Brazilian Journal of Biology®

ISSN 1519-6984 (Print)
ISSN 1678-4375 (Online)

Original Article

Influence of weather conditions and plant growth on populations of the solenopsis mealybug (*Phenacoccus solenopsis* Tinsley) infesting maize plants

Influência das condições climáticas e do crescimento das plantas nas populações da cochonilha solenopsis (*Phenacoccus solenopsis* Tinsley) que infestam plantas de milho

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Abstract

The cotton or solenopsis mealybug, *Phenacoccus solenopsis* (Tinsley, 1898) (Hemiptera: Pseudococcidae), infests various host plants in Egypt. A study was conducted to observe the incidence of mealybugs and the possible influences of meteorological variables and plant age on the insect population of maize (single-hybrid 168 yellow maize cultivar) plants in Esna district, Luxor governorate, Egypt, in two consecutive seasons (2021 and 2022). *P. solenopsis* infested maize plants from the 3rd week of June to harvest, and had three peaks of seasonal incidence/season namely; in the 1st week of June in the 3rd/4th week of July, and the 2nd week of August. Similarly, there were three peaks in the percent of infestations per season. In the first season, the average population density of *P. solenopsis* per sample was 174.04 ± 16.93 individuals, and in the second season, 156.72 ± 14.28 individuals. The most favorable climate for *P. solenopsis* population increase and infestation occurred in August in the first season and in September in the second season, while June was less suitable in both growing seasons (as estimated by weekly surveys). The combined effects of weather conditions and plant age are significantly related to the estimates of *P. solenopsis* populations, with an explained variance (E.V.) of 93.18 and 93.86%, respectively, in the two seasons. In addition, their influences explained differences in infestation percentages of 93.30 and 95.54%, respectively, in the two seasons. Maize plant age was the most effective factor in determining changes in *P. solenopsis* population densities in each season. The mean daily minimum temperature in the first season and mean daily dew point in the second season were the most important factors affecting the percent changes in infestation. However, in both seasons, the mean daily maximum temperature was the least effective variable in population and infestation variation. This study paves the way for monitoring and early detection of mealybugs in maize; as well as the optimal climatic conditions for its development.

Keywords: solenopsis mealybug, cotton mealybug, *phenacoccus solenopsis*, population estimation, maize or corn plants, climatic conditions, maize plant age.

Resumo

A cochonilha do algodão ou solenopsis, *Phenacoccus solenopsis* (Tinsley, 1898) (Hemiptera: Pseudococcidae), infesta várias plantas hospedeiras no Egito. Um estudo foi conduzido para observar a incidência de cochonilhas e as possíveis influências de variáveis meteorológicas e da idade da planta na população de insetos de plantas de milho (cultivar de milho amarelo 168 híbrido único) no distrito de Esna, província de Luxor, Egito, em duas temporadas consecutivas (2021 e 2022). *P. solenopsis* infestou plantas de milho desde a terceira semana de junho até a colheita, e teve três picos de incidência/estação sazonal, a saber: na primeira semana de junho, nas terceira e quarta semanas de julho e na segunda semana de agosto. Da mesma forma, ocorreram três picos na percentagem de infestações por estação. Na primeira temporada, a densidade populacional média de *P. solenopsis* por amostra foi de 174,04 ± 16,93 indivíduos, e na segunda temporada, 156,72 ± 14,28 indivíduos. O clima mais favorável ao aumento populacional e à infestação *de P. solenopsis* ocorreu em agosto na primeira época e em setembro na segunda época, enquanto junho foi menos adequado em ambas as épocas de cultivo (conforme estimado por inquéritos semanais). Os efeitos combinados das condições climáticas e da idade das plantas estão significativamente relacionados com as estimativas das populações de *P. solenopsis*, com variância explicada (E.V.) de 93,18 e 93,86%, respectivamente, nas duas estações. Além disso, suas influências explicaram diferenças nos percentuais de infestação de 93,30 e 95,54%, respectivamente, nas duas épocas. A idade da planta de milho foi o fator mais eficaz na determinação das mudanças nas densidades populacionais de *P. solenopsis* em cada estação. A temperatura mínima diária média na

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Received: February 13, 2024 – Accepted: April 19, 2024

primeira época e o ponto de orvalho médio diário na segunda época foram os fatores mais importantes que afetaram as alterações percentuais na infestação. Porém, em ambas as estações, a temperatura máxima média diária foi a variável menos eficaz na variação populacional e de infestação. Este estudo abre caminho para o monitoramento e a detecção precoce de cochonilhas no milho, bem como as condições climáticas ideais para o seu desenvolvimento.

Palavras-chave: cochonilha solenopsis, cochonilha-do-algodão, *Phenacoccus solenopsis*, estimativa populacional, plantas de milho ou milho, condições climáticas, idade da planta de milho.

1. Introduction

After wheat and rice crops, maize (*Zea mays*) ranked as the 3rd important cereal crop in Egypt (Ouda et al., 2017; Bakry and Abdel-Baky, 2023a, b). Its economic importance comes as it can be used as food for humans and fodder for animals, and its derivatives are used in the manufacture of medicines, starch, ethanol, and antibiotics (Moghazy, 2021).

The cotton or Solenopsis mealybug *Phenacoccus solenopsis* (Hemiptera: Pseudococcidae), is one of the most important pests attacking maize plants in recent years (Abd El-Mageed et al., 2020; Bakry and Aljedani, 2023), which attacks several plant hosts and therefore considered polyphagous pests (Babasaheb and Suroshe, 2015). Solenopsis mealybug is a dangerous pest that damages crops around the world (Sreedevi et al., 2013) by attacking leaves, main stems, and branches of affected plants (Hodgson et al., 2008; Aheer et al, 2009; Bakry et al., 2023a) and causes great damage by sucking cell sap, deforming plants by injecting toxic saliva and excreting enormous amounts of honeydew that promotes the spread of sooty mold, which can affect photopheresis, reducing the vegetative growth of maize and increasing yield loss (Sahayaraj et al., 2015; Bakry, 2022; Bakry et al., 2024b). The insect has a gradual metamorphosis in which both the adults and the nymphs of *P. solenopsis* suck the sap from leaves, twigs, stems, and fruiting bodies, weakening the infested plants and inhibiting their growth (Bakry et al., 2023b). Flowers, buds, ripe bolls and, in the case of cotton, even the leaves fall off. As a result, the bolls of the infested plants are deformed and become smaller and smaller. The honeydew secreted by the adults and nymphs favors the development of the black cohosh fungus, which impairs photosynthetic activity (Joshi et al., 2010; Tanwar et al., 2011; Guan et al., 2012; Singh and Kumar, 2013; Suroshe et al., 2016).

The appearance of ecdysis cuticles and the increase in pest populations with an accumulation of their numbers on infested maize is a common sign of pest infestation. In addition, *P. solenopsis* is considered an important vector of virus (Saeed et al., 2007; Shah et al., 2015). Due to their ability to attack and infest the plant buds, forming waxy layers on their bodies, their control with insecticides is extremely difficult (Joshi et al., 2010). So, pseudococcid insects are referred to as "difficult-to-control pests" (Saad, 2021; Bakry et al., 2024a).

It is important to understand the bioecological information about *P. solenopsis*, including the effects of weather conditions on population dynamics that affect the insect's phenological stages and biological parameters, to develop an effective control program against it. Abiotic factors such as weather conditions have significant effects on both the maize plants and the population dynamics of Solenopsis mealybug (Woiwod, 1997). As *P. solenopsis* is a poikilothermic animal, the temperature has a major impact on the biology, activities, and growth rate of the insect (Lamb, 1992). The infestation with mealybugs can be influenced by the phenology of the plants (age of the plants). For example, phenology provides information on when a crop is most likely to be infested by mealybugs and which crops are most affected (Williams and Dixon, 2007). Solenopsis mealybug populations are affected by temperature (Kim et al., 2008), and insect growth is reduced at low temperatures (Jarosik et al., 2004). Therefore, its fecundity can be influenced by relative humidity and temperature, and the insect duration life and its developmental periods could be influenced (Kumar et al., 2013). Furthermore, an increase in humidity is negatively related to an increase in mealybug populations (Bakry and Fathipour, 2023).

This study aims to identify the factors that influence the population dynamics of mealybugs, *P. solenopsis*, on maize plants during two growing seasons 2021 and 2022. This information will help decision-makers to select an effective control program within the framework of the Integrated Pest Management (IPM) approach and strategy.

2. Materials and Methods

In this study, the population of Solenopsis mealybug was expressed by two concepts, the first is population density and the second is infestation percentage, to determine the size of the insect population.

2.1. Population studies of P. solenopsis

2.1.1. Seasonal frequency of infestation of maize plants with P. solenopsis

Field experiments were conducted on a private maize field located at (32°33'42" E, 25°15'20" N) in Esna district, Luxor governorate, in two consecutive cropping seasons (2021 and 2022). A field area of about one feddan (4200 m^2) was planted with maize plants (single hybrid 168 yellow maize cultivar). The plot was divided into four replicates of 6 m × 7 m each and sown at the scheduled time (first week of June of each season). The usual conventional cultivation practices were used, without chemical pesticide treatments. We applied nitrogen fertilizer in the form of urea with 46.5% nitrogen content at 285 $N{\cdot}ha^{-1}$, split into two equal doses. The first dose was given before the first round of irrigation, while the second one, along with potassium sulphate with 48% K_2O content at a rate of 114 kg $K_2O{\cdot}ha^{-1}$, was applied before the second round of irrigation. Additionally, we used phosphorus fertilizer in the form of superphosphate with 15.5% P_2O5 at a rate of 475 kg $P_2O{\cdot}ha^{-1}$ was added during soil preparation.

Random samples of 40 maize plants (10 plants from each replicate, approximately 10 cm long leaves per plant) were taken and examined weekly until harvest. The pest attacked the maize plants when they were 15 days old. Samples of the different stages of this pest were taken from the different parts of the infested maize plants, which were identified by specialists from the Scale and Mealybug Department of the Plant Protection Research Institute of the Agricultural Research Center in Giza, Egypt.

The leaf samples were randomly selected from different directions and layers of the plant in the experimental region. The samples were taken at regular intervals and transported to the laboratory in plastic bags, where they were examined under a stereomicroscope. The number of live insects on the upper and lower surfaces of the maize leaves was sorted individually into immature stages (nymphs) and mature stages (adult females) and then counted and recorded together, in contrast to each control date. The number of live nymphs and adult females per sample (10 leaves examined, i.e. 10 cm long leaves per plant) was counted and recorded to reflect each examination date ± standard error (SE) used to indicate the population size of the pest.

2.1.2. Percentage of infestation by P. solenopsis

The population density of *P. solenopsis* was estimated, while the percentage of infestation was calculated according to the formula of Bertin et al. (2010) (Formula 1):

$$\mathbf{A} = (\mathbf{n} \;/\; \mathbf{N}) \times \mathbf{100}. \tag{1}$$

Where **A** = the percentage of infestation.
n = the number of infested plants on which the pest first appeared.
N = the total number of plants examined (infested and non-infested) on each day of the study.
- The development of the plant or the age of the plant (in days).

2.1.3. Mealybug days

The duration of mealybugs' days is a measure of the total number of mealybugs counted if samples were taken every day and the totals added up. A linear relationship between the first and next sample is assumed. The number of days with mealybugs is a common measure in such studies as it allows for more accurate comparisons between different treatments, locations, and other variables observed during the trial.

The formula presented was used by Ruppel (1983) to calculate this technique (Formula 2):

$$\mathbf{D} = \mathbf{t} \times \left[(\mathbf{a1} + \mathbf{a2}) /\; \mathbf{2} \right] \tag{2}$$

Where:
$\mathbf{a_1}$= Average number of pests per sample on the day before the study.
$\mathbf{a_2}$= Average number of pests per sample on the next day of testing.
t = number of days between the two inspection dates.

2.1.4. Cumulative mealybug days

The number of days with mealybugs can be estimated from more than two sampling periods. It is the sum of all aphid days, which allows the establishment of a cumulative trend, i.e. t x [(a1+a2) /2] + t x [(a2+a3)/2] + t x [(a3+a4) /2]. This method was evaluated according to Bakry et al. (2020) and Bakry and Fathipour (2023).

2.1.5. Cumulative number of mealybugs

To allow comparisons between growing seasons of different years, the seasonal abundance of *P. solenopsis* was determined. The "total cumulative population of mealybugs" was calculated by summing the counts of *P. solenopsis* on the 10 leaves collected each week during the season and these procedure was done in each maize growing season. On each sampling day, the percentage of the accumulated mealybug population was calculated by dividing the sum of the estimated mealybugs up to that day by the total accumulated mealybug population. These percentages were used to represent the overall trend in population size (Bakry, 2018). The rate of weekly variance of the population was determined according to the formula of Bakry et al. (2020) as follows (Formula 3):

$$\mathbf{R} = (\mathbf{w} \;/\; \mathbf{W}) \tag{3}$$

Where:
R = rate of weekly variation
w = average number of pests in the samples for that week
W = average pest count in the previous week's samples

2.2. Effects of climatic conditions and plant age on seasonal abundance of P. solenopsis on maize plants

Mean daily maximum temperature (X_1), minimum temperature (X_2), mean percentage of relative humidity (X_3) and dew point (X_4) in Luxor governorate for two consecutive growing seasons (2021 and 2022) were determined by the Central Laboratory for Agricultural Climate (CLAC) of the Agricultural Research Center (ARC) of the Ministry of Agriculture in Giza. The flour beetle counts on the day of sampling were linked to the average climate factors of the seven days preceding the flour beetle count.

In the mealybug census, the biotic factor was examined in conjunction with the age of the plants (X_5). The relationships between these variables and the population density of mealybugs were modeled using a third-degree nonlinear Equation 4:

$$\mathbf{Y} = \mathbf{a} + \mathbf{b_1 X_5} + \mathbf{b_2 X_5^2} + \mathbf{b_3 X_5^3} \tag{4}$$

Where **Y** is the population density of mealybugs and **a**, $\mathbf{b_1}$, $\mathbf{b_2}$ and $\mathbf{b_3}$ are constants.

Following Fisher's (1950) approach, correlation and regression analyzes were performed to relate each of the independent variables (abiotic or biotic factors) to the dependent variable (*P. solenopsis* population density and infestation rate). The software MSTATC (MSTAT Development Team, 1980) and the program SPSS (1999) were applied to determine the percentage of explained variance (E.V.%) in the population size of *P. solenopsis* described by the independent parameters, and these data were presented using the program Microsoft Excel 2010.

3. Results

In the Figure 1 shows photos of the infestation of various parts of the maize plant by the mealybug *P. solenopsis*. Weekly estimates of infestation of maize plants by *P. solenopsis* in Esna district, Luxor governorate, over two growing seasons (2021 and 2022) are presented in Tables 1 and 2 and Figures 2 and 3. The weekly average values of meteorological variables and plant age are also presented. It's better to speak of seasonal abundance, which was calculated by counting the average number of nymphs and adult females per sample (10 leaves were studied, as each leaf is 10 cm long) on each sampling day.

3.1. Estimation of P. solenopsis populations

3.1.1. Seasonal abundance

3.1.1.1. A- nymphal stage

The data presented in Tables 1 and 2 and Figures 2 and 3 indicate that the overall average population density of nymphs was 148.04 ± 15.03 and 133.45 ± 13.09 individuals per sample during the two seasons. Statistical analysis of the data revealed that there were significant differences in the number of nymphs between the two seasons (F value was 4.38 and L.S.D. value was 13.79).

In the first season, the seasonal activity of *P. solenopsis* nymphs had three peaks: in the third week of July, in the second week of August and in the first week of September, when the average population was 175.00 ± 20.21, 240.00 ± 27.71 and 306.00 ± 35.33 individuals/sample, respectively. As in the second season, there were three seasonal peaks: in the fourth week of July, in the second week of August and in the first week of September, when the average population was 188.00 ± 21.18, 220.37 ± 24.82 and 260.56 ± 29.35 individuals/sample, respectively. The number of nymphs examined at the different dates in each season showed statistically very significant variations. L.S.D. values for each seasons wereof 33.68 (2021) and 28.62 (2022), as shown in (Tables 1 and 2).

3.1.1.2. B- Females adult stage

As shown in Tables 1 and 2 and Figures 2 and 3, the general average of the number of adult females per sample was 26.00 ± 2.48 and 23.18 ± 2.17 individuals / sample during the first and second growth periods, respectively.

Figure 1. The infestation of *P. solenopsis* on the different parts of maize plants: **A-** nymphs and adult *P. solenopsis* establishing the first infestation on the maize roots, **B-** *P. solenopsis* nymphs and adult *P. solenopsis* infesting the leaves, **C and D-** maize leaves and stems completely colonized with *P. solenopsis.* (the photos were taken in the third week of July 2021 in the maize field experiment) (Photo by Moustafa M. S. Bakry).

Table 1. Weekly average number of different stages of *P. solenopsis* and percentage of infestation on maize plants depending on climatic conditions in Esna district, Luxor governorate, during the first growing season (2021).

Sampling date (in weeks)		Plant age (in days)	Mean number of individuals per sample ± S.E.			% No. alive total of final total population	Infestation incidence %	Max. temp.	Min. temp.	% R.H.	Dew Point
			Nymphs	Adult females	Total						
June, 2021	3rd	16	5.00 ± 0.58	3.00 ± 0.58	8.00 ± 0.82	0.38	25.00 ± 2.89	40.34	27.39	22.73	12.19
	4th	23	18.00 ± 2.08	7.00 ± 1.35	25.00 ± 2.55	1.20	27.50 ± 2.50	39.82	28.57	19.87	10.09
July	1st	30	44.00 ± 5.08	11.00 ± 2.12	55.00 ± 5.61	2.63	35.00 ± 2.89	39.20	29.95	24.99	13.85
	2nd	37	78.50 ± 9.06	15.00 ± 2.89	93.50 ± 9.54	4.48	40.00 ± 4.08	40.06	29.01	23.72	13.31
	3rd	44	175.00 ± 20.21	28.00 ± 5.39	203.00 ± 20.72	9.72	47.50 ± 2.50	41.27	31.89	26.17	15.96
	4th	51	103.00 ± 11.89	20.00 ± 3.85	123.00 ± 12.55	5.89	35.00 ± 2.89	41.38	30.98	22.33	13.94
Aug.	1st	58	160.00 ± 18.48	30.00 ± 5.77	190.00 ± 19.39	9.10	40.00 ± 7.07	38.91	30.20	23.96	14.34
	2nd	65	240.00 ± 27.71	44.00 ± 8.47	284.00 ± 28.99	13.60	42.50 ± 2.50	39.40	29.06	24.48	13.29
	3rd	72	195.00 ± 22.52	35.00 ± 6.74	230.00 ± 23.47	11.01	47.50 ± 2.50	39.08	28.56	25.55	13.01
	4th	79	292.00 ± 33.72	39.00 ± 7.51	331.00 ± 33.78	15.85	42.50 ± 6.29	42.38	30.63	22.77	14.12
Sept.	1st	86	306.00 ± 35.33	45.00 ± 8.66	351.00 ± 35.82	16.81	50.00 ± 4.08	40.52	28.77	27.43	14.52
	2nd	93	160.00 ± 18.48	35.00 ± 6.74	195.00 ± 19.91	9.34	35.00 ± 6.45	41.46	27.12	27.83	16.37
Total			146.95	25.18	172.14	100.00					
General average			148.04 ± 15.03	26.00 ± 2.48	174.04 ± 16.93		38.96 ± 1.40	40.32	29.34	24.32	13.75
F-value			75.00 **	26.99 **	92.00 **		7.62 **				
L.S.D. at 0.05 level			33.68	8.04	34.62		8.15				

F-value refers to analysis of variance. %R.H. = The percentage of relative humidity. L.S.D.= Least significant difference. SE = standard error; ** Highly significant at $P \leq 0.01$.

Table 2. Weekly average number of *P. solenopsis* at different stages and the percentage of infestation on maize plants depending on climatic conditions in Esna district, Luxor governorate, during the second growing season (2022).

Sampling date (in weeks)		Plant age (in days)	Mean number of individuals per sample ± S.E.			% No. alive total of final total population	Infestation incidence %	Max. temp.	Min. temp.	% R.H.	Dew Point
			Nymphs	Adult females	Total						
June, 2022	3rd	16	4.25 ± 0.48	2.75 ± 0.48	7.00 ± 0.41	0.37	15.00 ± 2.89	41.17	25.33	27.59	12.31
	4th	23	20.79 ± 2.34	6.30 ± 1.10	27.09 ± 1.58	1.44	17.50 ± 2.50	40.63	26.43	24.11	10.19
July	1st	30	32.94 ± 3.71	8.20 ± 1.43	41.14 ± 2.40	2.19	25.00 ± 2.89	40.00	27.70	30.33	13.13
	2nd	37	48.57 ± 5.47	13.50 ± 2.35	62.07 ± 3.62	3.30	37.50 ± 6.29	40.87	26.62	28.79	13.44
	3rd	44	110.53 ± 12.45	25.20 ± 4.39	135.73 ±7.92	7.22	42.50 ± 4.79	43.11	28.50	31.77	16.12
	4th	51	188.00 ± 21.18	18.00 ± 3.13	206.00 ± 12.01	10.95	32.50 ± 2.50	42.22	28.65	27.10	14.08
Aug.	1st	58	153.58 ± 17.30	29.00 ± 5.05	182.58 ± 10.65	9.71	37.50 ± 4.79	41.75	27.94	29.09	14.34
	2nd	65	220.37 ± 24.82	39.60 ± 6.89	259.97 ± 15.16	13.82	42.50 ± 2.50	40.21	26.88	29.71	13.42
	3rd	72	170.04 ± 19.15	31.50 ± 5.48	201.54 ± 11.75	10.72	40.00 ± 4.08	39.88	26.42	31.01	13.14
	4th	79	225.76 ± 25.43	35.10 ± 6.11	260.86 ± 15.21	13.87	37.50 ± 2.50	42.38	28.33	27.64	14.26
Sept.	1st	86	260.56 ± 29.35	40.50 ± 7.05	301.06 ± 17.56	16.01	47.50 ± 4.79	41.35	27.54	33.30	14.67
	2nd	93	167.04 ± 18.82	28.50 ± 4.96	195.54 ± 11.40	10.40	35.00 ± 2.89	42.30	27.86	33.79	13.04
Total			1600.94	279.65	1880.59	100.00					
General average			133.45 ± 13.09	23.18 ± 2.17	156.72 ± 14.28		34.17 ± 1.71	41.32	27.35	29.52	13.51
F value			78.81 **	33.01 **	131.52 **		12.76 **				
L.S.D. at 0.05 level			28.62	6.59	25.26		8.14				

F-value refers to analysis of variance. %R.H. = The percentage of relative humidity. L.S.D.= Least significant difference. SE = standard error; **Highly significant at $P \leq 0.01$.

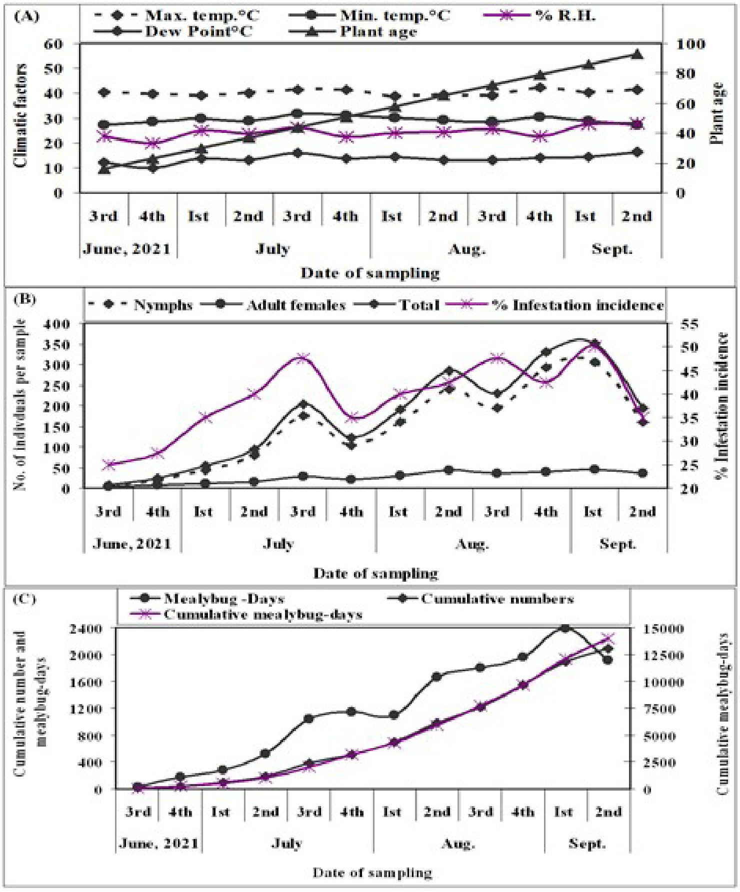

Figure 2. Weekly average number of *P. solenopsis* at different stages and the percentage of infestation on maize plants depending on climatic factors in Esna district, Luxor governorate, during the first growing season [2021 (A-C)]: A- the weekly average values of meteorological variables and plant age, B- the weekly estimates of pest individuals and the percentage of infestation incidence, and C- the cumulative numbers of *P. solenopsis*, mealybug-days, and cumulative mealybug-days in 2021.

Statistically significant changes in the number of adult females were observed between the two growing seasons (F = 6.40; L.S.D. = 2.22). Addtionally, the female peaks were observed in the third week of July, the second week of August, and the first week of September, with an average population of 28.00 ± 5.39, 44.00 ± 8.47, and 45.00 ± 8.66 individuals per sample during the first growing season, and 25.20 ± 4.39, 39.60 ± 6.89, and 40.50 ± 7.05 individuals/sample during the second growing season, respectively. The number of adult females at the different control dates in each season was highly significant (L.S.D. values were 8.04 and 6.59) for the two seasons, according to the analysis of variance (Tables 1 and 2).

3.1.1.3. C- Total population

As shown in Tables 1 and 2 and Figures 2 and 3, in the first season, three activity peaks were observed in the third week of July, the second week of August, and the first week of September, when the average population was 203.00 ± 20.72, 284.00 ± 28.99 and 351.00 ± 35.82 individuals per sample, respectively. In the second season, three seasonal peaks were recorded in the fourth week of July, the second week of August and the first week of September, when the average population was 206.00 ± 12.01, 259.97 ± 15.16, and 301.06 ± 17.56 individuals per sample, respectively. The total population density counts at the different control dates showed highly significant variances, with L.S.D. values of 34.62 and 25.26 for each season, respectively (see Tables 1 and 2). The total density of the living population of *P. solenopsis* was higher in the first growing season (174.04 ± 16.93 individuals) than in the second growing season (156.72 ± 14.28 individuals). Statistical analysis showed that the total population numbers differed significantly between the two growing seasons (F value was 5.83; L.S.D. value was 14.27). This could be due to the influence of climatic parameters and plant age, as shown in Tables 1 and 2 and Figures 2 and 3.

3.1.1.4. D- Percent of P. solenopsis infestation

The weekly infestation rates were estimated in Tables 1 and 2 and Figures 2 and 3, and it was found that the infestation rates of *P. solenopsis* reached three peaks in the third week of July, the third week of August, and the first week of September, with mean infestation rates of

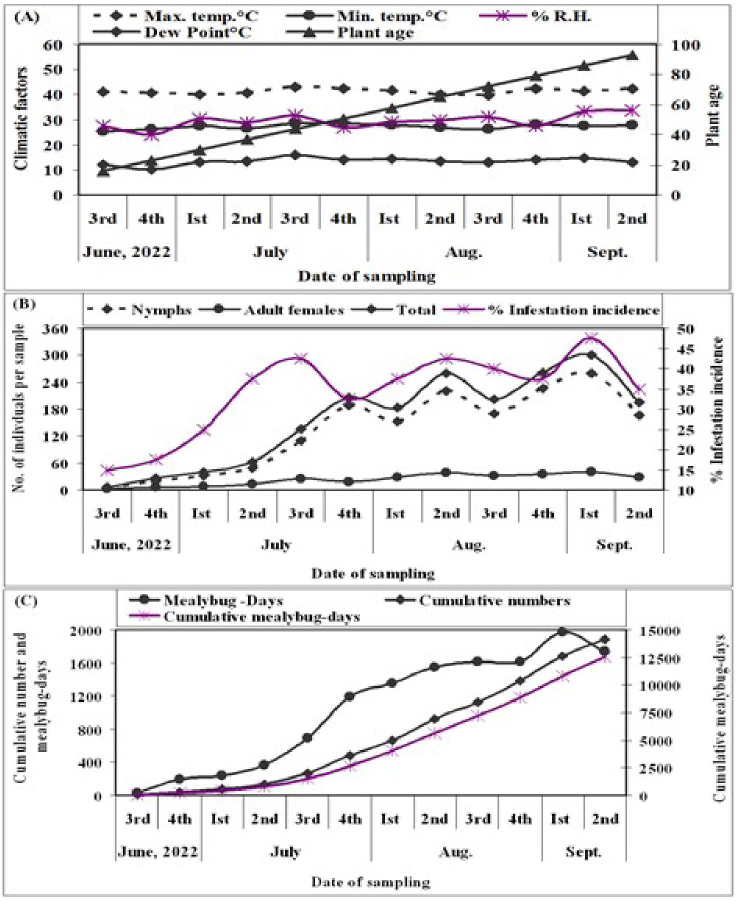

Figure 3. Weekly average number of *P. solenopsis* at different stages and the percentage of infestation on maize plants depending on climatic factors in Esna district, Luxor governorate, during the second growing season [2022 (A-C)]: A- the weekly average values of meteorological variables and plant age, B- the weekly estimates of pest individuals and the percentage of infestation incidence, and C- the cumulative numbers of *P. solenopsis*, mealybug-days, and cumulative mealybug-days in 2022.

47.50 ± 2.50, 47.50 ± 2.50 and 50.00 ± 4.08%, respectively in the first season. In addition, the infestation rates in the second season were 42.50 ± 4.79%, 42.50 ± 2.50%, and 47.50 ± 4.79% in the third week of July, the second week of August, and the first week of September, respectively.

The data in Tables 1 and 2 show that the percentage of infestation on each control date varied considerably in each season (L.S.D. values of 8.15 and 8.14, respectively). The mean total *P. solenopsis* infestation in each season was 38.96 ± 1.40 and 34.17 ± 1.71% respectively. A highly significant difference in the infestation rate was observed between the two seasons (F value was 15.75; L.S.D. value was 2.40).

In both seasons, the lowest seasonal activity of the different pest stages, total population, and percentage infestation rates by *P. solenopsis* was observed in June, which could be due to the lower relative humidity and drop in dew point during these periods. This is thought to have a dramatic effect on the rate of insect development and infestation. This period coincided with vegetative development and branching. However, the highest population and infestation rates were reported for September in all seasons. This could be due to the influence of climate conditions and plant phenology.

3.1.2. The weekly occurrence of P. solenopsis, percentage of the seasonal total, and abundance

Population density was expressed as the percentage of counts in each week studied relative to the total count in the entire growing season to allow for easier comparisons across seasons and growing seasons. The percentage of mealybugs each week was also related to the course of the season and thus the growth of the maize plants (Tables 1 and 2, and Figures 2 and 3). The total number of *P. solenopsis* individuals during the two growing seasons was 2088.50 and 1880.59 individuals, respectively.

The highest percentages of *P. solenopsis* in the first growing season were recorded in the third week of July (9.72%), the second week of August (13.60%), and the first week of September (16.81%). In the second growing season, 10.95, 13.82 and 16.01% of the total number were recorded in the fourth week of July, the second week of August, and the first week of September respectively. However, the lowest proportion of *P. solenopsis* was observed in the third week of June for each season (0.38% and 37%).

3.1.3. Cumulative mealybug developmental in days

Cumulative *P. solenopsis* developmental in days on maize plants are described in Table 3, and Figures 2 and 3, to illustrate the potential influences of changing climate on *P. solenopsis* populations and the cumulative effects of mealybugs on plant growth. Cumulative mealybug days for *P. solenopsis* were higher in the first growing season (13996.50 individuals per season) than in the second (12550.03 mealybugs per season). The increasing number of days with mealybugs had a greater influence on plant development in the first season than in the second.

3.1.4. Weekly fluctuation rate of P. solenopsis population

The best week for insect activity is defined as the week with the greatest insect population growth during the season, as measured by the weekly rate of change in population and infestation. When this indicator value is greater than one, it indicates improved insect performance; less than one indicates decreased insect performance; and when it is equal to one, it indicates no change in insects (Bakry et al., 2020; Bakry and Fathipour (2023).

The data in Table 4 show that the suitable weeks for counting the nymphal stage were the fourth week of June, the first, second, and third weeks of July, the first, second, and fourth weeks of August, and the first week of September in the first season (2021), when the weekly differences were 3.60, 2.44, 1.78, 2.23, 1.55, 1.50, 1.50 and 1.05, respectively. However, in the second season (2022), the best growing seasons tended to be the fourth week of June, the first, second, third, and fourth weeks of July, the second and fourth weeks of August, and the first week of September when the weekly variance ratios were 4.89, 1.58, 1.47, 2.28, 1.70, 1.43, 1.33 and 1.15, respectively.

In addition, the weekly variance rates for the number of adult females showed that the appropriate time points for growth were in the fourth week of June, the first, second, and third weeks of July, the first, second, and fourth weeks of August and the first week of September in each season, where the variance rates in the first season (2.33, 1.57, 1.36, 1.87, 1.50, 1.47, 1.11 and 1.15) and in the second season (2.29, 1.30, 1.65, 1.87, 1.61, 1.37, 1.11 and 1.15).

The correct times for the increase in total population were in the fourth week of June, the first, second, and third weeks of July, the first, second, and fourth weeks of August, and the first week of September in the first season, when the differences were 3.13, 2.20, 1.70, 2.17, 1.54, 1.49, 1.44 and 1.06, respectively, in the first season. Also in the second season, the most favorable times for growth were the fourth week of June, the first, second, third and fourth weeks of July, the second and fourth weeks of August, and the first week of September, when the variation rates were 3.87, 1.52, 1.51, 2.19, 1.52, 1.42, 1.29 and 1.15, respectively). As for the percentage infestation by *P. solenopsis*, the appropriate weekly data for the increase in percentage infestation were recorded in the fourth week of June, the first, second, and third weeks of July, the first, second and third weeks of August and the first week of September of the first growing season when the variation rates were 1.10, 1.27, 1.14, 1.19, 1.14, 1.06, 1.12 and 1.18, respectively. However, in the second growing season, the suitable times for infestation increase appeared in the fourth week of June, the first, second and third weeks of July, the first and second weeks of August, and the first week of September when the variation rates were 1.17, 1.43, 1.50, 1.13, 1.15, 1.13 and 1.27, respectively.

It was evident that the weekly variation rate of *P. solenopsis* population size and percentage infestation per weekly inspection time was greater than one, indicating that the climatic conditions tended to favor the growth of the insects. In addition, the appropriate times for insect emergence are similar in both seasons.

3.2. Effect of environmental factors and plant age on P. solenopsis seasonal:

3.2.1. Effect on total population size (Y_1):

3.2.1.1. Effect of four climatic variables (X_1, X_2, X_3, and X_4) and plant age (X_5)] on total population number of P. solenopsis (as dependent variable)]:

3.2.1.2. A- Influence of mean daily maximum temperature (X_1)

The simple correlation (r) and the partial regressions for both the mean daily maximum temperature and the total population of *P. solenopsis* during the two seasons was only marginally positive and weak (+0.28 and +0.26, respectively, see Table 5). In addition, the simple regression showed that a 1 °C increase in the mean daily maximum temperature would lead to an increase in the population of 28.73 and 24.72 individuals per sample during the two seasons. The data show that this variable had an insignificant positive effect on population size in the first season (P. reg. = 13.04) and an insignificant negative effect in the second season (P. reg. = -20.48). In addition, the partial correlation values were (0.26 and -0.50, respectively) and the t-test values were (0.66 and -1.40, respectively).

The results show that the mean daily maximum temperature was in the optimal range of the total population size in the first growing season and was active around the optimal range of the total population size in the second growing season. This variable was the least effective factor in the two seasons and explained 0.80% and 2.32% of the variation in population size of *P. solenopsis* (Table 5).

3.2.1.3. B- Influence of the average daily minimum temperature (X_2)

The simple correlation was insignificantly positive (+0.21 and +0.50, respectively) for both the average daily minimum temperature and total population size of *P. solenopsis* in the two seasons. The regression coefficient shows that an increase in the mean daily minimum temperature by 1 °C increases the population size in both seasons by 16.87 and 50.01 individuals per sample (Table 5).

The exact influences of the mean minimum temperature on the total population size of *P. solenopsis* had a significant positive influence in the first season (P. reg. = 40.86) and an insignificant negative significance in the second season

Table 3. Weekly cumulative number, percent cumulative number, days with survey mealybugs, and cumulative days with survey mealybugs of *P. solenopsis* counted on maize plants in Esna district, Luxor governorate, during the two cropping seasons (2021-2022).

Sampling date (in weeks)		Plant age /] (in days)	First growing season (2021)				Second growing season (2022)			
			Cumulative numbers per samples	% Cumulative	Mealybug -Days	Cumulative mealybug-days	Cumulative numbers per sample	% Cumulative	Mealybug -Days	Cumulative mealybug-days
June	3rd	16	8.00	0.38	28.00	28.00	7.00	0.37	24.50	24.50
	4th	23	33.00	1.58	175.00	203.00	34.09	1.81	189.64	214.14
July	1st	30	88.00	4.21	280.00	483.00	75.23	4.00	238.80	452.94
	2nd	37	181.50	8.69	519.75	1002.75	137.30	7.30	361.23	814.17
	3rd	44	384.50	18.41	1037.75	2040.50	273.03	14.52	692.32	1506.49
	4th	51	507.50	24.30	1141.00	3181.50	479.03	25.47	1196.06	2702.55
Aug.	1st	58	697.50	33.40	1095.50	4277.00	661.61	35.18	1360.03	4062.58
	2nd	65	981.50	47.00	1659.00	5936.00	921.58	49.01	1548.93	5611.50
	3rd	72	1211.50	58.01	1799.00	7735.00	1123.12	59.72	1615.29	7226.79
	4th	79	1542.50	73.86	1963.50	9698.50	1383.99	73.59	1618.41	8845.20
Sept.	1st	86	1893.50	90.66	2387.00	12085.50	1685.05	89.60	1966.73	10811.93
	2nd	93	2088.50	100.00	1911.00	13996.50	1880.59	100.00	1738.10	12550.03
	Total				13996.50				12550.03	

Table 4. Weekly variation rate of mean number of *P. solenopsis* and percent infestation of maize plants in Esna district, Luxor governorate, during the two growing seasons (2021 and 2022).

Sampling date in weeks)		2021 Season				Sampling date		2022 Season			
		Nymphs	Adult females	Total	%Infestation incidence			Nymphs	Adult females	Total	%Infestation incidence
June, 2021	3rd	—	—	—	—	June, 2022	1st	—	—	—	—
	4th	3.60	2.33	3.13	1.10		2nd	4.89	2.29	3.87	1.17
July	1st	2.44	1.57	2.20	1.27	July	1st	1.58	1.30	1.52	1.43
	2nd	1.78	1.36	1.70	1.14		2nd	1.47	1.65	1.51	1.50
	3rd	2.23	1.87	2.17	1.19		3rd	2.28	1.87	2.19	1.13
	4th	0.59	0.71	0.61	0.74		4th	1.70	0.71	1.52	0.76
Aug.	1st	1.55	1.50	1.54	1.14	Aug.	1st	0.82	1.61	0.89	1.15
	2nd	1.50	1.47	1.49	1.06		2nd	1.43	1.37	1.42	1.13
	3rd	0.81	0.80	0.81	1.12		3rd	0.77	0.80	0.78	0.94
	4th	1.50	1.11	1.44	0.89		4th	1.33	1.11	1.29	0.94
Sept.	1st	1.05	1.15	1.06	1.18	Sept.	1st	1.15	1.15	1.15	1.27
	2nd	0.52	0.78	0.56	0.70		2nd	0.64	0.70	0.65	0.74

(P. reg. = -3.50). In addition, the partial correlation values were 0.74 and -0.08, and the t-test estimates (2.71 and -0.20) for the two seasons.

In the first growing season, the daily temperature minimum was below the appropriate range for the overall activity of the *P. solenopsis* population and in the second growing season, it was in the optimal range for the overall census activity. This variable was the most efficient in the first season, explaining 13.58% of the variation in the *P. solenopsis* population, while it was the least efficient factor in the second season, accounting for 0.05% of the variance (Table 5).

3.2.1.4. C- Influence of mean relative humidity (X_3)

During both seasons, the correlation between total population and relative humidity was insignificant and positive (r-values = +0.53 and +0.46). Similarly, the simple regression coefficient showed that a 1% increase in mean relative humidity would increase population numbers in the two seasons by 26.73 and 16.65 individuals per sample (Table 5). The partial regression model shows that the effect of relative humidity on total population numbers is insignificant and is positive in the first season (P. reg. = 26.84) and significantly negative in the second season (P. reg. = -16.46). The partial correlation values were (0.51 and -0.73) and the t-values were (1.47 and -2.64) for each growing season. In the first season, the mean relative humidity was always within the appropriate range for population activity, and in the second season it was always above the optimum range for population activity. This variable was responsible for some fluctuations in the *P. solenopsis* population during the two seasons and accounted for 4.00 and 8.31% of the fluctuations.

3.2.1.5. D- Influence of dew point (X_4)

The relationship between dew point and total population number in the two seasons was an insignificant positive correlation (r-values, 0.55 and 0.56, respectively). The regression coefficient shows that each 1 °C increase in dew point increases the population number in the two seasons by 35.38 and 37.73 individuals/sample, respectively (Table 5). According to the partial regression, the dew point had an insignificant negative effect (P. reg. value: -47.88) for the first season and a significant positive effect (P. reg. value: 35.80) for the second season (Table 5). For each of the two growing seasons, the partial correlation values were -0.59 and 0.75 and the t-values were -1.78 and 2.75. Accordingly, the mean dew point was always within the correct range of total *P. solenopsis* population in the first growing season, but always below the optimal range of total count activity in the second growing season. In the two seasons, the dew point explained 5.84% and 9.00% of the variation of the total *P. solenopsis* population.

3.2.1.6. E- Influence of maize plant age (X_5)

In both growing seasons, the correlation values were very strongly positive (r-values; 0.91 and 0.89, respectively). The estimated simple regression for the effect of this variable showed that for each additional day of maize age, the total number of the population increased by 3.95 and 3.56 individuals per sample in each season, respectively (Table 5). The relationship between the age of the maize plant and the total number of *P. solenopsis* was determined using the partial regression method (Table 5). The relation between the age of the maize plants and the total number of *P. solenopsis* was highly significant and positive in each season (P. regression = 4.28 and 4.14). The partial correlation estimates were (0.90 and 0.94) and the t-values were (4.93 and 6.71) for the two seasons. This variable was the most successful factor in describing abundance in the total population of *P. solenopsis*, explaining 45.21 and 53.58% of the variance in each season.

Table 5. Correlation and regression models describing the relationship between some weather factors and plant age on the total population of *P. solenopsis* on maize plants during the two growing seasons (2021 and 2022).

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.%
2021	Max. temp (X_1)	0.28	28.73	31.53	0.91	0.26	13.04	19.80	0.66	0.80	5	9.57 **	0.94	0.89	88.86
	Min. temp (X_2)	0.21	16.87	24.93	0.68	0.74	40.86	15.10	2.71 *	13.58	2				
	R.H.% (X_3)	0.53	26.73	13.63	1.96	0.51	26.84	18.23	1.47	4.00	4				
	Dew point (X_4)	0.55	35.38	19.12	1.85	-0.59	-47.88	26.94	-1.78	5.84	3				
	Plant age (X_5)	0.91	3.95	0.72	5.50 **	0.90	4.28	0.87	4.93**	45.21	1				
	Plant ages (X_5, X_5^2, X_5^3)											15.45 **	0.92	0.85	85.28
	Combined effect (X_1 to X_5^3)											7.81*	0.97	0.93	93.18
2022	Max. temp (X_1)	0.26	24.72	29.32	0.84	-0.50	-20.48	14.66	-1.40	2.32	4	15.64 **	0.96	0.93	92.88
	Min. temp (X_2)	0.50	50.01	27.08	1.85	-0.08	-3.50	17.54	-0.20	0.05	5				
	R.H.% (X_3)	0.46	16.65	10.25	1.62	-0.73	-16.46	6.23	-2.64 *	8.31	3				
	Dew point (X_4)	0.56	37.73	18.60	2.03	0.75	35.80	13.02	2.75 *	9.00	2				
	Plant age (X_5)	0.89	3.56	0.56	6.32 **	0.94	4.14	0.62	6.71 **	53.58	1				
	Plant ages (X_5, X_5^2, X_5^3)											28.94 **	0.96	0.92	91.56
	Combined effect (X_1 to X_5^3)											8.74 *	0.97	0.94	93.86

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 $P \leq 0.01$

3.2.1.7. F- The pooled effect of four climatic variables (X_1, X_2, X_3, and X_4) and plant age (X_5)] on the total number of P. solenopsis

The mutual effect of these studied parameters on the total number of *P. solenopsis* was highly significant with F values of 9.57 and 15.64 for each growing season. For the two growth periods, the variance amounts were 88.86 and 92.88%.

3.2.2. Influence of maize plant age (X_5):

The age of the maize plant was also analyzed and compared with the total number of *P. solenopsis* to determine their variance which was 85.28% and 91.56% for the two growing seasons (Figure 4). The regression equations are:

3.2.2.1. First season (2021):

$$Y_1 = -0.0023\, X_5^3 + 0.3228\, X_5^2 - 8.5947\, X_5 + 80.558 \qquad R^2 = 0.8528 \tag{5}$$

3.2.2.2. Second season (2022):

$$Y_1 = -0.0018\, X_5^3 + 0.2518\, X_5^2 - 5.4864\, X_5 + 36.613 \qquad R^2 = 0.9156 \tag{6}$$

In this non-linear regression, the F-values were highly significant and amounted to 15.45 and 28.94 for the two seasons (Table 5). *P. solenopsis* reached its population maximum after 86 days with 351.00 ± 35.82 and 301.06 ± 17.56 individuals per sample in the two growing seasons.

3.2.2.3. The combined effect of all tested variables on the total number of P. solenopsis:

A multiple regression method was used to investigate the combined effect of the four climatic variables and the biotic variable (plant age) on the estimate of the total population of *P. solenopsis*. The f-values were significant, with values of 7.81 and 8.74 in the two seasons. In two seasons, the explained variance was 93.18 and 93.86%. (Table 5).

3.2.3. Impact on the percentage of infestation (Y_2)

3.2.3.1. Influence of four climatic variables (X_1, X_2, X_3, and X_4) and plant age (X_5) the infestation percentage

3.2.3.2. A- The influence of mean daily maximum temperature (X_1)

A insignificant positive relationship between the mean daily maximum temperature and the percentage occurrence of *P. solenopsis* infestation in the two growing seasons (r= +0.03 and +0.23). Combined with the simple regression for the influence of this variable, it was found that each 1 °C increase in daily maximum temperature increases the infestation rate in the two seasons studied by 0.23% and 2.23%. The influences of

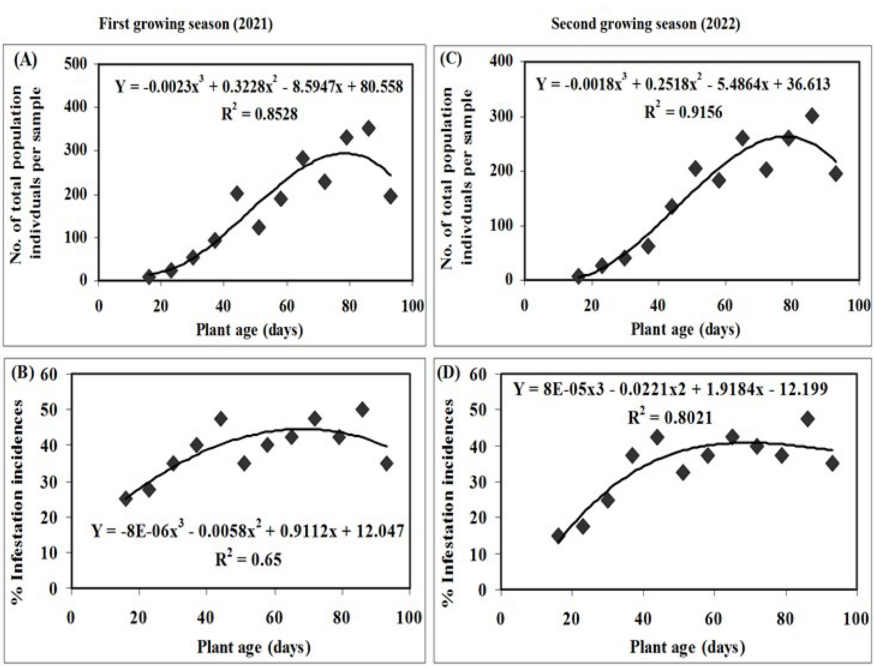

Figure 4. The nonlinear relationships between plant age (X_5) and *P. solenopsis* counts (Y_1) and percentage of infestations (Y_2) during the two growing seasons [2021 (A-B) and 2022 (C-D)]: A- the polynomial relationship between maize age and *P. solenopsis* populations in 2021, B- the polynomial relationship between maize age and percentage of infestation incidences in 2021, C- the polynomial relationship between maize age and *P. solenopsis* populations in 2022, and D- the polynomial relationship between maize age & percentage of infestation incidences in 2022.

the mean daily maximum temperature on the infestation rate of *P. solenopsis* are shown in Table 6. They were of insignificant positive significance (P. reg. = 0.15) for the first season and had an insignificant negative influence (P. reg. = -3.10) during the second season. In addition, the partial correlation estimates during the two growing seasons were 0.05 and -0.54 and the t-test values were 0.11 and -1.65 for the two growing seasons. The results showed that the mean daily maximum temperature was within the ideal infestation range in the first season, while it was around the ideal infestation range in the second growing season. This variable was the least effective component in the first season, explaining only 0.03% of the variance in infestation rate, while it explained 5.31% of the variance in the second season (Table 6).

3.2.3.3. B- Influence of average daily minimum temperature (X_2)

The simple correlation between the percentage of infestation with *P. solenopsis* and the daily mean of the minimum temperature in the two seasons was only slightly positive (r = 0.40 and 0.49). According to the simple regression coefficient, an increase in the mean daily minimum temperature by 1 °C increased the degree of infestation in the two seasons by 2.19 and 4.84% (Table 6). From the partial regression model values, the mean daily minimum temperature had a highly significant positive effect in the first season (P. reg. = 4.68) and an insignificant negative effect in the second season (P. reg. = -0.83) (Table 6).

For each growing season, the partial correlation values were 0.88 and -0.14 and the t-values were 4.57 and -0.35. In the first growing season, the lowest daily mean temperature was always completely below the optimal infestation range; in the second growing season, it was always around the optimal infestation range of the pest. At 38.94%, this climate variable was the most important element for the variation of the infestation percentage in the first season and the least important climate factor at 0.27% in the second season (Table 6).

3.2.3.4. C- Influence of mean relative humidity (X_3)

In both seasons, the relationship between relative humidity and percentage infestation was significantly positive (r = 0.61 and 0.64). A 1% increase in mean relative humidity increased the percentage infestation frequency in both seasons by 2.11 and 2.35, as shown by the simple regression (Table 6).

The actual effect of relative humidity on the percentage of infestation occurrence was significantly positive in the first season (P.reg. = 3.96) and insignificantly negative in the second growing season (P.reg. = -0.49). The partial correlation values (P.cor. = 0.79 and -0.23) and the t-test estimates (3.20 and -0.59) were also positive in both seasons. In the first season, the mean relative humidity was always below the optimal range of infestation rates; in the second season, it was always around the optimal range. This variable was responsible for 19.13% and 0.74% variation in infestation rates in the two seasons (Table 6).

3.2.3.5. D- Influence of dew point (X_4)

The effect of mean dew point on infestation percentage was marginally positive (+0.52) in the first season and highly significantly positive (+0.75) in the second season. In addition, the estimated regression method for the influence of this factor showed that for every 1 °C increase, the infestation rate would increase by 2.47 and 5.28% in both seasons, respectively (Table 6).

The data showed that the mean dew point had a significant negative effect on the percentage of infestation in the first season (P. reg. = -4.70) and a significant positive effect in the second growing season (P. reg. = 5.73). The partial correlation estimates in the two seasons were (-0.72 and 0.80) and the t-test values were (-2.57 and 3.25). The results showed that the mean dew point was always above the optimum infestation range in the first growing season, while it was always below the optimum infestation range in the second growing season. This factor was responsible for some changes in the infestation level of 12.33% in the first season, while it was most effective in the second season with 22.85% (Table 6).

3.2.3.6. E- Influence of plant age (X_5)

The simple correlation between plant age and the occurrence of infestation was not significantly positive in the first season (r= 0.57) and highly significantly positive in the second season (r= 0.74). Furthermore, the simple regression for the influence of this variable showed that for each additional day of maize plant age, the infestation percentage increased by 0.15 and 0.30% in each season.

The actual correlation between the age of the maize plant and the degree of infestation was estimated using the partial regression model, which was significantly positive for both seasons (P. regression = 0.17 and 0.24). At the same time, the values of the partial correlation (P. correlation = 0.76 and 0.77) and the t-test (2.89 and 2.93) were significantly positive for the two seasons. In the two seasons, plant age was responsible for 15.69% and 18.62% of the percentage variation in infestation (Table 6).

3.2.3.7. F- The pooled effect of four climatic variables [(X_1, X_2, X_3, and X_4) and plant age (X_5)] on the percentage occurrence of P. solenopsis infestation

The combined influence of these studied parameters on the percentage infestation in the two seasons was highly significant, with F-values of 9.51 and 8.05, respectively. In each season, the percentage variances were 88.79 and 87.03%, respectively.

3.2.3.8. Influence of plant age

The age of the maize plant was related to the infestation level. The variance for each was 65.00% and 80.21% in the two seasons (Figure 4). The regression equations are:

First season (2021)

$$\mathbf{Y_2 = -6 - 8X_5{}^3 - 0.0058\ X_5{}^2 + 0.9112X_5 + 12.047}$$
$$\mathbf{R^2 = 0.65} \qquad (7)$$

Table 6. This table shows the statistical analysis of the describe the relationship between some weather factors and plant age on the percent infestation of maize plants with *P. solenopsis* in the two growing seasons (2021/2022)..

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.%
2021	Max. temp (X_1)	0.03	0.23	2.22	0.11	0.05	0.15	1.34	0.11	0.03	5	9.51 **	0.94	0.89	88.79
	Min. temp (X_2)	0.40	2.19	1.58	1.38	0.88	4.68	1.03	4.57 **	38.94	1				
	R.H.% (X_3)	0.61	2.11	0.86	2.46 *	0.79	3.96	1.24	3.20 *	19.13	2				
	Dew point (X_4)	0.52	2.47	1.28	1.92	-0.72	-4.70	1.83	-2.57 *	12.33	4				
	Plant age (X_5)	0.57	0.15	0.07	2.19	0.76	0.17	0.06	2.89 *	15.69	3				
	Plant ages(X_5, X_5^2, X_5^3)											4.95 *	0.81	0.65	65.00
	Combined effect (X_1 to X_5^3)											7.95 *	0.97	0.93	93.30
2022	Max. temp (X_1)	0.23	2.23	2.96	0.75	-0.54	-3.10	1.99	-1.56	5.31	3	8.05 *	0.93	0.87	87.03
	Min. temp (X_2)	0.49	4.84	2.75	1.76	-0.14	-0.83	2.38	-0.35	0.27	5				
	R.H.% (X_3)	0.64	2.35	0.88	2.66 *	-0.23	-0.49	0.84	-0.59	0.74	4				
	Dew point (X_4)	0.75	5.28	1.46	3.62 **	0.80	5.73	1.76	3.25 *	22.85	1				
	Plant age (X_5)	0.74	0.30	0.08	3.53 **	0.77	0.24	0.08	2.93 *	18.62	2				
	Plant ages (X_5, X_5^2, X_5^3)											10.81 **	0.90	0.80	80.21
	Combined effect (X_1 to X_5^3)											12.24 *	0.98	0.96	95.54

3.2.3.9. Second season (2022)

$$Y_2 = -5-8X_5^3 - 0.0221\,X_5^2 + 1.9184\,X_5 - 12.199$$
$$R^2 = 0.8021 \quad (8)$$

In both seasons, plant age proved to be a significant factor in predicting the percentage infestation (F-values of 4.95 and 10.81) (Table 6). In both seasons, the percentage infestation with *P. solenopsis* increased with the increasing maize plants' age in August and September.

3.2.3.10. The combined effect of all tested variables on the percentage of P. solenopsis infestation

In the two seasons, the variability was 93.30% and 95.54% for each season. Moreover, the model was significant with F-values of 7.95 and 12.24 for the two seasons (Table 6).

4. Discussion

The cotton mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae), is one of several pests that infest maize plants (Abd El-Mageed et al., 2020 and Bakry et al., 2023a). It is a polyphagous and dangerous pest that damages plants all over the world (Sreedevi et al., 2013; Babasaheb and Suroshe, 2015). This pest attacks leaves, main stems, and branches by sucking sap with its mouthparts, deforming the plants with its toxic saliva, and secreting enormous amounts of honeydew, which promotes the spread of sooty mold. This leads to chlorosis, malformation, and mortality in the infested plants, as photosynthesis is delayed and vegetative growth is reduced (Hodgson et al., 2008; Aheer et al., 2009; Sahayaraj et al., 2015; Bakry, 2022). Therefore, this study was conducted to observe the seasonal occurrence of mealybugs and the possible influences of meteorological variables and plant age on the insect population of maize plants (single hybrid 168 yellow maize cultivar) in Esna district, Luxor governorate, Egypt, in two consecutive seasons (2021 and 2022).

Mealybug populations can fluctuate with the seasons. It may be more prevalent during certain times of the season. The results showed that *P. solenopsis* attacked maize plants from the third week of June until harvest in all studied seasons, with three peaks of seasonal occurrence per season in the third/fourth week of July, the second week of August, and the first week of June. There were also three peaks per season in percentage infestation. Dent (1991) reported that the number of insect populations at each site is determined by the weather conditions of that area.

Most researchers report two or three peaks per season for *P. solenopsis*, depending on the region and host plant. In this context, Nabil (2017) at Hihhya distract, Sharkia governorate, Egypt, mentioned that *P. solenopsis* had three or four activity peaks on eggplant during the season. Abd-El-Razzik (2018) at Giza Governorate, Egypt reported that three generations of *P. solenopsis* per year were observed on mulberry trees. Nabil and Hegab (2019) at Hihhya distract, Sharkia Governorate, Egypt, reported that the activity of *P. solenopsis* on maize plants included two or three generations per season. Abd El-Mageed et al. (2020) in Qena, Egypt, reported three activity peaks on maize plants during the year. Mohamed (2021) in Qena, Egypt, pointed out that *P. solenopsis* has three overlapping generations per season on maize plants in Qena, Egypt. Bakry and Fathipour (2023) in Luxor, Egypt, also mentioned three seasonal peaks of *P. solenopsis* on okra plants in each season. Bakry and Aljedani (2023); Bakry et al. (2023a) in Luxor, Egypt, reported that *P. solenopsis* had three activity peaks on maize plants.

Moreover, in this study, the climate was most favorable for *P. solenopsis* population increase and infestation in August in the first season and in September in the second season, while June was less suitable in both growing seasons (as estimated by weekly surveys). These results agree with those of Abd El-Mageed et al. (2020), who mentioned that the population density of *P. solenopsis* reaches its maximum in September. Mohamed (2021) determined the maximum proportion of *P. solenopsis* in the average monthly total population in June for the two seasons to be 37.87 and 39.56%, respectively, in Qena, Egypt.

Weather conditions and plant phenology can have a significant impact on mealybugs, which are small, soft-bodied insects (Bakry and Fathipour, 2023). Mealybugs are influenced by temperature, and their development and reproduction rates are dependent on it. Warmer temperatures generally accelerate their life cycle, leading to faster growth and increased reproduction. Mealybugs increment in humid environments. Humidity levels provide favorable conditions for their survival and reproduction (Mohamed and Bakry, 2020).

Plant phenology (plant age): Mealybugs often exhibit preferences for different plant growth stages. They may prefer plants with tender growth, new leaves, or young shoots. Mealybugs are known to be attracted to plants producing high levels of plant sap, which they feed on. Therefore, the phenological stage of the host plant can influence the vulnerability of plants to mealybug infestations. Data indicated that with a daily increase in the plant age of maize, the mealybug numbers and infestation rate increased.

The results of the environmental study in the study showed that the combined effects of weather conditions and plant age were significantly associated with the estimates of *P. solenopsis* populations, with an explained variance (E.V.) of 93.18 and 93.86% in the two seasons, respectively. In addition, their influences explained differences in infestation rates of 93.30 and 95.54% in the two seasons, respectively. Plant age was also the most effective variable in explaining the differences in the total population of *P. solenopsis* in each season. On the other hand, the mean daily minimum temperature in the first season and mean daily dew point in the second season were the most important variables influencing the variations in infestation rates. Otherwise, the mean daily maximum temperature was the least effective variable for population and infestation variation in both seasons.

Most authors conducted several experiments to determine the effects of climatic factors on *P. solenopsis* mealybugs. Abiotic variables have been shown to have a significant impact on the growth, development, distribution, and population dynamics of insect pests (Clark, 2003).

Both abiotic and biotic variables play an important role in causing differences in the population size of mealybugs (Naeem, 1996). In addition to temperature and humidity, other environmental factors may have influenced the increase in mealybug populations. Williams and Dixon (2007) reported that plant phenology could have a significant effect on the infestation status of mealybugs. According to Dhawan et al. (2009), there is a positive correlation between temperature and the development and spread of *P. solenopsis*, and warm weather promotes the production and spread of the pest. Prasad et al. (2012) observed that an increase in temperature from 18 to 32 °C significantly shortened the development time of *P. solenopsis*. Kumar et al. (2013) discovered a favorable relationship between temperature and the mealybug population. The best combination of temperature and relative humidity for the development of *P. solenopsis* is 35 ± 1 °C and 65% relative humidity. According to Zia and Haseeb (2019), relative humidity plays a crucial role in the population growth of mealybugs *P. solenopsis*.

According to Hameed et al. (2014) and El-Zahi and Farag (2017), relative humidity had the greatest effect on the population of *P. solenopsis*. Nabil (2017) found that maximum temperature, minimum temperature, and relative humidity were positively related to the population of *P. solenopsis*. According to Abd El-Razzik (2018), the relationship between the population of P. solenopsis mealybug and the maximum and minimum temperature was positive and highly significant, while the percentage of relative humidity had a negative and low influence. There is a significant positive relationship between the highest temperature and the female population of *P. solenopsis*. Relative humidity also has a strong negative influence on female populations (Nabil and Hegab, 2019). Zia and Haseeb (2019) reported that there is a negative correlation between the population of *P. solenopsis* and maximum temperature and a positive correlation with relative humidity. In Egypt, Elbahrawy et al. (2020) discovered a significant positive correlation between the maximum temperature and the total population of *P. solenopsis* in Giza. In Qalyubia, there was a highly significant relationship between relative humidity and the first Nili season, while relative humidity showed a significant relationship with the second summer and Nili seasons. Abd El-Mageed et al. (2020) found that the combined effect of weather factors, parasitoids, and plant age on the variation of nymph and adult populations was 87.81 and 85.59% and 93.99 and 87.33%, respectively. Shivakumara et al. (2022) found a significant positive correlation between temperature and abundance of *P. solenopsis* each year. Bakry and Fathipour (2023) mentioned that the daily mean relative humidity had the biggest impact on the number of *P. solenopsis* on the okra plants, while the daily mean minimum temperature was most important in explaining variations in the mealybug population during the second season. However, the daily mean maximum temperature had the smallest effect on the P. solenopsis population. Additionally, every additional day of okra plant age, the total *P. solenopsis* population will increase.

These results are partly consistent with our findings on the influence of climatic factors. The difference could be explained by variations in the host plants and climatic characteristics of this area. Conversely, Sreedevi et al. (2013) found that *P. solenopsis* completes its life cycle on hibiscus (*Hibiscus rosa-sinensis* L.) almost twice as fast at high temperatures than at lower ones.

5. Conclusions

It is noted that weather and plant phenology are factors that can affect mealybug numbers on maize plants. The effect of these factors varies from one season to another and from one factor to another, and on it in general. These factors play a role in managing mealybug infestation. IPM strategies take into account all of these various factors and are often recommended for effective and sustainable control of mealybugs. The data collected in this paper will help decision-makers better understand how pests behave and how many of them there are, as well as factors in the environment that could affect pest control operations. This information will be crucial for planning effective and environmentally friendly pest control measures. By studying pest behavior, estimating populations, and analyzing various factors, decision-makers will be able to determine the most appropriate time to carry out pest control activities. This will be especially useful in planning the integrated pest management program for controlling mealybugs in maize plants. Overall, the data gathered will provide valuable insights that will guide decision-makers in their efforts to effectively manage pest infestations while minimizing negative impacts on the environment.

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