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Population dynamics of *Phenacoccus solenopsis* Tinsley (Hem: Pseudococcidae) and its natural enemies on Chinese Hibiscus (*Hibiscus rosa-sinensis*) in urban landscapes of Dezful, Khuzestan Province, Southwestern Iran

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Abstract

The cotton mealybug, *Phenacoccus solenopsis* Tinsley, is an invasive pest posing a serious threat to agricultural and ornamental plants, including Chinese hibiscus (*Hibiscus rosa-sinensis*). The two-year (2016 & 2017) study examined the population dynamics and ecological interactions of *P. solenopsis* as well as its natural enemies in the urban landscape of Dezful, southwestern Iran. Biweekly sampling was performed to record population changes across developmental stages. Natural enemies—*Aenasius bambawalei* Hayat (parasitoid wasp), *Nephus arcuatus* Kapur and *Hyperaspis polita* Weise (predatory beetles), and *Dicrodiplosis manihoti* Harris (predatory fly) were also monitored. According to the results, *P. solenopsis* became active in March, with population peaks in early summer (from late June to early July) and early autumn (October). Natural enemies followed a similar pattern, appearing shortly following pest emergence and playing a key role in population suppression. Temperature had a significant positive correlation with both mealybug and natural enemy populations, while relative humidity indicated a negative effect. Field observations confirmed that during extreme summer temperatures, the pest retreated to protected areas within the plant canopy, while in winter, it overwintered mainly as first-instar nymphs and adult females in bark crevices as well as soil. The findings highlight the importance of seasonal monitoring and the conservation of natural enemies for effective integrated pest management (IPM) in urban horticulture. This study provides essential ecological insights into the behavior of *P. solenopsis* along with its biological control agents in a subtropical urban environment.

Keywords: Cotton mealybug, Chinese rosa, Aenasious bambawalei, Hyperaspis polita, population fluctuations

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پویایی جمعیت *Phenacoccus solenopsis Tinsley* (Hem: Pseudococcidae) و دشمنان طبیعی آن روی ختمی چینی (*Hibiscus rosa-sinensis*) در فضای سبز شهر دزفول، استان خوزستان، جنوب‌غرب ایران

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چکیده

شپشک آردآلود پنبه (*Phenacoccus solenopsis* Tinsley) یکی از آفات مهاجم و چندخواره است که تهدیدی جدی برای گیاهان زراعی و زینتی، از جمله ختمی چینی(*Hibiscus rosa- sinensis*) محسوب می‌شود. این مطالعه در طی سال‌های ۱۳۹۵ و ۱۳۹۶ (از فروردین تا اسفند) با هدف بررسی پویایی جمعیت و روابط اکولوژیک این آفت و دشمنان طبیعی آن در فضای سبز شهری شهرستان دزفول (جنوب غرب ایران) انجام شد. نمونه‌برداری به‌صورت دو هفته یک‌بار انجام گرفت و مراحل رشدی آفت و دشمنان طبیعی آن شامل زنبور پارازیتویید *Aenasius bambawalei* Hayat، کفشدوزک‌های شکارگر *Nephus arcuatus* Kapur، *Hyperaspis polita* Weise و پشه شکارگر *Dicrodiplosis manihoti* Harris ثبت شدند. نتایج نشان داد که فعالیت شپشک آردآلود از اواخر زمستان آغاز شده و اوج جمعیت آن در اوایل تابستان و پاییز مشاهده شد. دشمنان طبیعی اندکی پس از شروع فعالیت آفت ظاهر شدند و نقش مؤثری در کاهش جمعیت آن ایفا کردند. دمای هوا با جمعیت آفت و دشمنان طبیعی رابطه مثبت و معناداری داشت، در حالی که رطوبت نسبی تأثیر معناداری نداشت. مشاهدات میدانی نشان داد که در تابستان‌های گرم، آفت به نواحی محافظت‌شده داخل بوته پناه می‌برد و در زمستان عمدتاً به‌صورت پوره سن اول و ماده بالغ در زیر پوستک تنه و خاک زمستان‌گذرانی می‌کند. این یافته‌ها اهمیت پایش فصلی و حفاظت از دشمنان طبیعی را در مدیریت تلفیقی آفات (IPM) در فضاهای سبز شهری برجسته می‌سازند.

کلید واژه‌ها: شپشک آردآلود پنبه، ختمی‌چینی (Hibiscus rosa-sinensis)، Aenasious bambawalei، Hyperaspis polita، نوسانات جمعیت

دبیر تخصصی: دکتر ارسلان جمشیدنیا

Introduction

The cotton mealybug (*Phenacoccus solenopsis* Tinsley, 1978) is an invasive, polyphagous pest which has caused significant damage to agricultural crops and ornamental plants in tropical regions in recent years (Ben-Dov, 1994; Hodgson et al., 2008; Arif et al., 2009; Nagrare et al., 2009; Bagheri & Moghaddam, 2010; Fand & Suroshe, 2015). It was recorded from more than 200 host plants including field crops, vegetable, ornamentals, weeds, bushes and trees. There are plant species assigned to approximately 60 families preferring to Asteraceae, Euphorbiaceae, Fabaceae, Malvaceae and Solanaceae (Arif et al., 2009; Mossadegh et al., 2015). As a member of the family Pseudococcidae, this pest encourages the growth of sooty mold fungi through its honeydew secretion, thereby lowering the host plant's photosynthetic efficiency. Numerous studies have explored its biology and life cycle under natural conditions (Seyfollahi et al., 2017; Mohamed, 2021; Waqas et al., 2021). According to Boushi et al. (2020), *P. solenopsis* can complete up to 11 generations annually under favorable conditions and overwinter in protected sites such as tree bark crevices as well as the surrounding soil. These traits contribute to the difficulty of managing infestations in affected areas.

Biological control of the cotton mealybug has gained considerable attention in recent years. Several species of parasitoid wasps and predatory lady beetles have been collected and identified from infested areas (Noyes & Hayat, 1994; Sahito et al., 2011; Jalilvand et al., 2014; Mossadegh et al., 2015). Among the most effective natural enemies is the parasitoid wasp *Aenasius bambawalei* Hayat, first reported in India, exhibiting high parasitism rates, particularly on late-instar nymphs and adult females (Hayat, 2009). Moreover, predatory species such as *Nephus arcuatus* Kapur, *Hyperaspis polita* Weise, *Nephus hiekei* Fürsch, and *Dicrodiplosis manihotti* Harris play an important role in suppressing mealybug populations by feeding on eggs and early-instar nymphs (Nakhaei Madih et al., 2016, 2017, 2021; Ramezani & Zarghami, 2017; Ramezani et al., 2021; Zilaei et al., 2022; Poorzandian et al., 2022). Studies on the prevalence and distribution of the cotton mealybug have emphasized the critical role of climatic conditions, host plant availability, and biological interactions in shaping the population dynamics of both the pest as well as its natural enemies (Hanchinal et al., 2010; Arve et al., 2011; Pawar et al., 2017; Harde et al., 2020; Waqas et al., 2021; Desai et al., 2022). Suroshe et al. (2019) researched the seasonal abundance of *P. solenopsis* and its natural enemies on various host plants, including hibiscus, and concluded that environmental variables—such as temperature, humidity, and rainfall—along with biotic factors such as the presence of natural enemies, are positively correlated with fluctuations in both pest and predator populations. Likewise, Ghada (2021) explored the pest's population dynamics and biology on okra and confirmed the strong influence of environmental factors on population fluctuations. In a study in Egypt, Bakry and Fathipour (2023) tested the effects of climatic conditions and host plant age on the seasonal fluctuations of the cotton mealybug on okra. Their results indicated three distinct population peaks along the growing season (Bakry & Fathipour, 2023). In a study performed in the Rasheed region, Beheira Governorate, Refaei et al. (2024) inspected the effects of temperature and humidity on *P. solenopsis* populations infesting sweet potato. Their findings demonstrated that both the mealybug and its associated natural enemies were significantly affected by climatic conditions. Further, population peaks of the pest were closely synchronized with those of its predators and

revealed a strong dependence on minimum temperature and relative humidity (Refaei et al., 2024).

Despite numerous studies on other host plants, no research has yet addressed the population dynamics and spatial distribution of the cotton mealybug on Chinese hibiscus (*Hibiscus rosa-sinensis*) in Iran. Thus, the present study aims to explore the population fluctuations of *P. solenopsis*, along with the population trends of its principal natural enemies, in Khuzestan Province, southwestern Iran.

Materials and Methods

To ascertain the population dynamics of the cotton mealybug and its natural enemies on Chinese hibiscus (*H. rosa-sinensis*), biweekly sampling was conducted over two consecutive years (from April to March 2016 & 2017) in the landscape of Dezful County (32.3840° N, 48.3996° E), Khuzestan Province, southwestern Iran. Along each sampling session, ten shrubs were randomly selected. From each shrub, 10-cm-long branches were collected from the four cardinal directions and placed in labeled plastic bags. The collected samples were transported to the laboratory, where all developmental stages of the cotton mealybug and its associated predators, if present, were inspected and identified under a stereomicroscope. For parasitoid identification, mummified mealybugs were kept in ventilated plastic containers (15 × 10 × 5 cm) under room conditions until adult emergence. Emerged parasitoids were subsequently employed for species determination. The collected natural enemies were identified through comparison with available reference specimens and standard taxonomic keys (Noyes & Hayat, 1994; Raimundo & van Harten, 2000; Noyes, 2003; Hayat, 2009). When necessary, specimens were submitted to specialized experts for confirmation. All counts were recorded separately based on species and developmental stage, both on branches and leaves, and systematically organized using pre-designed data sheets.

Microsoft Excel was utilized to generate population fluctuation graphs, while SPSS version 16 was employed to analyze the relationships between population changes and both biotic factors (e.g., natural enemies) as well as abiotic factors (e.g., temperature and relative humidity).

Results

Figures 1–4 display the population dynamics of the cotton mealybug (*Phenacoccus solenopsis*) and its natural enemies on Chinese hibiscus (*Hibiscus rosa-sinensis*) in the urban green spaces of Dezful, over a two-year period. As depicted in Figures 1 and 2, *P. solenopsis* activity started in late winter to early April, primarily involving adult females. Prior to this period, no external signs of infestation were visible, as the insects remained concealed in bark crevices, beneath branches, as well as in the soil at the base of the infested shrubs. Once they colonized young host tissues—particularly newly emerged leaves—adult females began producing nymphs. Within a short span, a sharp rise was recorded in population density of various developmental stages of *P. solenopsis*. (Figure 5).

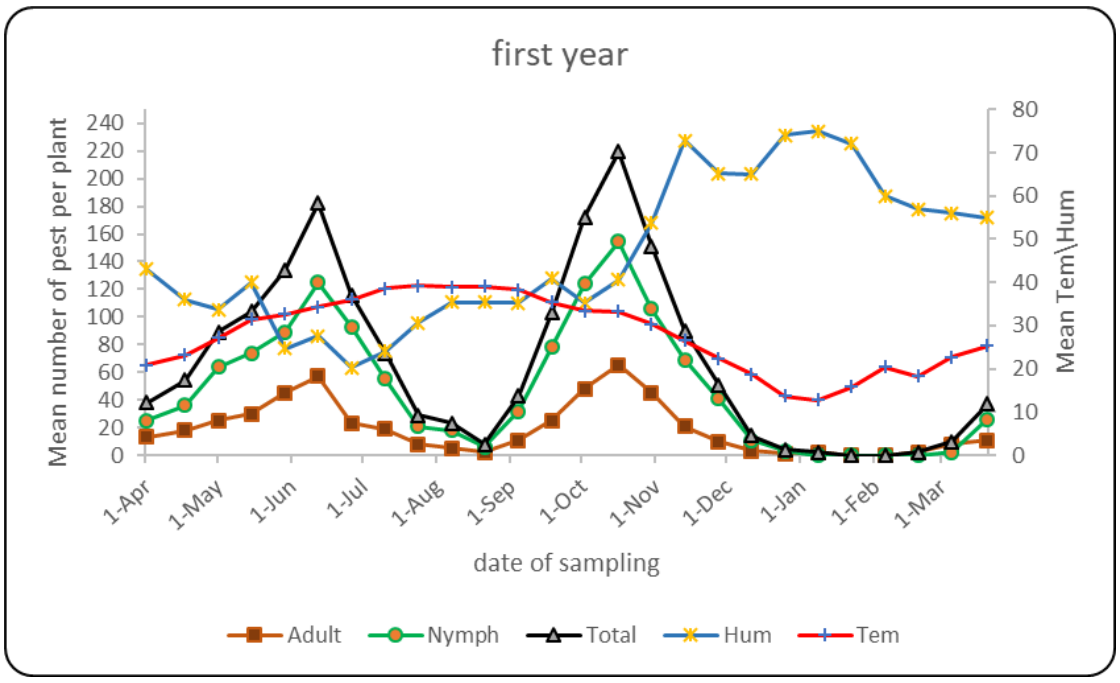


Figure 1. Population dynamics of different developmental stages of cotton mealybug (*Phenacoccus solenopsis*) in relation to temperature and humidity variations in Dezful, southwest Iran, during the first year (2015-2016) of sampling.

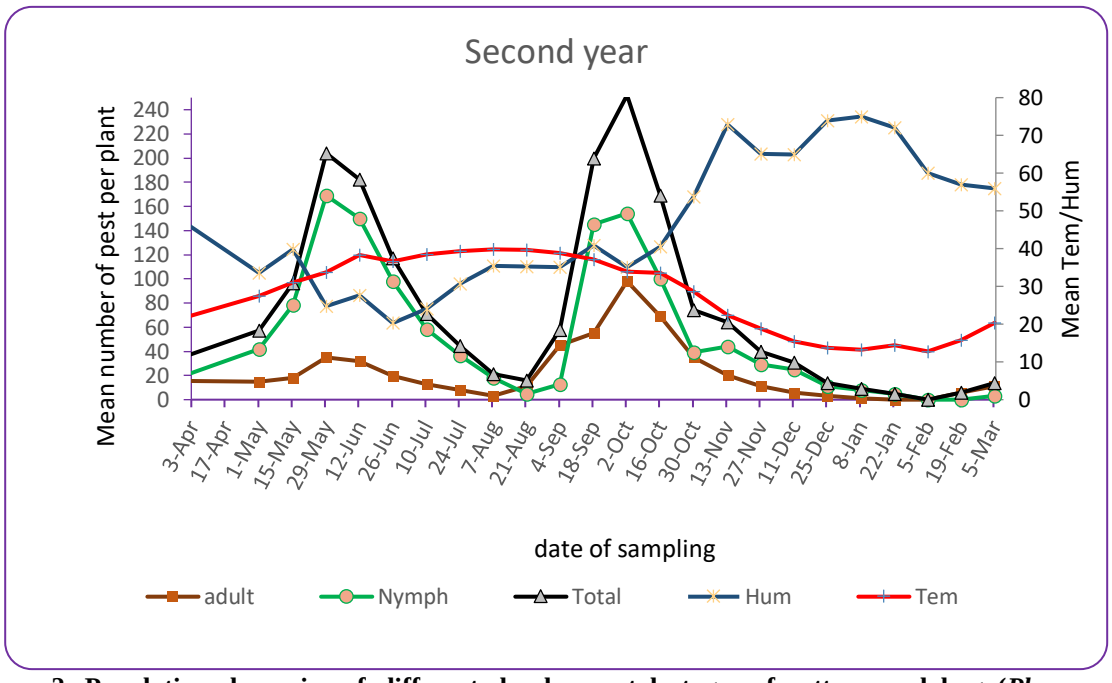


Figure 2. Population dynamics of different developmental stages of cotton mealybug (*Phenacoccus solenopsis*) in relation to temperature and humidity variations in Dezful, southwest Iran, during the second year (2016-2017) of sampling.

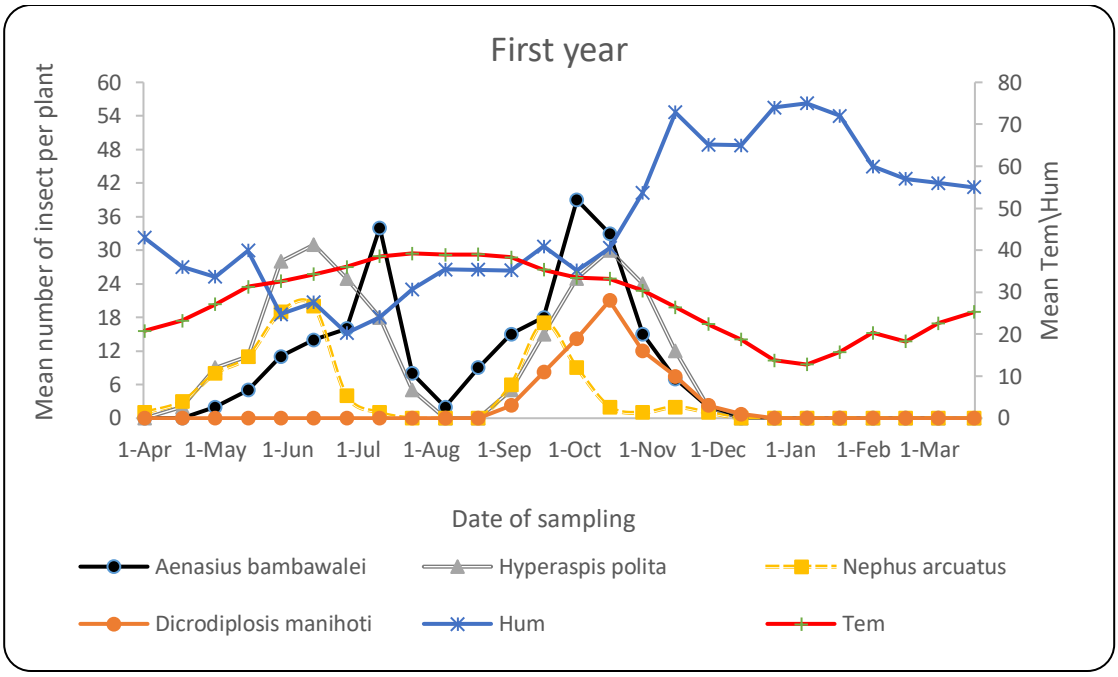


Figure 3. Population dynamics of various natural enemy species of the cotton mealybug (*Phenacoccus solenopsis*) in relation to temperature and humidity fluctuations in Dezful, southwest Iran, during the first year (2015-2016) of sampling.

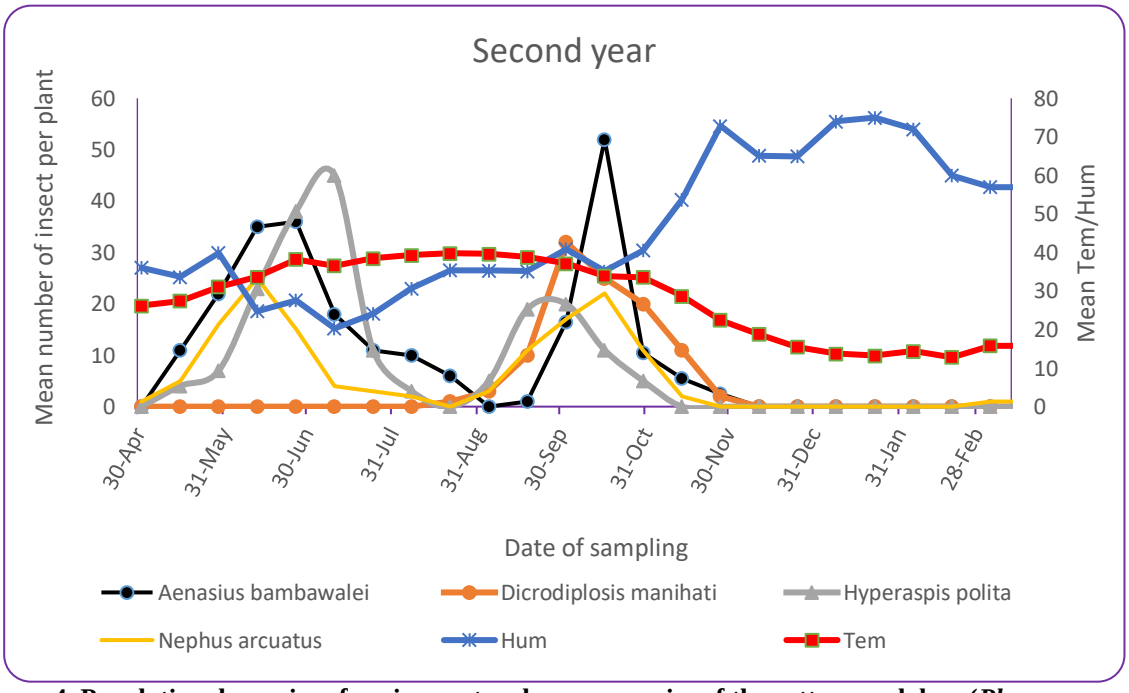


Figure 4. Population dynamics of various natural enemy species of the cotton mealybug (*Phenacoccus solenopsis*) in relation to temperature and humidity fluctuations in Dezful, southwest Iran, during the second year (2016-2017) of sampling.



Figure 5. Damage symptoms and population density of cotton mealybug (*Phenacoccus solenopsis*) on the leaves and branches of Chinese Hibiscus (*Hibiscus rosa-sinensis*) in urban landscape settings.

In the first year, the activity of mealybug began about early March and population increased as temperature rise moderately and density peaked from late June to early July, reaching a maximum of 182 individuals per branch on 12 June (Figure 1). The population declined through July and August owing to hot weather temperatures but resurged in early autumn by lowering the hot weather to moderate temperature, reaching a second peak of 219 individuals per branch on 16 October. A similar trend was observed in the second year, with activity starting slightly earlier (11 February). The first peak occurred in late May, reaching 204 individuals per branch, followed by a decline during midsummer. A second peak was recorded on 2 October, with the population reaching 252 individuals per branch. Shortly after the initial appearance of mealybugs, natural enemies—including predatory beetles (*N. arcuatus* and *H. polita*) and the parasitoid wasp *A. bambawalei*—became active. Their populations grew in parallel with rising mealybug densities and increase in temperatures, peaking between late June and early July (Figures 3 and 4). Although their activity diminished during midsummer, a secondary growth occurred in mid-September. The data suggest a close biological interaction between *P. solenopsis* and its natural enemies. The midsummer population crash of the mealybug coincided with the highest temperature and humidity levels, during which only individuals protected in concealed plant parts survived. A partial recovery was observed in late September, though post-summer populations remained lower than in spring (Figures 1 and 2). Along this time, the predatory fly *D. manihoti* also emerged and was active from late September through late November. No mealybugs or natural enemies were recorded during winter sampling (Figures 1–4). Nevertheless, detailed inspections of bark crevices, inner branches, and surrounding soil revealed that the pest primarily overwintered as first-instar nymphs and adult females, often hidden beneath bark or within waxy ovisacs.

Figure 6 demonstrates the parasitism rates of *A. bambawalei* on *P. solenopsis* across different seasons. The parasitoid's activity revealed a strong correlation with host availability, reaching its highest levels during the summer months when mealybug populations were most abundant. In 2016, parasitism rates were minimal in early spring, gradually rose from May onward, and peaked in July (44%) before declining in autumn and ceasing entirely in winter. In contrast, the 2017 data indicated an earlier onset of parasitism, with similar peak rates observed between June and July (37–44%), followed by a sharp decline after August. The reduction in parasitism during autumn and its absence in winter may reflect the combined effects of diminished host density and suboptimal climatic conditions.

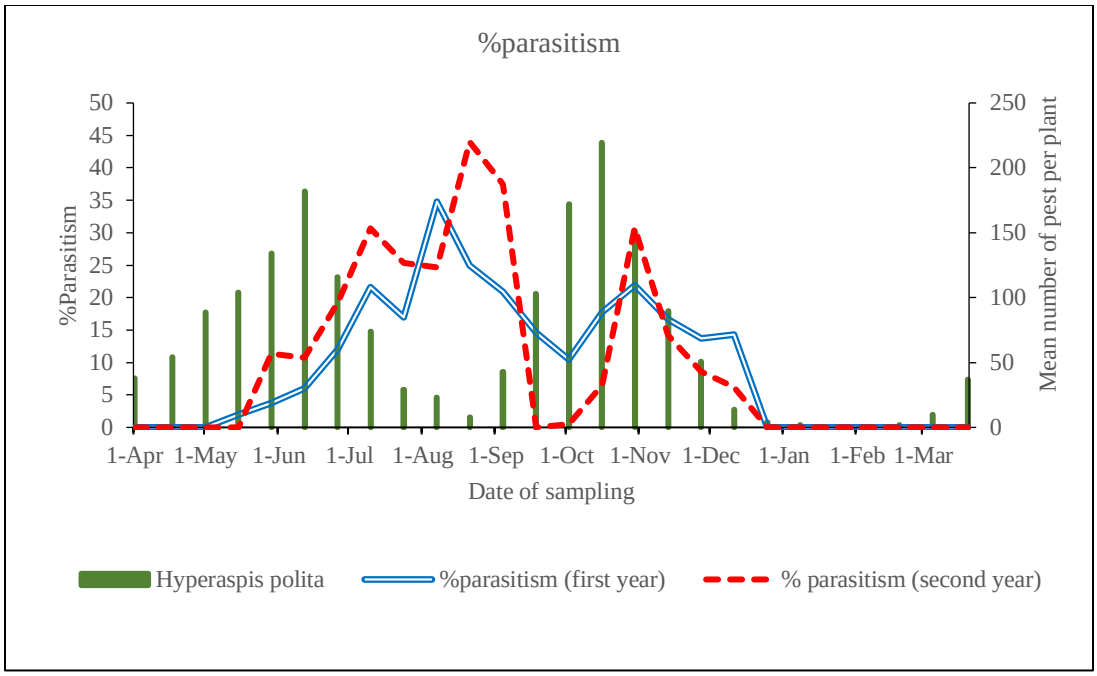


Figure 6. Percentage parasitism of *Aenasius bambawalei* on the cotton mealybug (*Phenacoccus solenopsis*) during 2016 and 2017.

Effect of Temperature and Humidity on *P. solenopsis* and its natural enemies

The correlation analysis indicated that the population of *P. solenopsis* was significantly influenced by both temperature and relative humidity (Table 1). Temperature manifested a positive and significant correlation with the pest population (r = 0.444, p = 0.001), demonstrating that warmer conditions favored its abundance. In contrast, relative humidity had a negative and significant correlation (r = –0.349, p = 0.012), suggesting that higher moisture levels suppressed population growth.

All natural enemies combined revealed a strong positive correlation with temperature (r = 0.659, p < 0.001) and a negative correlation with humidity (r = –0.552, p = 0.001) (table 1). At the species level, the strongest positive links with temperature were recorded for *N. arcuatus* (r = 0.646, p = 0.001) and *Hyperaspis polita* (r = 0.644, p = 0.001). *A. bambawalei* (r = 0.510, p = 0.001) and *D. manihoti* (r = 0.380, p = 0.006) also responded positively to temperature, though the relationship was weaker for the latter. With humidity, negative correlations were detected for most natural enemies, being strongest for *H. polita* (r = –0.550, p = 0.001) and *N. arcuatus* (r = –0.504, p = 0.001). In contrast, *D. manihoti* presented no significant response to humidity (r = –0.188, p = 0.186).

Relationship between *P. solenopsis* and Natural Enemies

The population of *P. solenopsis* was positively correlated with all its natural enemies (Table 1). Among them, the parasitoid *A. bambawalei* (r = 0.440, p = 0.001), predators *N. arcuatus* (r = 0.400, p = 0.004), and *D. manihoti* (r = 0.422, p = 0.002) presented significant positive associations, reflecting density-dependent responses to host availability. When natural enemies were considered collectively, their abundance was significantly and positively associated with *P. solenopsis* density (r = 0.511, p < 0.001).

Table 1. Correlation between population fluctuations of *Phenacoccus solenopsis* and biotic (natural enemies) as well as abiotic (temperature and humidity) factors

	Temperature		**Humidity**		***Phenacoccus solenopsis***		**All natural enemies**	
	Correlation coefficient (R)	*P* value	Correlation coefficient (R)	*P* value	Correlation coefficient (R)	*P* value	Correlation coefficient (R)	*P* value
Phenacoccus solenopsis	0.444**	0.001	-0.349*	0.012	-	-	0.511**	0.000
Aenasious bambawalei	0.510**	0.000	-0.467**	0.001	0.440**	0.001	-	-
Hyperaspis polita	0.644**	0.000	-0.550**	0.000	0.357*	0.010	-	-
Nephus arcuatus	0.646**	0.000	-0.504**	0.000	0.400**	0.004	-	-
Dicrodiplosis manihoti	0.380**	0.006	-0.188^{ns}	0.186	0.422**	0.002	-	-
All natural enemies	0.659**	0.000	-0.552**	0.000	0.511**	0.000	-	-

*: Indicates significance at the 5% level, **: significance at the 1% level and ns: non-significance.

These results highlight the importance of incorporating environmental factors and natural enemy dynamics into integrated pest management (IPM) strategies, particularly in urban landscapes. The two-year field study undertaken in Dezful demonstrated clear phenological patterns in *P. solenopsis* populations, with activity starting in late winter (February–March) as overwintering adult females emerged from bark crevices and soil to colonize new vegetative growth. These findings underscore the ecological significance and conservation value of the natural enemy complex in the sustainable management of *P. solenopsis* in urban landscape.

Discussion

The use of natural enemies in urban landscape management offers a sustainable alternative to chemical pesticides, mitigating environmental contamination, safeguarding public health, and conserving beneficial organisms (van Lenteren, 2012). Overreliance on chemical control in urban landscapes not only threatens biodiversity but also exposes residents to pesticide residues and contributes to environmental pollution, making it unsuitable for areas of direct human interaction (Fand, 2012).

In this study, we ascertained the relationship between natural enemies and environmental factors along with their influence on the population dynamics of *P. solenopsis* on Chinese hibiscus. The results revealed that

temperature was positively correlated with the abundance of both the mealybug and its natural enemies, while high humidity had a generally negative effect. These findings align with previous studies in southern Iran, India, and Pakistan, which reported that warm, dry conditions accelerate pest development and reproduction, often leading to outbreaks during hot seasons (Hodgson et al., 2008; Fand & Suroshe, 2015; Boushi et al., 2020).

Suroshe et al. (2019) reported that the largest population of the cotton mealybug on eggplant in new Delhi, India occurred in March (33.8 adults), while the lowest was recorded in November (0.93 adults). Their study presented a significant positive correlation between mealybug population and temperature, as well as a negative correlation with rainfall. Similarly, the present study also found a significant positive correlation between temperature and the population density of *P. solenopsis*, though negative significant correlation was observed with relative humidity.

Further, Suroshe et al. (2019) reported a significant positive correlation between natural enemy abundance and mealybug population on eggplant, a finding consistent with the current results. On Chinese hibiscus, Suroshe et al. (2019) documented the highest mealybug population (51.82 individuals) in July, with the lowest recorded in October. The analysis revealed significant positive correlations between the pest population and temperature, relative humidity, and rainfall, as well as a significant positive relationship with parasitoid abundance on Chinese hibiscus in new Delhi (Suroshe et al. 2019). In the same vein, our findings confirmed a statistically significant correlation between the abundance of natural enemies and *P. solenopsis* population dynamics.

Singh and Kumar (2012), in their study on the population dynamics of the cotton mealybug in Gujarat, India, reported that pest populations on cotton and okra peaked in October, while the highest populations on tomato and potato were observed in February. They found a significant positive correlation between mealybug density and temperature, along with a negative correlation between the abundance of predators and parasitoids with low temperature and relative humidity. These findings are in line with the present study, which also recorded a significant positive correlation between predator and parasitoid abundance and temperature, with negative significant correlation observed with relative humidity.

Likewise, Saber El-Zahi and Ismail Farag (2017) reported that *P. solenopsis* infestations on cotton began in June—approximately two months after planting—and peaked in early September in both years of their study in Egypt. Similar to the current findings, they observed a significant positive correlation between mealybug infestation and temperature. However, in contrast to our results, they also found a significant positive correlation with relative humidity.

The study by Pawar et al. (2017) during 2010–11 at the Main Cotton Research Station in Surat, Gujarat, India, explored the population dynamics of *P. solenopsis* and its natural enemies on Bt cotton. The results showed a strong positive correlation between mealybug incidence and sunshine hours, while natural predators such as ladybird beetles, green lacewings, and spiders manifested seasonal fluctuations influenced by weather parameters—findings that are consistent with our study.

Refaei et al. (2024), examining the impact of ecological conditions on *P. solenopsis* and its predators on sweet potato in Egypt, found that mealybug populations were initially low, gradually increased, and peaked on 30 July, coinciding with a growth in predator populations. A second peak occurred on 21 August, with predator numbers also reaching

their highest levels. Their results demonstrated a significant correlation between mealybug and natural enemy populations, as well as with climatic factors. These trends align with our findings, which likewise indicated a significant correlation between the abundance of natural enemies and both mealybug density and temperature.

Overall, the observed trends in the population dynamics of natural enemies in relation to *P. solenopsis* fluctuations presented a clear ecological interaction. Natural enemies typically became active shortly following the initial rise in mealybug populations and increased in number alongside the pest, ultimately contributing to a decline in mealybug density later in the season. This pattern highlights the important role of natural enemies in the biological control of the cotton mealybug. Climatic factors also played a substantial role in shaping insect population dynamics. Growing temperatures during July and August, along with high humidity in August, significantly influenced both pest and predator populations. Conversely, sharp temperature reductions and rainfall during winter contributed notably to the suppression of mealybug populations during that season. Boushi et al. (2020), in their study on the biology of *P. solenopsis* on Chinese hibiscus in Dezful's landscape, reported that the first through third generations took place in spring. The fourth generation emerged in early July and reached the highest density, causing the most severe damage through intensive sap feeding and excessive honeydew production. These findings are in accordance with those of the present study, which also recorded the highest mealybug population in July. Shortly after mealybug activity resumed, natural enemies such as *N. arcuatus*, *H. polita*, and the parasitoid wasp *A. bambawalei* became active—possibly in response to the availability of prey. In addition, Boushi et al. (2020), noted that the fifth generation of mealybugs coincided with the hottest months (August–September), during which a marked population decline was witnessed. This reduction was attributed to a combination of environmental stress—such as high temperatures and host plant wilting, extending developmental periods, particularly the pre-oviposition phase—and the heightened activity of natural enemies during this period. Field observations of infested shrubs in the sampled areas indicated that, during summer, unfavorable conditions in the outer, sun-exposed parts of the host plant forced mealybugs to retreat to the inner, more shaded regions of the canopy. As such, only a limited number of individuals—mostly those sheltering in protected areas—survived, leading to a notable reduction in overall pest density. According to Boushi et al. (2020), the sixth and seventh generations of *P. solenopsis* emerged with the onset of cooler temperatures and the regrowth of Chinese hibiscus in early autumn, which facilitated the recovery of the pest population. The eighth through eleventh generations occurred along the autumn and winter months. However, as temperatures continued to fall and rainfall rose, the development rate of later generations—particularly the tenth and eleventh—was markedly reduced. Winter field observations indicated that although the pest's development did not cease entirely, it slowed significantly. *P. solenopsis* overwintered in all developmental stages, especially as first-instar nymphs and adult females, within bark crevices, branch junctions, and soil near the base of shrubs.

Conclusion

Overall, this two-year field study could provide valuable insights into the population dynamics and phenology of *P. solenopsis* as well as its key natural enemies on Chinese hibiscus across the urban landscapes of Dezful, southwest Iran. The pest's bimodal seasonal pattern, driven primarily by

temperature fluctuations, along with the observed decline in populations during midsummer owing to thermal stress and increased natural enemy activity, highlights the complex interactions influencing pest abundance. The presence and strong ecological synchrony of natural enemies such as *A. bambawalei*, *N. arcuatus*, *H. polita*, and *D. manihoti* emphasize their significant role in suppressing pest populations. Considering the environmental and human health risks linked to pesticide use in urban green spaces, the incorporation of natural enemies into integrated pest management programs offers a sustainable and ecologically sound alternative. Further, the integration of temperature-based population models and early pest detection can boost the effectiveness of management strategies against this invasive pest in urban and ornamental horticulture. Ultimately, this study highlights the importance of native natural enemy communities in promoting environmentally responsible pest management practices that support urban sustainability and biodiversity conservation.

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Conflict of interest

The authors declare that they have no conflict of interest

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