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Original article (Orijinal araştırma)

Distribution and infestation rates of *Phenacoccus solenopsis* Tinsley, 1898 (Hemiptera: Pseudococcidae) in cotton fields in Aydın province (Türkiye) and its alternative host plants[1]

Aydın ilinde (Türkiye) pamuk tarlalarında *Phenaoccus solenopsis* Tinsley, 1898 (Hemiptera: Pseudococcidae)'in yayılışı, bulaşma oranları ve diğer konukçu bitkileri

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Abstract

Intense infestations of a mealybug species were observed on cotton plants in Aydın province (Türkiye) between 2022 and 2023. Insect samples were identified as the cotton mealybug, *Phenacoccus solenopsis* Tinsley, 1898 (Hemiptera: Pseudococcidae). In 2024, surveys were conducted to determine the distribution, infestation rates and alternative hosts of the cotton mealybug in cotton cultivation areas in Aydın. As a result of the surveys, it was determined that the cotton mealybug was distributed in 12 districts of Aydın province and 44.37% of total cotton cultivation areas was infested in Aydın. The infestation rates per field varied between 0.00% and 100%, and for each district changed between 0.00% and 46.13%. In and around cotton fields, 27 alternative host plants were found. Of these, four species are for the first time recorded as hosts of cotton mealybug, of which the most common host plants were *Conyza* spp. (Asterales: Asteraceae).

Keywords: Cotton mealybug, first record, *Gossypium hirsutum*, insect pest, invasive species, Türkiye

Öz

Aydın ilinde (Türkiye) 2022 ve 2023 yıllarında pamuk bitkisinde yoğun bulaşmalar gözlenmiştir. Alınan örnekler pamuk unlubiti, *Phenacoccus solenopsis* Tinsley, 1898 (Hemiptera: Pseudococcidae) olarak teşhis edilmiştir. Pamuk unlubitinin, 2024 yılında Aydın'daki pamuk yetiştirilen alanlarda yaygınlığı, bulaşma oranlarını ve alternatif konukçularını belirlemek amacıyla sürveyler gerçekleştirilmiştir. Sürveyler sonucunda pamuk unlubitinin Aydın ilinin 12 ilçesine ve pamuk üretim alanlarının %44,37'sine yayıldığı belirlenmiştir. Tarla başına bulaşma oranları %0,00 ile%100 arasında değişmektedir. İlçelere göre bulaşma oranlarının %0,00 ile %46,13 arasında değiştiği saptanmıştır. Pamuk alanları ve çevresinde 27 alternatif konukçu bitki tespit edilmiştir. Bunlardan dört tür pamuk unlubitinin konukçusu olarak ilk kez kaydedilmiş olup, en yaygın görülen alternatif konukçu bitkiler *Conyza* spp. (Asterales: Asteraceae) olarak belirlenmiştir.

Anahtar sözcükler: Pamuk unlubiti, ilk kayıt, *Gossypium hirsutum*, zararlı böcek, istilacı türler, Türkiye

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Introduction

The cotton mealybug, *Phenacoccus solenopsis* Tinsley, 1898 (Hemiptera: Pseudococcidae) was first detected in New Mexico, USA in 1898 by Tinsley (1898), and in the following years it has been recorded in many different countries in Africa, Asia, North America, South America and the Caribbean countries (García Morales et al., 2016). *Phenacoccus solenopsis* is a polyphagous pest with the ability of spreading rapidly in a short time, and it has been detected in 212 different plants belonging to 64 families (García Morales et al., 2016). The first invasive species record of *P. solenopsis* in Türkiye was in Adana in 2012 in ornamental plants (Kaydan et al., 2013), and the species is now widespread in the Mediterranean region of Türkiye. In a study conducted in agricultural fields and ornamental plants in Aydın province, *P. solenopsis* was found on 45 different host plants belonging to 25 families (Yerlikaya et al., 2023).

The mealybugs not only damage the host plant by sucking plant sap, but in general they are also responsible for the transmission of viral diseases (Bertin et al., 2010). In addition, the honeydew secreted by mealybugs provides an environment for the development of sooty molds, which also disrupts the photosynthesis process of the plant (Williams & Granara de Willink, 1992). This pest is often overlooked due to the very small nymphal stages. In recent years, as a result of the increase in agricultural products and ornamental plant trade worldwide and the increased mobility of plant material carried by people, many pest species living on these plant parts are entering other countries from where they are found. Thus, as in many other pest groups, species of the family Pseudococcidae are rapidly spreading on earth (Hodgson et al., 2008; Chong, 2009; Zhu et al., 2011; Kaydan et al., 2012; Ibrahim et al., 2015; Waqas et al., 2021). In addition, due to global warming, milder winter months and the expansion of the distribution areas of their host plants contribute to mealybug species becoming invasive species (Yerlikaya, 2022). The cotton mealybug has up to 15 generations per year in tropical climates, with a generation time of 25-30 days; females are ovoviviparous, laying 150-600 eggs per brood, and have a temperature tolerance of 0-45°C, indicating the pest's population can increase rapidly (Sharma, 2007; Kondo & Watson, 2022). In 2012, eleven species were announced as dangerous pest species in the invasive species list of CABI (Center for International Agriculture and Bioscience) and it was reported that *P. solenopsis* was one of the most important pest species among these. *Phenacoccus solenopsis* is adaptable to various climatic conditions and has many host plants. Therefore, the expected distribution of this species has a great potential of threat to agricultural areas (Wang et al., 2010). *Phenacoccus solenopsis* can easily become a problem in the areas where it spreads due to its wide host range and high reproductive potential (Kahya, 2020). Since *P. solenopsis* has a high-risk to become an invasive species, it is as quarantine pest in Argentina, China, Chile, Japan, Peru and many EPPO (European and Mediterranean Plant Protection Organization) member countries (Kondo & Watson, 2022).

Phenacoccus solenopsis causes significant problems in Pakistan and India, which account for 75% of the world cotton production, and this situation negatively affects the cotton trade at a global basis (Kahya, 2020). In fact, a study conducted in Pakistan reported a yield loss of 44% in cotton production due to *P. solenopsis* damage (Dhawan et al., 2009). In studies conducted in India, 30-80% of yield losses in cotton have been reported (Nagrare et al., 2009; Nalwar et al., 2009; Vennila et al., 2010). The impact of global climate change on the distribution and population density of *P. solenopsis* was estimated in a study in India. As a result of the study, it was determined that in 80% of the cotton cultivated areas, the mealybug can produce 4 or more times offspring, and cause significant economic losses (Fand et al., 2014). It was reported that this invasive species could spread over large areas and caused significant economic damages in China, and was therefore accepted as a high-risk invasive species (Wang et al., 2009).

Aydın province is a significant contributor to Türkiye's cotton production, ranking third with 12% of the national output (MAF, 2022). In recent years, meteorological records show that the relative humidity has increased in Aydın province due to reasons such as the increase in the number of dams, geothermal

energy facilities and the increase in irrigation due to expanding corn production areas (Table 1). It is thought that these conditions provide positive ecological conditions for the reproduction and multiplication of many insect species and are also an important factor in terms of the increase in the population of mealybugs.

Table 1. Some meteorological data of cotton growing periods (April-October) in Aydin province over years (DGM, 2023)

Meteorological parameters	1991-2021 (average)	2019	2020	2021	2022
Average temperature (°C)	23.93	23.90	24.34	24.60	24.65
Average maximum temperature (°C)	30.10	31.96	33.30	32.82	32.83
Average minimum temperature (°C)	17.67	17.20	17.34	17.47	17.89
Average relative humidity (%)	46.86	53.58	53.12	46.00	48.73
Total precipitation (mm)	210.00	192.80	121.40	50.40	85.40

Most of the research conducted in Türkiye on the invasive cotton mealybug, which causes significant problems in many countries, has been limited to non-agricultural areas and laboratory studies (Kaydan et al., 2013; Çalışkan et al., 2016; Çalışkan Keçe, 2019; Kahya et al., 2019; Kahya, 2020; Görür & Karut, 2021). Therefore, it is essential to determine the damage potential of this invasive pest in cottonfields. Additionally, complaints have been received from the Nazilli Cotton Research Institute and cotton producers that the spreading areas and population density of the mealybug have increased. For these reasons, this study aimed to determine the distribution and infestation rates of *P. solenopsis* in cotton fields in Aydın province, and surveys were conducted. In addition, other host plants infested with *P. solenopsis* in and around the cotton fields were determined.

Materials and Methods

Field surveys and sampling methods

The main material of the study was *P. solenopsis* in cotton fields and other host plants in and around cotton fields in Aydın province. In the preliminary study, samples were taken from cotton fields in Nazilli, Söke and Koçarlı districts between 2022 and 2023. The mealybugs species in the samples were identified as *P. solenopsis*. During the cotton growing season in 2024, surveys were conducted in all districts, especially in the districts where cotton cultivation was more extensive, and the distribution and infestation rates of *P. solenopsis* were determined. In addition, other plants in and around the cotton fields were also examined and plants infested with *P. solenopsis* were recorded as host plants.

In order to determine the distribution and infestation rates of *P. solenopsis*, surveys and sampling were conducted in cotton fields covering 0.01% of the cotton cultivation areas in the province (Bora & Karaca, 1970). The surveys started in June and continued until the end of September, the period when mealybug found in cotton fields. Adapted from MAF (2017) protocols, in each cotton field up to 50 decares (da), 50 cotton plants were randomly examined from different points in the field. The plant was considered infested if an individual in any biological stage of *P. solenopsis* was observed on the plant. The number of infested plants was divided by the total number of plants examined to determine the percentage (%) of infestation rate in the field. For fields larger than 50 da, this process was repeated for every 50 da. To determine the distribution rate, a cotton field was considered to be infested if even one cotton plant was found to be infested with *P. solenopsis.* At the same time, samples were obtained from mealybug infested fields for the identification of *P. solenopsis*. In addition, weeds and other plants in and around the cotton fields were examined, and if *P. solenopsis* was observed on these plants, samples were collected, and the host plant was recorded. Weed samples were identified by the authors and their identification was confirmed by relevant researchers. The infestation rate of *P. solenopsis* was calculated according to the formula below (Bertin et al., 2010):

IP : Infestation percentage

$IP=(X\div T)\times 100$ X : Number of plants infested with mealybug

T : Total number of plants examined

The infestation rate of *P. solenopsis* in provinces and districts was calculated according to the weighted average (Bora & Karaca, 1970).

The distribution rate was calculated according to the formula below:

DP: Distribution percentage

$DP=(A\div Y)\times 100$ A : Mealybug infested area

Y : Total area surveyed

Laboratory studies and morphological identification

Identification of mealybugs is made by observing the morphological characters of adult female individuals. For this reason, mealybug samples were examined under a stereo-binocular microscope and about 20 adult females from each sample were preserved in vials containing 70% ethyl alcohol. Female adult mealybugs were slide-mounted at the Sultanhisar Vocational School, Aydın, Türkiye, using the methods proposed by Kosztarab & Kozár (1988) with modifications (using sterile water after KOH to clean the specimens with a fine brush). The specimens were identified using the keys of Williams (2004) and Hodgson et al. (2008). A Leica DM2500 phase-contrast binocular microscope was used for identification of mealybugs. In addition, weeds and other plants in and around the cotton field infested with mealybug were prepared for the identification and preserved in a herbarium. The herbarium is in Sultanhisar Vocational School, Aydın, Türkiye. For the floristic catalogue, Güner et al. (2012) was followed.

Results and Discussion

***Phenacoccus* Cockerell, 1893 (Hemiptera: Pseudococcidae)**

***Phenacoccus solenopsis* Tinsley, 1898**

Material examined. Türkiye, Aydın: Buharkent, 144 m, 15.VIII.2024, 18 ♀♀; Didim, 7 m, 9.VIII.2024; 12 ♀♀; Efeler, 30 m, 28.VI.2024; 9 ♀♀; Efeler, 38 m, 25.VII.2024, 24 ♀♀; Efeler, 34 m, 2.VII.2024, 6 ♀♀; Efeler, 33 m, 4.VIII.2024, 15 ♀♀; Efeler, 32 m, 10.IX.2024, 12 ♀♀; Germencik, 27 m, 05.VII.2024, 3 ♀♀; Germencik, 14 m, 26.VII.2024, 6 ♀♀; Germencik, 32 m, 24.IX.2024, 78 ♀♀; İncirliova, 42 m, 25.VII.2024, 6 ♀♀; İncirliova, 40 m, 24.IX.2024, 21 ♀♀; Koçarlı, 26 m, 14.VIII.2022, 9 ♀♀; Koçarlı, 28 m, 19.VII.2023, 12 ♀♀; Koçarlı, 35 m, 8.VIII.2024, 3 ♀♀; Koçarlı, 40 m, 9.VIII.2024, 18 ♀♀; Koçarlı, 32, 10.IX.2024, 39 ♀♀; Köşk, 55 m, 17.IX.2024, 15 ♀♀; Kuyucak, 108 m, 15.VIII.2024, 30 ♀♀; Nazilli, 60 m, 10.IX.2022; 12 ♀♀; Nazilli, 61 m, 7.VII.2023, 15 ♀♀; Nazilli, 62 m, 10.VI.2024, 6 ♀♀; Nazilli, 60 m, 26.VI.2024, 12 ♀♀; Nazilli, 55 m, 02.VII.2024, 6 ♀♀; Nazilli, 86 m, 15.VIII.2024, 3 ♀♀; Söke, 15 m, 12.VIII.2022, 6 ♀♀; Söke, 10 m, 22.VIII.2023, 6 ♀♀; Söke, 6 m, 28.VI.2024, 3 ♀♀; Söke, 10 m, 22.VII.2024, 3 ♀♀; Söke, 5 m, 26.VII.2024, 6 ♀♀; Söke, 13 m, 9.VIII.2024, 60 ♀♀; Sultanhisar, 49 m , 27.VI.2024, 3 ♀♀; Yenipazar, 52 m, 17.IX.2024, 9 ♀♀.

Phenacoccus solenopsis, which was previously reported in non-agricultural areas and ornamental plants in Aydın by Yerlikaya et al. (2023), is for the first time reported in cotton plants in this study. *Phenacoccus solenopsis* infests all above-ground parts of the plant during the cotton growing season (Figure 1a,1b,1c). The cotton mealybug reached high populations and caused the death of plants especially in the edge rows of the fields (Figure 1d). *Phenacoccus solenopsis* was also observed infesting many weeds in and around the cotton field and reached to high populations on these plants. It is possible to state that the first infestations on cotton plants are due to mealybugs that move from weeds.

Figure 1. *Phenacoccus solenopsis* on cotton plants: a) on the top shoots; b) on the stem of the flowers; c) on the leaves; d) on the edge rows of the field.

Distribution and infestation rates of *Phenacoccus solenopsis* Tinsley, 1898 (Hemiptera: Pseudococcidae)

According to the Farmer Registration System data from the Turkish Ministry of Agriculture and Forestry, 560 343 da of cotton is cultivated in Aydın province. The biggest cotton area in the province is located in Söke district with 321 031 da, followed by Koçarlı and Efeler districts with 72 655 da and 41 633 da, respectively (Table 2).

As a result of the surveys conducted in Aydın province, 13 908.60 da (280 fields) cotton fields were observed and 6 171.50 da (142 fields) cotton fields were found to be infested with *P. solenopsis* (Table 2). In this case, the distribution rate of *P. solenopsis* in Aydın province was determined as 44.37%.

In the fields, infestation rates varied between 0.00% and 100%. The highest infestation rate was 100% in a cotton field in Yenipazar district (Figure 3c). This was followed by Germencik and Buharkent with 84.00 % and 82.00% infestation rates, respectively (Table 3).

Table 2. Cotton cultivation areas and survey results in different districts of Aydın province

Districts	Cotton cultivated areas (decare)	Surveyed areas (decare)	Infested areas (decare)	Number of survey fields	Number of infested fields
Söke	321 031	4 928.50	862.80	59	24
Koçarlı	72 655	1 631.70	1 041.70	43	20
Efeler	41 633	1 540.40	913.70	44	22
Germencik	39 663	2 006.00	1 505.20	39	29
İncirliova	27 420	451.30	308.90	13	9
Didim	18 630	734.20	232.80	8	4
Nazilli	16 150	631.80	479.40	16	9
Yenipazar	11 615	269.90	44.90	13	3
Köşk	4 007	549.00	307.20	12	5
Sultanhisar	3 955	224.00	11.00	6	1
Kuyucak	1 324	508.40	354.90	15	10
Çine	962	310.20	0,00	4	0
Buharkent	903	109.00	109.00	6	6
Bozdoğan	395	14.20	0.00	2	0
Total	560 343	13 908.60	6171.50	280	142

Table 3. Infestation and distribution rates of *Phenacoccus solenopsis* in cotton fields in different districts in Aydın province

District	Minimum infestation rates per field (%)	Maximum infestation rates per field (%)	Average infestation rates (%)	Average distribution rates (%)
Söke	0	80	7.53	17.51
Koçarlı	0	80	10.65	63.84
Efeler	0	66	8.91	59.32
Germencik	0	84	30.10	75.03
İncirliova	0	56	19.38	68.45
Didim	0	54	13.00	31.71
Nazilli	0	36	9.38	75.88
Yenipazar	0	100	17.69	16.64
Köşk	0	70	21.50	55.96
Sultanhisar	0	4	0.67	4.91
Kuyucak	0	56	46.13	69.81
Çine	0	0	0.00	0.00
Buharkent	8	82	35.33	100.00
Bozdoğan	0	0	000	0.00

Considering the average infestation rates by districts, the highest infestation was found in Kuyucak with 46.13%. This was followed by Buharkent and Germencik with 35.33% and 30.10% infestation, respectively. No infestation was observed in Bozdoğan and Çine districts (Table 3).

Considering the distribution rates by districts, Buharkent ranked first with 100%, followed by Nazilli and Germencik with 75.88% and 75.03%, respectively (Table 3).

Other host plants of *Phenacoccus solenopsis* Tinsley, 1898 (Hemiptera: Pseudococcidae)

In the study, 27 species of host plants infested with *P. solenopsis* were recorded in and around the cotton field (Figure 2). The most prevalent host plants were *Conyza* spp. (Asterales: Asteraceae) with 72 samples, followed by *Portulaca oleracea* L. (Caryophyllales: Portulacaceae) with 37 samples and *Convolvulus arvensis* L. (Solanales: Convolvulaceae) with 33 samples (Table 4). According to ScaleNet data (García

Morales et al., 2016), four species were first recorded as hosts of *P. solenopsis*: *Alhagi maurorum* Medik. subsp. *maurorum* (Fabales: Fabaceae), *Glycyrrhiza glabra* L. (Fabales: Fabaceae), *Vigna unguiculata* (L.) Walp. (Fabales: Fabaceae), *Xanthium spinosum* L. (Asterales: Asteraceae).

Table 4. Other hosts of *Phenacoccus solenopsis* in cotton fields and number of samples

Host Plant	Family	Samples
Abelmoschus esculentus (L.) Moench	Malvaceae	4
Alhagi maurorum Medik. subsp. *maurorum*	Fabaceae	1
Amaranthus viridis L.	Amaranthaceae	29
Capparis sp.	Capparaceae	1
Chenopodium album L.	Amaranthaceae	22
Citrullus lanatus (Thunb.) Matsum. & Nakai	Cucurbitaceae	1
Conyza bonariensis (L.) Cronquist	Asteraceae	49
Conyza canadensis (L.) Cronquist	Asteraceae	23
Convolvulus arvensis L.	Convolvulaceae	33
Cucurbita sp.	Cucurbitaceae	1
Cuscuta sp.	Convolvulaceae	2
Cyperus rotundus L.	Cyperaceae	1
Datura stramonium L.	Solanaceae	4
Daucus carota L.	Apiaceae	2
Ecballium elaterium (L.) A. Rich.	Cucurbitaceae	1
Glycyrrhiza glabra L.	Fabaceae	6
Heliotropium europaeum L.	Boraginaceae	2
Malva parviflora L.	Malvaceae	9
Physalis alkekengi L.	Solanaceae	1
Portulaca oleracea L.	Portulacaceae	37
Solanum melongena L.	Solanaceae	1
Solanum nigrum L.	Solanaceae	9
Sonchus oleraceus L.	Asteraceae	4
Tribulus terrestris L.	Zygophyllaceae	16
Vigna unguiculata L. Walp.	Fabaceae	3
Xanthium spinosum L.	Asteraceae	2
Xanthium strumarium L.	Asteraceae	16

If *Conyza* spp. at the border of the cotton field were infested with *P. solenopsis*, it was observed that the cotton plants were also infested. This situation was also noticed by the farmers. In fact, some of the farmers we encountered during the surveys stated that mealybugs were in *Conyza* spp. at the beginning of the season and then they moved from this weed to cotton fields by wind and other means. Our observations also supported this report. As a matter of fact, it was observed that some farmers used methods such as ploughing, burning and spraying herbicides to control *Conyza* spp. at the edge of the field. While heavy infestations *P. solenopsis* was determined on other weed hosts only from time to time, but *Conyza* spp. were observed to be infested always with *P. solenopsis* throughout the cotton production season. In support of all these observations, it was determined that *P. solenopsis* overwintered on weeds at the edges of the field and increased its populations in the following year and then moved to cotton plants. The presence of weed hosts that act as alternate hosts around cotton fields was reported to be an important factor in the distribution of this mealybug (Jhala et al., 2008). In order to prevent *P. solenopsis* infestations, it is necessary to control the weeds effectively in the early season, especially at the edge of the fields.

Figure 2. Host plants infested with *Phenacoccus solenopsis* in and around the cotton field: a) *Amaranthus viridis*; b) *Chenopodium album*; c) *Ecballium elaterium*; d) *Ecballium elaterium*; e) *Heliotropium europaeum*; f) *Malva neglecta*; g) *Physalis peruviana*; h) *Portulaca oleracea*; I) *Solanum nigrum*; j) *Sonchus oleraceus*; k) *Xanthium spinosum*; l) *Xanthium strumarium*.

Due to the damage caused to cotton plant by *P. solenopsis*, it has been observed that the plants grow poorly, wither and may even die. Mealybugs could infest all above-ground parts of the plant and caused damage by forming dense populations in the stem part of the bolls. This damage results in the bolls to be weak, remain small and wilt without completing its development. It has been also reported in many studies that mealybugs caused indirect damage to plants by sooty molds that grow on the honeydew they produce (Williams & Granara de Willink, 1992). Sooty mold damage was observed both in the early period and after the bolls opened. At an early stage, sooty mold on the green parts of the plant reduces the area of photosynthesis and causes poor development of the plant, while sooty mold on cotton after the bolls have opened significantly decreases quality.

Figure 3. Damage caused by *Phenacoccus solenopsis* on cotton: a) on the stem of a cotton boll; b) sooty mold on cotton; c) up to 100% damage in the cotton field; d) colony of *Phenacoccus solenopsis* on cotton stalks.

As a result, all districts of Aydın province where cotton is cultivated were found to be infested with *P. solenopsis*, except Bozdoğan (the district with the least cotton area in Aydın province) and Çine. In some cotton fields, high levels of infestation was observed and this was expected to reduce cotton yields significantly. The cotton mealybug was reported to cause yield losses up to 80% in Pakistan and India, which produce most of the world's cotton (Nagrare et al., 2009; Nalwar et al., 2009; Vennila et al., 2010). It is known that with the increase in the population density of cotton mealybug, yield, quality. will drop dramatically and on the other hand, it can be expected that economic losses in cotton fields will increase (Fand et al., 2014). In fact, it should be taken into account that no marketable crop could be obtained due to infestations up to 100% in some fields. During the study, economic production was observed to become almost impossible because of the intense infestations in some fields. Therefore, it can be suggested that studies on the bio-ecology and control of the cotton mealybug in this area should be supported as a priority.

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