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RESEARCH ARTICLE

Spatial Distribution and Abundance of the Mealybug, *Phenacoccus solenopsis* (Hemiptera: Pseudococcidae) Infesting Okra Plants

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Abstract

Phenacoccus solenopsis Tinsley (Hemiptera: Pseudococcidae), poses a significant threat to newly targeted okra plants. This pernicious pest can be found on all plant parts, leading to desiccation and ultimate demise. Our study aimed to examine the spatial distribution pattern of *P. solenopsis* infestation in okra plants, specifically focusing on the Balady cultivar, over two consecutive seasons (2021-2022) in the Luxor region of Egypt. We employed insect counts and determined the percentage of infested plants to characterize the insect population. Our findings revealed that *P. solenopsis* infestation on okra plants emerged five weeks after planting (WAP) and persisted until harvest in every season. During each season, we observed three distinct peaks in population numbers and infestation rates of *P. solenopsis*. Notably, the initial season exhibited higher overall quantities of *P. solenopsis* compared to the subsequent season. At 20 WAP, we observed the most suitable time for population estimates to increase, while at 5 WAP, it was the least favorable for activity during both seasons. Statistical analysis of variance demonstrated significant variations in *P. solenopsis* population estimates and infestation percentages across different inspection periods. Additionally, through nonlinear regression analysis, we elucidated the relationship between *P. solenopsis* numbers and phenological development. Data were evaluated using dispersion measures, and all *P. solenopsis* dispersal indices had substantial aggregated behavior and were strongly related to the host's phenological evolution during each season. Based on the available data, we can develop effective strategies for monitoring and controlling mealybugs in okra plants.

Keywords: distribution patterns; okra plants; *Phenacoccus solenopsis*; population density.

1. Introduction

Okra, *Abelmoschus esculentus* L. belonging to the Malvaceae family, holds significant global significance as it is widely cultivated across various regions as a crucial crop. It occupies a significant position among vegetable crops in Egypt (Abdel-Razek *et al*., 2023). Okra plants face the danger of various piercing-sucking insect pests. One particular menace is the mealybug, *Phenacoccus solenopsis* Tinsley, which is recognized as a substantial threat to numerous crops due to its role as a highly destructive pest (Sreedevi *et al*., 2013), and it is one of the most dangerous pests that attack okra plants (Mohamed, 2021; Bakry, 2022). *P. solenopsis* devastates various parts of the plant, including delicate shoots, twigs, leaf veins, branches, and fruits, through its sap-sucking behavior, causing their destruction. This pest has the potential to infest and thrive on all plant parts throughout different stages of growth (Hodgson *et al*., 2008; Aheer *et al*., 2009). This sap has a very low content of protein; therefore, this pest needs to consume a lot of it to get enough protein for

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growth and the formation of its eggs (Sahayaraj *et al*., 2014; Shehata, 2017).

A significant amount of sap is lost because of the large number of insects damaging the leaves, branches, and fruits, which then manifests as chlorosis, malformed leaves, wilting of growth tips, early leaf drop, dryness, dwarfing, wrinkles, stunting, deformation, leaf loss, and death-out plants (Babasaheb and Suroshe, 2015; Bakry*et al*., 2023). As a result of severe injury, long-term nutrient restriction harms plant growth and okra productivity (Ibrahim *et al*., 2015; Saad, 2021).

Honeydew secreted by *P. solenopsis* on the leaves led to the spread of ants and it is a favorable medium for the growth of sooty mold fungus. The plant's ability to synthesize food is therefore hindered, which could result in more leaf drops and reduce plant vitality. Additionally, toxic saliva released by the insects may cause deformed leaves, general weakness of the plant, and continued death (Arif *et al*., 2012; Sahayaraj *et al*., 2014).

In most situations, spatial distribution is one of the most distinguishing characteristics of insect populations. It is a common attribute in insect populations and a notable characteristic of ecosystems (Debouzie and Thioulouse, 1986). Without a thorough understanding of the underlying spatial distribution, no field sampling can be adequate (Taylor, 1984). Recognizing the residents' dispersion (i.e., random, regular, or aggregated) is useful for population biology and field surveillance programs (Binns *et al*., 2000). Knowledge of an insect's spatial distribution is essential for designing a management program, as is understanding the bioecology of species and forming the basis for constructing a sample protocol (Wearing, 1988; Cho *et al*., 2001).

The existing literature lacks information regarding the spatial arrangement of *P. solenopsis*. Hence, this study was conducted to establish the spatial pattern of *P. solenopsis* populations on okra plants, aiming to provide valuable insights for the development of pest monitoring and control strategies.

2. Materials and methods

Many researchers used various insect expressions to express the pest's population density. In this study, two insect terms were used, namely, insect numbers and infestation percentages.

2.1. Population fluctuation of P. solenopsis individuals and infestation percentages on okra plants

The field trials were conducted in a private okra field (Balady cultivar) at Armant district, Luxor region, Egypt, located 25º37'50" N, 32º29'52" E, to estimate the spatial dispersion pattern for monitoring estimates of *P. solenopsis* infesting okra plants during two consecutive seasons (2021 and 2022). The area of the okra field is about 4200 square meters, and it was divided into four plots (replicates), which were planted on a suitable date (1st week of February) per season. All other agronomic practices were conducted following the Egyptian Ministry of Agriculture, except for applying any chemical control.

Sampling time started with the first attack of *P. solenopsis* in the study location after a month of cultivation and continued until harvest. Forty okra leaves are randomly selected each week (ten leaves per plot). Leaf samples were gathered from the various parts of the infested plants and four main directions of the field then transported in polyethylene bags to the lab for inspection. Individuals obtained from *P. solenopsis* were identified by Prof. Dr. Fatma Moharom, Agricultural Research Center, Plant Protection Research Institute, Egypt. *P. solenopsis* total live individuals on both surfaces (upper and lower) of leaves were inspected, estimated, and counted at every investigation date.

The infested and uninfested leaf numbers per plot were estimated and counted. The infestation percentages were calculated according to the formula of Bertin *et al*. (2010):

$$A = \left(\frac{n}{N}\right) X100$$

Where, A = Percentage of infestation

n = where the infested leaves in the sample are taken.

N = The total number of inspected leaves (uninfested + infested) on each inspection date.

A total sampling was 1600 leaves, i.e. (10 leaves × 4 replicates × 20 dates × 2 seasons). Each season had 800 leaves.

2.2. *Influence of phenological evolution of plants on population estimates of P. solenopsis on okra plants*

The biotic parameter analyzed was related to plant development, i.e., to plant age [periods after planting, in weeks) (X)] at the period of mealybug population estimates. Estimation of the relationship between the population fluctuations of *P. solenopsis* and the plant development of okra cultivation (intervals after planting, in weeks) was modeled using a third-degree nonlinear equation, i.e., $Y = a + b_1X + b_2X^2 + b_3X^3$ (where Y is the population estimates of *P. solenopsis*, and a, b_1, b_2, and b_3 are constants). Bakry and Abdel-Baky (2020) utilized this method.

2.3. *Spatial distribution:*

The spatial pattern of the sample was examined using twenty-two metrics.

2.3.1. Distribution indices

Multiple measures, including the index of dispersion, clumping, crowding, and Green's index, rely on sample means and variances for their computation. (Green, 1966).

- Mean $(\bar{X})$:The average number of individuals per 10 leaves across the season.
- Range: The difference between a population's maximum mean number and its minimum for the entire season.
- The population range is defined as the maximum population density minus the minimum population density throughout the season.
- Coefficient of variance (*C.V.*): The *C.V.* values for the analysed populations were compared to measure sampling fidelity:

$$C.V. = \frac{s}{X} \times 100$$

To compare the efficacy of different sampling procedures, relative variation (R.V.) is used (Hillhouse and Pitre, 1974).

The sample's relative variation between seasons was calculated as follows:

Relative variation (*R.V.*) = (standard error/population mean) × 100.

- Ratio of variation to mean ($S^2/\bar{X}$):

The variance-to-mean ratio was the easiest tool for estimating insect distribution (Patil and Stiteler, 1974). In terms of the 'Poisson' analysis, the variance-to-mean proportion is one. Less than one indicates a positive binomial distribution, and more than one indicates a negative binomial distribution. The variance-to-mean ratio can be used to classify the dispersion of a population, with ($S^2/\bar{X}$) = 1 indicates a random distribution, < 1 indicates a regular distribution, and > 1 indicates an aggregated distribution.

- To determine the dispersion of *P. solenopsis*, the Lewis index (I_L):was determined using the following equation:

$$I_L = \sqrt{S^2/\bar{X}}$$

The results of this indicator revealed that > 1 indicates a contagious, < 1 indicates a regularity, and = 1 indicates a random distribution.

- Cassie index (*Ca*):

$$Ca = (S^2 - \bar{X})/\overline{x^2}$$

When *Ca*> zero, *Ca* = zero, and *Ca*<zero, the distribution pattern is aggregative, random, and uniform, respectively (Cassie, 1962).

The negative binomial distribution (*K* value) is one measure of aggregation that must be applied to insect species with an aggregated spatial distribution. When *k* values are low and positive (*k*< 2), they indicate a highly aggregated population; when *k* values range from 2 to 8, they indicate moderate aggregation; and when values exceed 8 (*k*> 8) they indicate a random dispersion (Southwood, 1995; Costa *et al.*, 2010).

$$k = \overline{x^2}/(S^2 - \bar{X})$$

$I_{D=(n-1)}s^2/\bar{X}$

The I_D values outside of a confidence interval restricted by *n*-1 degrees of freedom and set probability levels of 0.95 and 0.05, for example, would indicate a significant divergence from a random dispersion (Kuno, 1991).

This statistic can be investigated using the Z test as follows:

$Z = \sqrt{2I_D} - \sqrt{(2V - 1)}$

V=n-1

The distribution pattern would be random if 1.96 ≥ Z≥ -1.96, but uniform and aggregated if Z < -1.96 or Z > 1.96, respectively (Patil & Stiteler 1974).

- David and Moore's index, David and Moore (1954) of mean clumping (I_{DM}):

$(I_{DM}) = (S^2/\bar{X}) - 1$

With greater aggregation, the David and Moore index of clumping values rises. The distribution is random if the index value is zero, (+) for negative binomial distribution (aggregated), and (-) for positive binomial distribution (regular).

- Lloyd's index m^* :

Lloyd proposed the term "mean crowding" to describe the effect of mutual interference or competition among individuals.

$m^* = \bar{X} + [(S^2/\bar{X})] - 1$

Mean crowding is strongly reliant on the degree of clumping and population density as an index. Lloyd created the patchiness index, which is stated as the ratio of mean crowding to the mean, to exclude the effect of density variations. Like the variance-to-mean ratio, the index of patchiness is influenced by the size of the quadrat (Lloyd, 1967).

- The index of patchiness (I_P): is proportional to the size of the quadrat:

$I_P = (m^*/\bar{X})$

It's a random pattern if *IP* = 1, a regularity pattern if it's less than 1, and aggregated if it's larger than 1.

- Green's index(*GI*): This index is a variant of the cluster size index that is unaffected by n. (Green, 1966).

$GI = [(S^2/\bar{X}) - 1]/\,(n - 1)$

If GI > zero or (+) values, it indicates aggregated dispersion, while *GI* values (-) indicate regular dispersion, and *GI* equals zero or negative values closer to zero indicate randomness.

- An aggregation index (1/*k*) (Southwood and Henderson, 2000), also known as Cassie's index, was used to assess the temporal changes in the pest population's spatial pattern over the study seasons. $1/K = (m^*/\bar{X}) - 1$

If 1/*k* is less than zero, 1/*k* equals zero, or 1/*k* exceeds zero, the spatial distribution is said to be regular, random, or aggregation, respectively (Feng and Nowierski 1992).

- The aggregations of population (λ) **(**Blackith, 1961) were used to investigate the reasons for the insect population's aggregation. It was calculated as follows:

$\lambda = m/2kx\gamma$

Where, $y = X^2_{0.5}$, when the degree of freedom rate is 2*K*. The aggregation of pest individuals is produced by environmental variables when λ < 2; while, if λ > 2, The observed phenomenon is a result of either the aggregation pattern itself or the interaction between the aggregation behavior and the surrounding environment. (Li *et al*., 2017).

The data obtained were subjected to analysis using SPSSProgram software (1999) and graphically depicted using Microsoft Excel Program 2007.

3. Result and discussion

The mealybug, *P. solenopsis*, attacked the okra plants in every part of them and caused several plant malformations, as shown in Fig. 1.

3.1. Population fluctuation of P. solenopsis individuals' infestation percentages on okra plants

Weekly counts of *P. solenopsis* individuals, as well as the percentage of infestation, were registered across the two seasons (2021 and 2022) and represented in Figures (2 and 3) and Tables (1 and 2). The weekly mean counts, variance, mean of crowding, and percentages of infestation by *P. solenopsis* are also shown. The effect of plant development on *P. solenopsis* abundance and infestation was assessed based on a count of the average number of individuals per 10 leaves per inspection date.

3.1.1. P. solenopsis population

The results indicated that *P. solenopsis*-infested okra plants appeared five weeks after planting (5 WAP) and continued until harvest per season, with three peaks of seasonal abundance per season, which were recorded in the 9, 15, and 20 WAP in 2021 and 2022 seasons, as shown in Tables (1 and 2).

However, the general averages of total live numbers of *P. solenopsis* during the first season were higher as compared to the second season. The general mean number of total live *P. solenopsis* individuals was 210.80 ± 14.93 and 205.31 ± 14.38 individuals per 10 okra leaves in 2021 and 2022seasons, respectively (Tables 1 and 2).

At 20 weeks old after planting, it was the most appropriate time for *P. solenopsis* population estimates to increase, while 5 WAP was the least appropriate for activity for both seasons.

Figure 1. Symptoms of *Phenacoccus solenopsis* invaded okra plants in every part of them and caused several plant malformations.

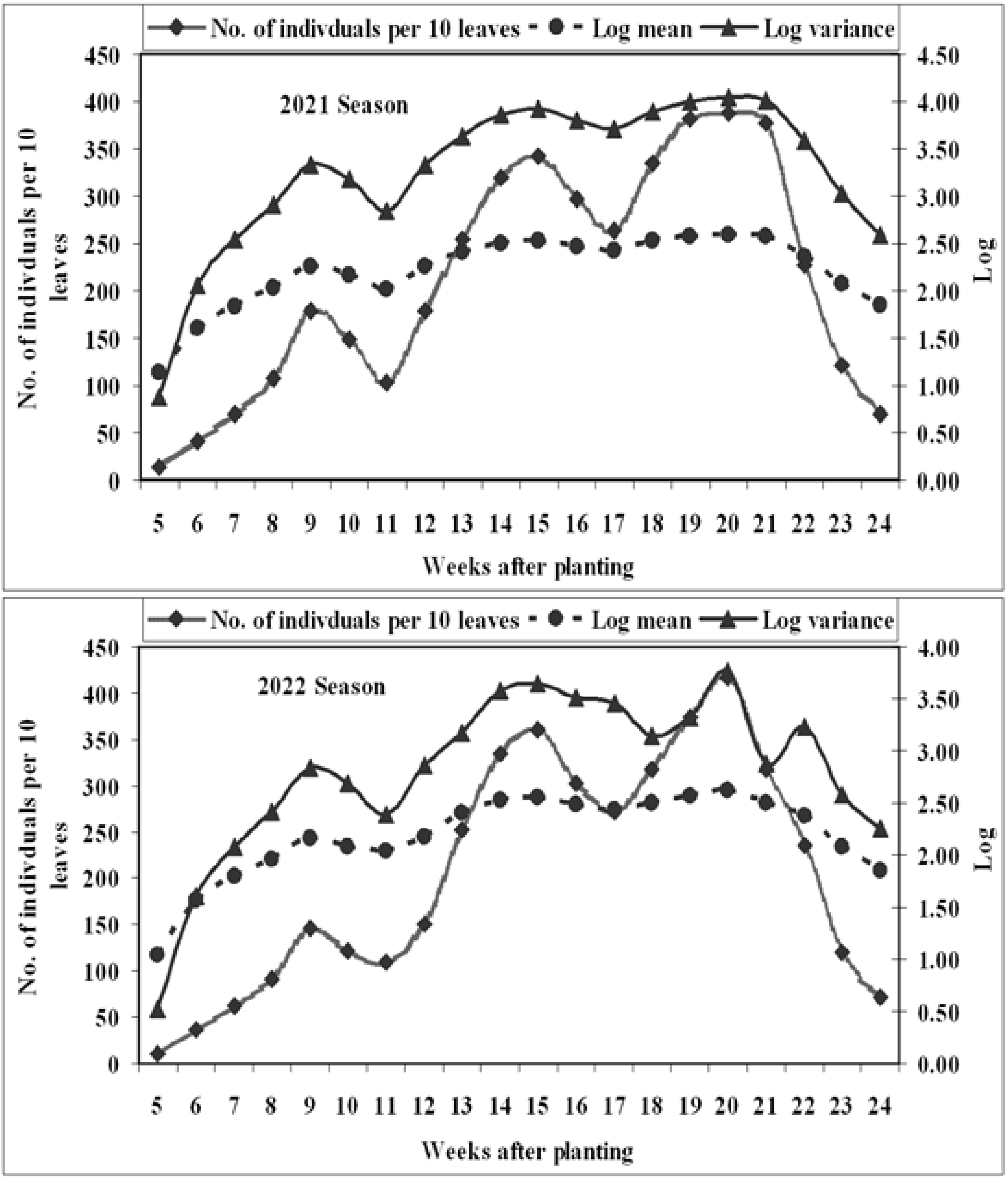

Figure 2. Weekly mean counts, variance and mean of crowding of *P. solenopsis* on okra plants at Armant district, Luxor Governorate during 2021 and 2022 seasons.

By the time the plant was 20 weeks old after planting in the two succeeding seasons, the greatest values of the log mean population and the average crowding of the total alive population for *P. solenopsis* had been recorded. The highest variance values for the population and log variance were noted simultaneously (20 WAP) for each season (Tables 1 and 2).

The analysis of variance confirmed the presence of significant differences in the population estimates and percentages of infestation by *P. solenopsis* at the various inspection times (L.S.D. values of 16.20 and 15.90) throughout the two seasons, respectively (Tables 1 and 2).

Table 1. Weekly mean counts, variance, mean of crowding, and percentages of infestation by *P. solenopsis* on okra plants at Armant district, Luxor Governorate during 2021 season.

Sampling date	Weeks after planting (WAP)	Mean number of individuals per 10 leaves ± S.E.	Variance	Log mean	Log variance	*m**	Infested leaves %	Variance	Log mean	Log variance	*m**
March	5	13.75 ± 1.38	7.58	1.14	0.88	13.30	20.00 ± 4.08	66.67	1.30	1.82	22.33
	6	41.00 ± 5.40	116.67	1.61	2.07	42.85	25.00 ± 5.00	100.00	1.40	2.00	28.00
	7	69.25 ± 9.38	351.58	1.84	2.55	73.33	32.50 ± 6.29	158.33	1.51	2.20	36.37
	8	108.00 ± 14.33	821.33	2.03	2.91	114.60	35.00 ± 5.00	100.00	1.54	2.00	36.86
April	9	178.25 ± 23.40	2190.92	2.25	3.34	189.54	40.00 ± 7.07	200.00	1.60	2.30	44.00
	10	148.50 ± 19.36	1499.67	2.17	3.18	157.60	42.50 ± 4.79	91.67	1.63	1.96	43.66
	11	102.50 ± 13.24	701.67	2.01	2.85	108.35	37.50 ± 2.50	25.00	1.57	1.40	37.17
	12	179.25 ± 23.20	2152.92	2.25	3.33	190.26	40.00 ± 5.77	133.33	1.60	2.12	42.33
May	13	255.00 ± 33.08	4376.00	2.41	3.64	271.16	42.50 ± 4.79	91.67	1.63	1.96	43.66
	14	319.25 ± 42.81	7331.58	2.50	3.87	341.22	45.00 ± 5.00	100.00	1.65	2.00	46.22
	15	342.50 ± 46.15	8521.00	2.53	3.93	366.38	47.50 ± 2.50	25.00	1.68	1.40	47.03
	16	296.25 ± 39.83	6344.25	2.47	3.80	316.67	42.50 ± 2.50	25.00	1.63	1.40	42.09
June	17	264.00 ± 35.77	5117.33	2.42	3.71	282.38	40.00 ± 4.08	66.67	1.60	1.82	40.67
	18	334.50 ± 43.98	7736.33	2.52	3.89	356.63	45.00 ± 5.00	100.00	1.65	2.00	46.22
	19	381.25 ± 50.43	10172.92	2.58	4.01	406.93	50.00 ± 4.08	66.67	1.70	1.82	50.33
	20	387.50 ± 52.50	11025.00	2.59	4.04	414.95	52.50 ± 2.50	25.00	1.72	1.40	51.98
July	21	377.50 ± 51.28	10517.67	2.58	4.02	404.36	55.00 ± 8.66	300.00	1.74	2.48	59.45
	22	227.75 ± 31.03	3850.92	2.36	3.59	243.66	50.00 ± 7.07	200.00	1.70	2.30	53.00
	23	120.50 ± 16.50	1089.00	2.08	3.04	128.54	45.00 ± 6.45	166.67	1.65	2.22	47.70
	24	69.50 ± 9.84	387.00	1.84	2.59	74.07	40.00 ± 7.07	200.00	1.60	2.30	44.00
General average		210.80 ± 14.93	3158.64	2.32	3.50	224.78	41.38 ± 1.40	138.67	1.62	2.14	43.73
F value		24.00					5.20				
L.S.D. at 0.05 level		16.20 *					12.14 *				

*m *= mean of crowding; S.E. = Standard error; L.S.D. = Least significant difference; * Highly significant at $P \leq 0.01$.*

Table 2. Weekly mean counts, variance, mean of crowding, and percentages of infestation by *P. solenopsis* on okra plants at Armant district, Luxor Governorate during 2022 season.

Sampling date	Weeks after planting (WAP)	Mean number of individuals per 10 leaves ± S.E.	Variance	Log mean	Log variance	*m**	Infested leaves %	Variance	Log mean	Log variance	*m**
March	5	11.00 ± 0.91	3.33	1.04	0.52	10.30	20.00 ± 4.08	66.67	1.30	1.82	22.33
	6	36.75 ± 3.20	40.92	1.57	1.61	36.86	27.50 ± 2.50	25.00	1.44	1.40	27.41
	7	62.50 ± 5.48	120.33	1.80	2.08	63.43	35.00 ± 2.89	33.33	1.54	1.52	34.95
	8	91.50 ± 8.15	265.67	1.96	2.42	93.40	37.50 ± 2.50	25.00	1.57	1.40	37.17
April	9	146.50 ± 13.18	694.33	2.17	2.84	150.24	42.50 ± 2.50	25.00	1.63	1.40	42.09
	10	121.75 ± 11.12	494.92	2.09	2.69	124.82	40.00 ± 4.08	66.67	1.60	1.82	40.67
	11	109.75 ± 7.88	248.25	2.04	2.39	111.01	37.50 ± 4.79	91.67	1.57	1.96	38.94
	12	151.25 ± 13.61	740.92	2.18	2.87	155.15	42.50 ± 2.50	25.00	1.63	1.40	42.09
May	13	252.50 ± 19.31	1491.67	2.40	3.17	257.41	45.00 ± 2.89	33.33	1.65	1.52	44.74
	14	334.25 ± 30.84	3805.58	2.52	3.58	344.64	52.50 ± 4.79	91.67	1.72	1.96	53.25
	15	360.50 ± 33.27	4427.67	2.56	3.65	371.78	50.00 ± 4.08	66.67	1.70	1.82	50.33
	16	302.50 ± 28.39	3225.00	2.48	3.51	312.16	47.50 ± 4.79	91.67	1.68	1.96	48.43
June	17	271.75 ± 26.67	2845.58	2.43	3.45	281.22	45.00 ± 2.89	33.33	1.65	1.52	44.74
	18	317.50 ± 18.87	1425.00	2.50	3.15	320.99	47.50 ± 2.50	25.00	1.68	1.40	47.03
	19	374.00 ± 23.01	2117.33	2.57	3.33	378.66	50.00 ± 7.07	200.00	1.70	2.30	53.00
	20	417.00 ± 38.54	5942.67	2.62	3.77	430.25	45.00 ± 6.45	166.67	1.65	2.22	47.70
July	21	317.50 ± 13.77	758.33	2.50	2.88	318.89	42.50 ± 4.79	91.67	1.63	1.96	43.66
	22	236.25 ± 20.55	1689.58	2.37	3.23	242.40	40.00 ± 4.08	66.67	1.60	1.82	40.67
	23	120.00 ± 9.70	376.00	2.08	2.58	122.13	37.50 ± 8.54	291.67	1.57	2.46	44.28
	24	71.50 ± 6.69	179.00	1.85	2.25	73.00	35.00 ± 6.45	166.67	1.54	2.22	38.76
General average		205.31 ± 14.38	996.65	2.31	3.00	209.17	41.00 ± 1.24	109.11	1.61	2.04	42.66
F value		27.10					5.12				
L.S.D. at 0.05 level		15.90 *					9.10 *				

*m *= mean of crowding; S.E. = Standard error; L.S.D. = Least significant difference; * Highly significant at P ≤ 0.01.*

3.1.2. P. solenopsis infestation

The percentage of leaf infestation by *P. solenopsis* fluctuated with increasing dates of examination of okra plants throughout the two successive seasons (Tables 1 and 2; Figures 2 and 3). The infestation percentages of pests showed three peaks for every season: 10, 15, and 19 WAP in 2021 season, and 9, 14, and 19 WAP in 2022 season. But the mean percentages of infestation were 41.38 ± 1.40 and 41.00 ± 1.24% over the two growing seasons, respectively.

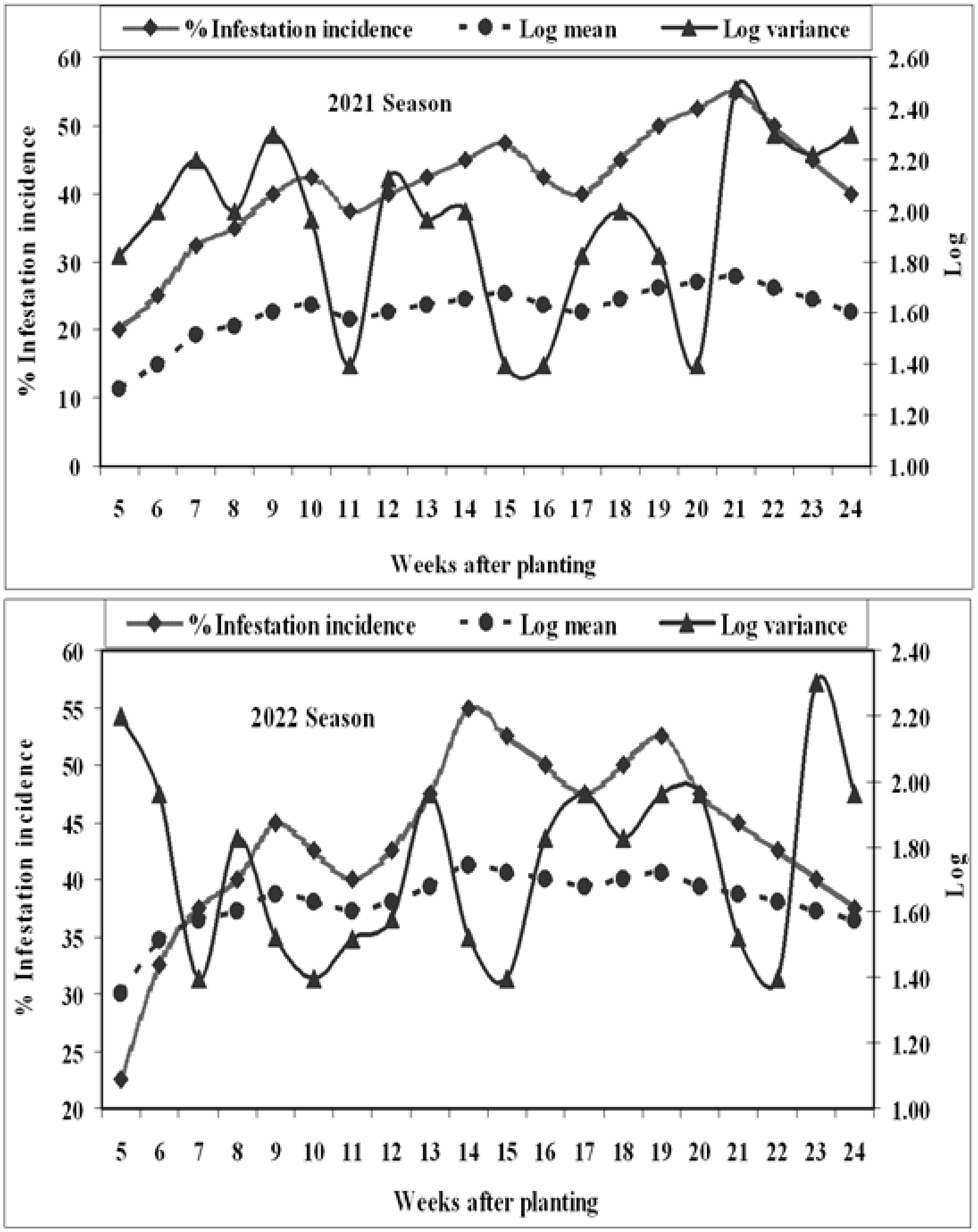

Figure 3. Infestation percentages, variance and mean of crowding of *P. solenopsis* on okra plants at Armant district, Luxor Governorate during 2021 and 2022 seasons.

The best period for *P. solenopsis* infestation to grow was 21 WAP in 2021 season and 14 WAP in 2022 season. These times recorded the highest mean infestation logarithm values. By the time the plant reached 5 WAP was the beginning of invasion for both seasons. This period recorded the lowest values of the logarithm of the average injury during the two seasons (Tables 1 and 2).

Regarding the average crowding of *P. solenopsis* infestation, it was measured at 21 weeks old after transplanting in the first season and by the time the plant was 14 WAP in the second season.

There were highly significant differences between the percentages of infestation incidences at different inspected dates during each season (L.S.D. values were 12.14 and 9.10) throughout the two seasons, respectively (Tables 1 and 2).

Most researchers point out two or three peaks per season for *P. solenopsis* based on the region and the host plant. In this respect, Nabil (2017) in Sharkia governorate, Egypt, mentioned that *P. solenopsis* had three or four peaks of activity on eggplant across the season. In Egypt, Abd-El-Razzik (2018) mentioned that three generations of *P. solenopsis* were observed per year on mulberry trees. Nabil and Hegab (2019) stated that the activity of *P. solenopsis* had two or three generations per season on maize plants. AbdEl-Mageed *et al*. (2020) reported three peaks of activity on the maize plants across the year. Mohamed (2021) in Qena, Egypt, indicated that *P. solenopsis* had three overlapping generations per season on maize plants.

3.2. Effect of host phenological development on insect populations and infestation percentage of P. solenopsis

Plant phenology refers to the days after planting (in weeks) at the date of calculating the insect population and infestation percentage. Relationships between them were modeled using a third-order polynomial.

3.2.1. Insect populations

The phenological development model is the most effective in forecasting the counts of *P. solenopsis* attacking okra plants. The explained variance was 86.62 and 88.40% over the two seasons, respectively (Fig. 4). The polynomial regression equations are:

First season (2021)

$$Y_1 = -0.3149 X^3 + 11.053 X^2 - 91.97 X + 268.22$$

$R^2 = 0.8644$

Second season (2022)

$$Y_1 = -0.3345 X^3 + 11.855 X^2 - 101.17 X + 288.92$$

$R^2 = 0.8837$

At 20 weeks old after planting (WAP), the counts of *P. solenopsis* exhibited the maximum seasonal peak of 387.50 ± 52.50 per 10 leaves in 2021 and 417.00 ± 38.54 per 10 leaves in 2022. While at 5 WAP, it had the lowest population densities for both seasons.

3.2.2. Infestation percentage

The explained variance with this equation was 80.07 and 87.98% in the 2021 and 2022 seasons, respectively, as illustrated in Fig. (4). The polynomial regression equations are:

First season (2021)

$$Y_2 = 0.0013 X^3 - 0.1825 X^2 + 5.5163X - 0.0728$$

$R^2 = 0.8007$

Second season (2022)

$$Y_2 = -0.001 X^3 - 0.2537 X^2 + 7.2914X - 7.292$$

$R^2 = 0.8798$

In general, when the okra plants were in the harvest stage *P. solenopsis* recorded the highest infestation incidence percentages during the two seasons, respectively. The infestation percentages of *P. solenopsis* fluctuated with the increase in weeks after planting okra plants throughout the two seasons (Figure 4).

Based on the data shown in Figure 4, it shows that *P. solenopsis* populations and infestations tend to decline towards the end of the vegetative growth stage. As well, the infested plants suffer more harm from *P. solenopsis* when the pest takes place in the primary growth stages as compared to subsequent stages. Therefore, infestation all over the vegetative growth of okra gives an evaluation of the reply or compensation to the loss of plant sap caused by attacking insects.

Upon estimating the behavior of *P. solenopsis* infestations observed on okra plants and its relationships with plant development, it becomes obvious that *P. solenopsis* population reaches its maximum peaks of population and infestation when the plant is in complete vegetative growth, resulting in a normal distribution curve, as illustrated in Fig. (4). Williams and Dixon (2007) mentioned that plant phenology reveals when a plant is most likely to be plagued by mealybugs. Bakry and Abdel-Baky (2023) determined the preferable date of plant age at which *Spodoptera frugiperda* infest and attack the maize plants, which may cause dangerous damage.

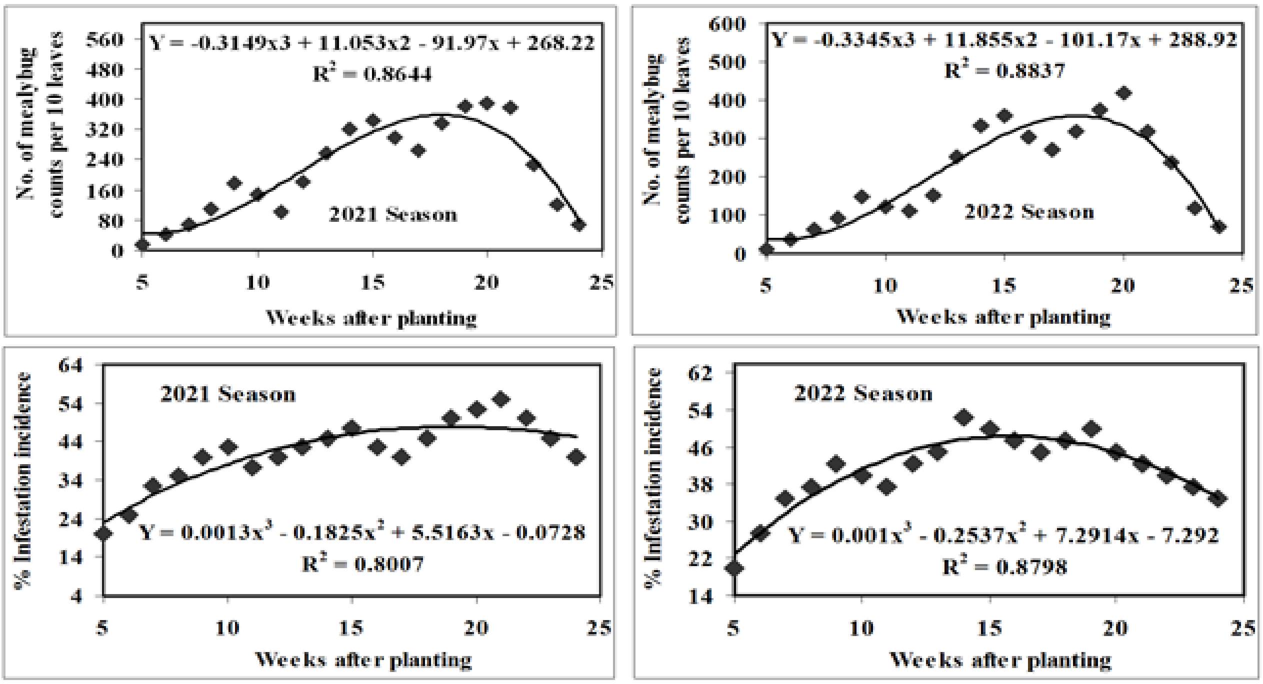

Figure 4. The nonlinear regression relationship between host phenological development (weeks old after planting) and counts of *P. solenopsis*, as well as the infestation percentages over 2021 and 2022 growing seasons.

3.3. Sampling program

As shown in Table (3), the percentage relative variation for the primary sampling data of *P. solenopsis* suggested that the pest population densities were (7.08 and 7.00%) during the two years, respectively. Furthermore, the relative differences in percentages for elementary sampling data of infestation incidences were (3.38 and 3.02%) for the first and second seasons, respectively. The relative variation accounts were quite suitable for a sampling program.

However, when other insect species and hosts were used, Bakry (2018), the proportional variance for the rudimentary sampling data of total populations of *Waxiella mimosae* (Signoret) (Coccomorpha: Coccidae) on sunt trees (*Acasia arabica*) ranged from 8.52 to 19.79 % in all seasons and across the entire year. Based on Bakry (2020) findings, the relative variation in elementary sampling data for *Parlatoria oleae* on mango trees demonstrated that the total population density was 2.41%, 2.35%, and 1.73% during the initial and subsequent years, as well as for the combined two-year period. Bakry and Arbab (2020), the proportional difference for the incipient sampling data of *Icerya seychellarum* on guava trees indicated that the overall population density was 4.07 (2017-2018), 5.62 (2018-2019), and 3.55 % (pooled).

3.4. Spatial distribution

The results in Table (3) showed that twenty-two analyses determined the distribution indices among the sample units. The distribution results utilizing the variance of the *P. solenopsis* population on okra plants and infestation incidences were more than the general average of the pest's population densities and infestations, and thus the variance-to-mean ratio (S^2/m) was greater than one in both parameters (population and infestation). As a result, the spatial distribution of *P. solenopsis* population densities and infestation occurrences was aggregative across the two seasons.

Table 3. Estimated parameters for the spatial distribution of population densities and infestation incidences by *P. solenopsis* infesting okra plants during 2021 and 2022 seasons.

Parameters		Total alive population		Infestation incidences %	
		First season (2021)	Second season (2022)	First season (2021)	Second season (2022)
1	Max.	387.50	417.00	55.00	52.50
2	Min.	13.75	11.00	20.00	20.00
3	Mean	210.80	205.31	41.38	41.00
4	Range of mean	373.75	406.00	35.00	32.50
5	Median	203.50	193.75	42.50	42.50
6	S^2	17829.33	16534.65	156.31	123.04
7	S	133.53	128.59	12.50	11.09
8	S.E.	14.93	14.38	1.40	1.24
9	*C.V.*	63.34	62.63	30.22	27.05
10	*R.V.*	7.08	7.00	3.38	3.02
11	$S2/\bar{X}$	84.58	80.53	3.78	3.00
12	Lewis Index	9.20	8.97	1.94	1.73
13	Cassie index	0.40	0.39	0.07	0.05
14	*k*	2.52	2.58	14.89	20.49
15	I_D	6681.77	6362.19	298.46	237.07
16	Z test	103.07	100.27	11.90	9.24
17	I_{dm}	83.58	79.53	2.78	2.00
18	$m*$	294.38	284.85	44.15	43.00
19	I_P	1.40	1.39	1.07	1.05
20	*GI*	1.06	1.01	0.04	0.03
21	1/*k*	0.40	0.39	0.07	0.05
22	λ	9.60	7.44	0.04	3.92

The Lewis index of the population and the infestation by pests were much higher than one, indicating highly contagious dispersion. As the distribution of population and infestation incidences by pest was greater than zero, two expressions of *P. solenopsis* had an aggregated dispersion. The negative binomial dispersion (*K*) of the *P. solenopsis* population densities ranged from 2 to 8 throughout the two seasons, implying moderate congregation, whereas infestation occurrences greater than 8 (*k*> 8) indicate a random assemblage across the two seasons.

The index of clumping (IDM) values of the population densities and infestation occurrences by pest were positive for the negative binomial. The Z-test coefficients were greater than 1.96. Green's index was greater than zero, and the patchiness index was greater than one. Over two years, all of these indices revealed an aggregated distribution of population densities and infestation incidences by pests. The temporal fluctuations in the distribution of population densities and infestation occurrences by pest during each season as calculated by 1/k (the aggregation indicator). The values were greater than zero, indicating an aggregative form that dispersed with time.

The values of aggregations (λ) were all greater than 2 in *P. solenopsis* population densities throughout all seasons of study, showing that the aggregation phenomena may be generated by aggregation behavior in combination with environmental fluctuations (Table, 3).

On the other hand, the aggregations of pest infestation occurrences percentages were fewer than two during the first season, indicating that the aggregation phenomena could be caused by environmental fluctuations. However, during the second season, the infestation incidence aggregations were greater than 2, showing that the aggregation phenomenon may be induced by aggregation behavior in conjunction with climatic changes (Table, 3). A similar conclusion was reached with the spread of *Aulacaspis tubercularis* (Hemiptera: Diaspididae) on mango trees (Bakry and Abdel-Baky, 2020).

Additionally, there is no publicly accessible information on the spatial pattern of *P. solenopsis* in literature. Nonetheless, with a variety of pest types and hosts. Chellappan *et al*. (2013) recorded that as the population density of *Paracoccus marginatus* (Hemiptera: Pseudococcidae) increased, it was observed that the average crowding value also rose. Li *et al*. (2017) indicated that throughout May, the aggregation index, the Cassie index, and the K value of the negative binomial distribution all had values greater than zero. This would imply that *Parapoynx crisonalis* (Lepidoptera: Crambidae) larvae were grouped. Bala and Kumar (2018) identified that the Lewis index values for all inspection times of the *Chauliops fallax* (Hemiptera: Malcidae) counts infesting soybean exceeded one for all inspection times, therefore suggesting that the population dispersion was aggregated. In the study conducted by Bakry (2018), a total of 14 dispersion indices were utilized to analyse the spatial arrangement of *W. mimosae* on sunt trees. The findings revealed that all the models indicated an aggregated distribution pattern, following a negative binomial distribution, for all life stages throughout each season as well as the combined seasons from 2016 to 2018. Bakry (2020) observed the spatial distribution of *P. oleae* on mango trees using twenty-one distribution indices and concluded that all measures of distribution exhibited significant aggregated behavior each year, except for the *K* values of the negative binomial distribution of the total population, which ranged between 15 and 17 for each year over two consecutive years, implying random behavior. Bakry and Abdel-Baky (2020) mentioned that distribution indicators for *Aulacaspis tubercularis* (Newstead) (Hemiptera: Diaspididae) on certain mango cultivars reflected aggregated behavior throughout the two successive years (2017/2018 and 2018/2019). Bakry and Arbab (2020) used distribution indices to study the spatial distribution of *I. seychellarum* on guava trees, which revealed aggregated behaviour over the full year. On a few wheat cultivars and lines, Bakry and Shakal (2020) documented the spatial distribution pattern of *Schizaphis graminum* (Hemiptera: Aphididae). They observed that all distribution indicators showed substantial aggregated behavior during each growing season in all the wheat cultivars and lines studied across each entire season.

4. Conclusions and recommendations

The current study focused on understanding the spatial distribution pattern for monitoring estimates of *P. solenopsis* infesting the okra plants. Right now, the okra plants are subject to infestation by *P. solenopsis*, as has been observed. It appeared on okra leaves five weeks after planting (5 WAP) and continued until harvest per season. *P. solenopsis* had three seasonal activity peaks in terms of insect numbers and three peaks regarding the percentages of infestation per season.

It is estimated that the spatial distribution of *P. solenopsis* is closely related to the okra plant phenology, and the present study confirmed that in okra plants, in young plants, that is, the initial vegetative stage, the counts and insect infestation begin to increase gradually with the increase in the development of growth, then decreases when the vegetative growth is complete. Thus, the application of control measures will depend on the plant's development (weeks after planting). The results of the current work can be considered through sampling to estimate acceptable infestation rates.

As well, every season, the data was assessed using distribution metrics, and all distribution indices revealed substantial aggregation behavior. As thorough evidence for the procedure of a pest scouting method, this trend can be explained by the above-mentioned outcomes. These investigations might be very valuable. Population counts on significantly affected plants should be done first to save time and effort. Second, the pesticide application program might be adjusted to concentrate on the areas of the plants that are most affected. However, tests need to be done to validate these concepts.

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Consent for Publication

Not applicable.

Conflicts of Interest

The authors disclosed no conflict of interest.

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