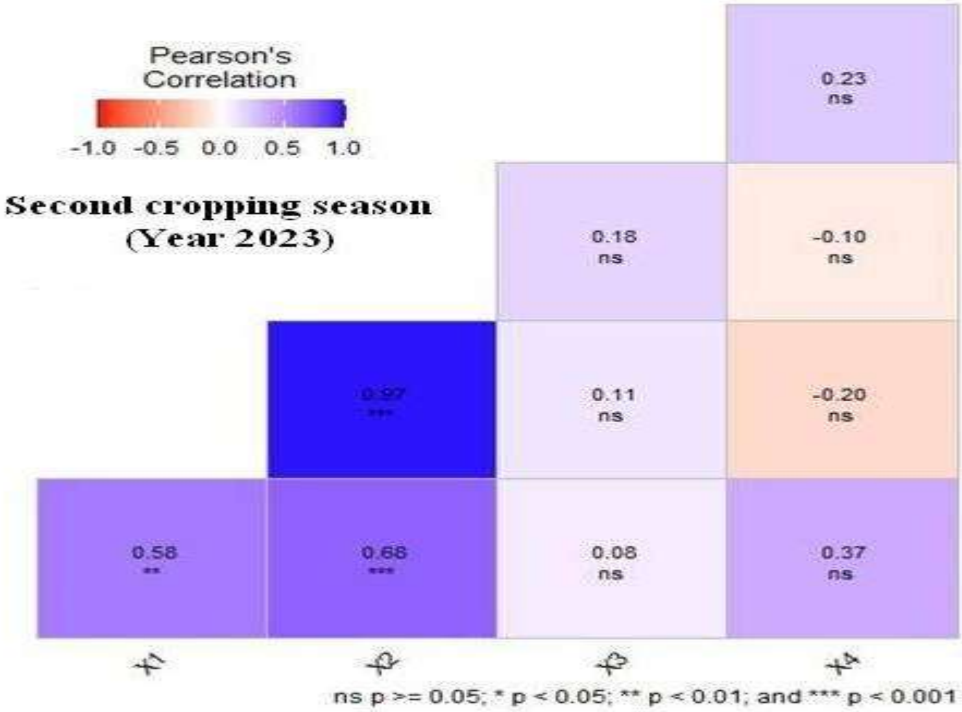


Figure 5. Correlation of Phenacoccus solenopsis estimates and weather parameters and biotic variables during the two seasons [2022 and 2023].Range −1 to +1 indicates the correlation coefficient of them. Y- pest counts, X1- Max. temp., X2- Min. Temp., X3- R.H.%, and X4- plant growth

Table 4. Multiple linear regression models between population fluctuations of *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) and weather parameters and biotic variables over the two cropping seasons (2022 and 2023)

Season	Tested Variables	Simple correlation and regression values				Partial correlation and regression values				Efficiency %	Rank	Analysis variance			
		r	b	S.E	t	P. cor.	P. reg.	S.E	t			F values	MR	R^2	E.V.%
2022	Max. temp (X_1)	0.65	2.72	0.68	4.02 **	-0.49	-3.92	1.59	-2.46 *	8.56	3	12.91 **	0.85	0.73	73.10
	Min. temp (X_2)	0.75	2.59	0.48	5.39 **	0.69	5.18	1.24	4.18 **	24.76	1				
	R.H.% (X_3)	-0.09	-0.31	0.70	-0.44	-0.47	-1.26	0.54	-2.34 *	7.76	4				
	Plant growth (X_4)	0.34	0.43	0.26	1.69	0.58	0.63	0.21	3.08 **	13.38	2				
	Plant growths (X_4, X_4^2, X_4^3)											52.48 **	0.94	0.89	88.73
	Combined effect (X_1 to X_4^3)											40.18 **	0.97	0.93	93.41
2023	Max. temp (X_1)	0.58	1.87	0.56	3.31 **	-0.33	-2.58	1.70	-1.51	3.43	4	11.97 **	0.85	0.72	71.58
	Min. temp (X_2)	0.68	2.10	0.48	4.36 **	0.56	4.72	1.62	2.92 **	12.76	2				
	R.H.% (X_3)	0.08	0.35	0.90	0.39	-0.34	-0.87	0.55	-1.57	3.71	3				
	Plant growth (X_4)	0.37	0.58	0.31	1.85	0.57	0.65	0.21	3.02 **	13.66	1				
	Plant growths (X_4, X_4^2, X_4^3)											51.47 **	0.94	0.89	88.53
	Combined effect (X_1 to X_4^3)											26.34 **	0.95	0.90	90.29

Where: r = Simple correlation; b = Simple regression; P. cor. = Partial correlation; MR = Multiple correlation; P. reg.= Partial regression; R^2= Coefficient of determination; E.V% = Explained variance; S.E = Standard error; * Significant at $P \leq 0.05$; ** Highly significant at $P \leq 0.01$

The observed impact of daily mean relative humidity, as indicated by the partial regression values, demonstrated a significant negative influence in the 2022 cropping season (*P. reg.* value = -1.26) and an insignificantly negative effect in the 2023 cropping season (*P. reg.* value = -0.87). The partial correlation values were -0.47 and -0.34, respectively, while the t-test values were -2.34 and -1.57 for the two seasons, respectively. This factor accounted for a 7.76% change in the number of mealybugs in the 2022 season cropping, and its impact was reduced to 3.71% in the 2023 season cropping (Table 4).

D- Effect of the biotic factor (plant growth development, i.e., WAS):

As shown in Table (4) and Fig. (5) revealed that the simple correlation coefficient (r) between the plant growth development and *P. solenopsis* counts was insignificantly positive (*r*-value = 0.34 and 0.37) during the two successive seasons, respectively. At the same time, the estimated regression coefficient (b) for the effect of this factor indicated that for every additional week of roselle age, the numbers of *P. solenopsis* increased by 0.43 and 0.58 insects per leaf in the 2022 and 2023 cropping seasons, respectively. The actual relationship between the roselle plant growth development and the *P. solenopsis* counts was determined by the partial regression values (Table 4), which was highly significantly positive (*P. reg.* value = 0.63 and 0.65) during the two cropping seasons, respectively. Additionally, the partial correlation values were (0.58 and 0.57) and the t-test estimates were (3.08 and 3.02) or the two seasons, respectively. Plant growth development was the biotic variable that was most effective for explaining variance in *P. solenopsis* counts by 13.38% and 13.66% during the two seasons, respectively (Table 4).

E- The combined effect of weather parameters and biotic variables on* P. solenopsis *abundance on roselle plants

As seen in Table 4 the combined effects of these tested factors on the estimates of *P. solenopsis* during the two growing seasons was very significant, with the F-values being 12.91 and 11.97 respectively. Across each season, the amounts of variability were 73.10 and 71.58%, respectively.

3.5.2. Effect of plant growth development

The biotic parameter analyzed was related with plant growth development, [*i.e*. the periods after sowing, in weeks) (X_4)] at the period of *P. solenopsis* population estimates (Y) were estimated to use a third-degree nonlinear equation. It showed a very significant relationship with the change in *P. solenopsis* populations with F-values being 52.48 and 51.47 for each season. The explained variance percentages were 88.73 and 88.53% in the two cropping seasons, respectively, as shown in Table (4) and illustrated in Figure (6). The polynomial (non-linear) regression equations are:

First cropping season (2022)

$$Y = -0.0795\, X_4^3 + 2.656\, X_4^2 - 5.4551\, X_4 - 54.479 \quad R^2 = 0.8873$$

Second cropping season (2023)

$$Y = -0.0099\, X_4^3 + 0.3356\, X_4^2 - 0.85\, X_4 - 7.033 \quad R^2 = 0.8853$$

3.5.3. Influence of all studied parameters on P. solenopsis counts

Multiple linear regression was used to determine the influences of weather parameters and biotic variables on *P. solenopsis* abundance on roselle plants. All of these factors had significant change in the numbers of *P. solenopsis*, with F values reaching 40.18 and 26.34 in the 2022 and 2023 cropping seasons, respectively. The explained variance values were 93.41and 90.29% over each cropping season, respectively (Table 4).

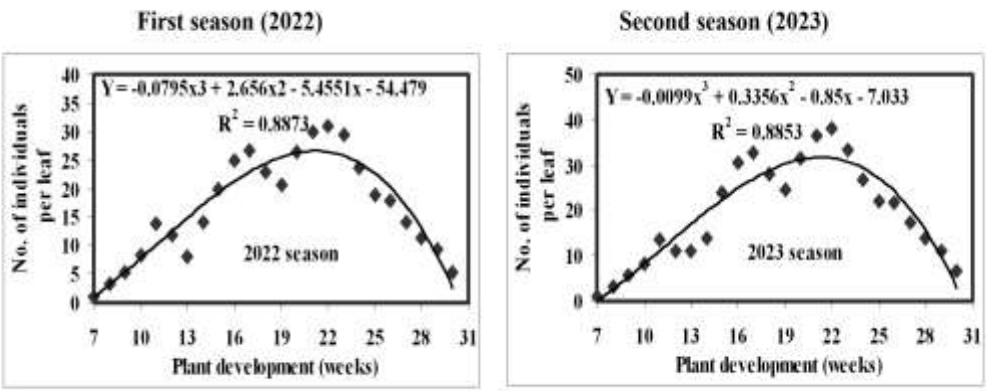


Figure 6. The polynomial relationship between the plant development (X4) and numbers of individuals per leaf (Y), through the two growing seasons (2022-2023).

4. Discussion

The mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Coccomorpha: Pseudococcidae), is an invasive species that severely damages (Vennila *et al*. 2011, Babasaheb and Suroshe 2015) and threatens many crops in Egypt (Saad 2021 and Bakry *et al*. 2024). Mealybug outbreaks on the roselle crop in Egypt occasionally resulted in significant commercial yield losses. The management of mealybugs on roselle in Egypt has acquired very little attention. The objective of this research was to investigate and monitor the infestation, and seasonal occurrence of *P. solenopsis* on roselle plants (cv. 'Balady') and estimate the relationship between the abiotic conditions and plant growth development on the abundance and population dynamics of *P. solenopsis*. This was achieved by conducting weekly monitoring of the pest for 48 weeks throughout the two growing seasons of 2022 and 2023 in a roselle field in Esna, Luxor, Egypt. Understanding the incidence of mealybugs and the impact of the weather enables management of pest control strategies to use resources in an environmentally responsible, current, and effective manner (Bakry and Fathipour, 2023). Furthermore, if the relationship between seasonal abundance of pests and meteorology is well comprehended, proper decisions can be taken on the timing and mode of the control approach. Therefore, monitoring and early detection are necessary to estimate the infestation and damage on the roselle plants. Studying population dynamics aids in comprehending the impact of both living and non-living elements on pest populations and scale of infestation and damage, according to Bakry *et al*. (2023b). Three variables were used to express the behavior and activity of *P. solenopsis* on roselle plants, namely, numbers of insects, percentages of damaged leaves, and infestation progression that damaged roselle plants. These were estimated weekly until harvest time. Based on our findings, *P. solenopsis* invasion and damage began on roselle plants from May 13th, *i.e.*, aged 7th WAS *i.e.*, in the 20th standard meteorological week (SMW), and fluctuated until the 43rd SMW (time of crop maturity) in each season. Bakry *et al*. (2023a) had concluded that the best time to estimate the population of *P. solenopsis* on okra plants was twenty weeks after planting. However, five weeks after planting was the least suitable period for activity in both seasons. Our study investigated three variables studied, namely the number of insects, the percentage of damaged leaves, and the development of the infestation, which have three distinct peaks on hibiscus plants in each season. The results indicated an increase in the number of *P. solenopsis*, the percentage of damaged leaves, and the infestation progression on roselle plants in the second roselle-growing season (2023) compared to the first growing season (2022). Many of studies showed two or three *P. solenopsis* peaks of abundance per season, depending on the host plant species and the location in Egypt. According to Nabil (2017), *P. solanopsis* exhibited three or four peaks of activity on eggplant during the period of the season. According to Abd-El-Razzik (2018), *P. solenopsis* was found on mulberry trees in three generations every year. According to Nabil and Hegab (2019), *P. solenopsis* offers two or three generations of maize plants per season. Abd-El-Mageed*et al*. (2020) noted three activity peaks on the maize plants. Bakry (2022) and Bakry& Abdel-Baky (2024) mentioned that *P. solenopsis* produced three overlapping generations on maize plants every season. Bakry *et al*. (2023a) reported three peaks in population numbers and infestation incidences of *P. solenopsis* on okra plants. Bakry and Aljedani (2023) and Bakry *et al*. (2023b) reported that *P. solenopsis* had three seasonal peaks on maize plants, Climate change has also significantly impacted on the growth, development, spread and population dynamics of insect pests. The effect of both climate variables and the roselle growth development on the *P. solenopsis* in terms of its numbers was extremely important during the two seasons. As is known, these weather variables are subject to change from one season to another. Therefore, by analyzing data on weather factors and weekly plant growth throughout the two growing seasons, the average daily minimum temperature and plant growth were the most accurate variables responsible for causing differences in population densities. On the contrary, relative humidity was the least influential variable on the independent variables studied in the two seasons. Williams and Dixon (2007)noted that the condition of mealybug species infestations can be significantly influenced by plant phenology. The spread and growth of *P. solenopsis* is positively correlated with temperature, and hot weather promotes the development and spread of the pest, Dhawan *et al*. (2009). According to Kumar et al. (2013), there was a positive relationship between temperature and mealybug activity. El-Zahi and Farag (2017) mentioned that *P. solenopsis* was most affected by relative humidity. Nabil (2017) indicated that the maximum and minimum temperature, and relative humidity showed favorable relationships with the *P. solenopsis* population. According to Abd El-Razzik (2018), the RH% had a negative and insignificant effect on the *P. solenopsis* population, but there was a positive and highly significant simple correlation between the temperature and population. Nabil and Hegab (2019) mentioned that the populations of female *P. solenopsis* and the maximum temperature have a substantial positive association. The population of females seemed to be significantly impacted negatively by the relative humidity. According to Zia and Haseeb (2019), there was a positive correlation between relative humidity and a negative correlation with maximum temperature in the *P. solenopsis* population. Elbahrawy *et al*. (2020) discovered an important positive correlation between *P. solenopsis* numbers and maximum temperature during the summer months. In Qalyubia, the second summer and autumn seasons had an important connection with relative humidity, whereas the first season had an extremely important association with it. Bakry and Fathipour (2023) mentioned that daily mean relative humidity was the most significant in explaining differences in *P. solenopsis* estimates on okra plants for the 2021 season, however, the daily mean minimum temperature was the main variable affecting population variations in the 2022 season. However, the daily maximum temperature was the least one in count variations in the two cropping seasons.

5. Conclusion

The infestation by *P. solenopsis* individuals commenced on roselle plants in the interval from May 13th, i.e., the 7th week old after sowing (WAS) i.e., through the 20th standard meteorological week (SMW), and fluctuated until the 43rd SMW (time of crop maturity) in each season. In addition, the general averages of *P. solenopsis* individuals during the second cropping season (2023) were higher than those in the first cropping season (2022). In both seasons, *P. solenopsis* abundance increased steadily in roselle in July and August, showing that the pest needs to be managed before it achieves its peak levels to prevent the infestation from harming the crop. The seasonality and population fluctuations of mealybugs in roselle were influenced by weather conditions and plant stages, these effects were highly significant, and these variables changed from season to season. Additionally, for the two cropping seasons, the coefficients of explained variance were 93.41 and 90.29%, respectively. The average daily minimum temperature was the variable that most affected the population of mealybugs in the field during both seasons. It is recommended to control mealybugs when the number of nymphs is in the highest peak. In addition, *P. solenopsis* prefers the lower surface on the bottom stratum leaves of roselle plants (based on weekly observations of the plants examined). This information can help farmers, and decision-makers reduce damage to roselle crops, and can develop plans to manage and control *P. solenopsis*.

Declarations

Contribution of the Author

Moustafa M. S. Bakry: designed the experiment, data collection, wrote the paper and performing data analysis. Amr M.M. Badawy: performing data analysis, revising the first draft of the manuscript and revising the final manuscript and interpretation of the results. Writing original draft, review and editing, methodology, and investigations are all handled by Fatma, M. Hussien and Eman A. Shehata.

Data availability:

This published article contains all of the data created or analyzed during this investigation.

Conflicts of Interest:

The authors declare that they have no conflict of interest.

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