



Factors affecting fruit damage caused by *Thrips hawaiiensis* (Morgan) (Thysanoptera: Thripidae) in citrus lemon groves in Turkey

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Abstract The Hawaiian flower thrips, *Thrips hawaiiensis* (Morgan) (Thysanoptera: Thripidae) is an economically important invasive species in citrus grown in the eastern Mediterranean region of Turkey. The diverse impacts of temperature on arthropods are well documented. This study was conducted with the aim of determining the influence of day-degree on insect population dynamics and crop damage levels in Mersin Province, Turkey during 2018–2019. In 2018, the first damage caused by *T. hawaiiensis* was observed at 300 degree-days (DD), while in 2019, it occurred at 800 DD. The damage percentage was recorded as 28% in the lemon grove, where the population of second instar larvae briefly reached a high level (approximately 2 individuals per fruit). During 2019, the average temperature remained relatively low, and the initial population density of thrips was below the 33-day development threshold (10.4 °C) from January to April. This pattern was observed even during the mild spring season. Additionally, in both sampling locations, the high adult densities, mainly adult females, led to the shedding of a limited number of flowers that had formed in June.

Keywords Insect abundance · Citrus crop damage · Degree-days · Population dynamics · *Thrips hawaiiensis* · Turkey

Introduction

A significant number of thrips species have been recorded in various citrus crops in Turkey (Nas et al., 2007; Tekşam & Tunç, 2009). On the other hand, Kelly's citrus thrips (KCT), *Pezothrips kellyanus* (Bagnall) (Thysanoptera: Thripidae) was identified as a harmful species in Turkey's Arsuz region of Hatay Province, with recorded damage reaching up to 6% (Ölçülü & Atakan, 2013). While the western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) is a common species in the Eastern Mediterranean region of Turkey, it has not been reported as a pest species in lemon groves (Atakan et al., 2016). *Pezothrips kellyanus* is an economically important thrips species in citrus, found not only in the Mediterranean climatic zone of Turkey but also in Italy (Conti et al., 2001, 2003; Vono et al., 2022), Spain (Navarro-Campos et al., 2012, 2013; Planes et al., 2014, 2015), and Cyprus (Vassiliou, 2007, 2008, 2010). Hawaiian flower thrips, *Thrips hawaiiensis* (Morgan) (Thysanoptera: Thripidae), on the other hand, is an invasive polyphagous species commonly found in Asian and Pacific countries (Murai, 2001). Its strong thigmokinetic behavior, adaptability to various climatic conditions, and high reproductive capacity have facilitated its distribution across a wide geographical range (Murai, 2001; Goldaranzena, 2011; Zhang et al., 2014; Marullo & De Grazia,

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2017), making it a significant pest in many agricultural crops (Fu et al., 2016, 2017). *Thrips hawaiiensis* quickly spread to the eastern Mediterranean region of Turkey within a year, beginning in 2015, and negatively affected the fruit quality of lemon varieties such as Lamas, Kütdiken, or local hybrid lemon varieties with thorns, collectively known as the Yediveren group, which bloom and bear fruit throughout the year. However, limited studies have been conducted on the economic importance and control of this pest species (Atakan et al., 2021; Hazır et al., 2022).

Citrus growers often resort to chemical control methods in their managements against pests. Typically, they prioritize rapid insecticides applications and consider chemical treatments as insurance for their crops. However, it is crucial to consider the target pest's biological cycle, plant phenology, appropriate chemicals, correct timing of application, as well as climatic factors, especially temperature, (Önder, 2004). In recent years, the use of day-degree modeling, which establishes a close relationship between temperature and the organism, has gained significance in the management of agricultural pests (Navarro-Campos et al., 2013). This approach aids in determining the optimum spray timing, reducing the frequency and quantity of pesticide use, and consequently minimizing unnecessary chemical applications against citrus thrips (Tanigoshi et al., 1980; Sharov, 2008). Studies conducted in Spain have demonstrated the importance of day-degree modeling in understanding the development, population densities, and damage caused by *P. kellyanus* larvae (Navarro-Campos et al., 2013). However, the population dynamics of *T. hawaiiensis* and the role of temperature in fruit damage formation are not well understood. Lemon producers in the region heavily rely on pesticide applications to control the pest, primarily during the flowering period. This study aimed to explore (a) the influence of temperature on pest development through degree-day modeling, (b) the impact of different phenological stages of lemon trees on population densities and damage formation in relation to plant phenology, and (c) the presence of alternative host wild plants within the lemon orchards. By investigating these parameters, the study aimed to establish fundamental principles in the control practices against economically damaging citrus thrips.

Materials and methods

Sampling sites

The sampling locations, namely in Barbaros and Kocahasanlı districts, are located in Mersin Province, situated in the Alata district, connected to Erdemli district. The geographical coordinates of Barbaros and Kocahasanlı are 36° 38' 10.2516'' N and 34° 17' 56.5080'' E, respectively. The lemon groves, where the two study sites are located, were roughly 5 km apart. In both districts, lemon production is carried out as a family-owned business in orchards spanning from 0.2 to 0.3 ha. In this region, lemon varieties such as lamas and Kütdiken, which belong to the "yediveren" group, are grown. *Thrips hawaiiensis* has been detected in this area, causing significant damage by scarring the fruits. The age of the trees in the sampling area were in the range of 25–30 years with plant spacing of 5×5 m in each sampling grove, and no pesticide application was done during the sampling period (April–June). In the lemon grove located in the Kocahasanlı district, no effort was made to control weeds; they were allowed to grow freely. In the Barbaros district, in contrast, the grower actively managed weeds by plowing or hoeing the area up.

Procedure for sampling the *Thrips hawaiiensis* populations

The sampling procedure for the *T. hawaiiensis* population was initiated when the trees reached 20% flowering. From each lemon orchard, 10 trees were randomly selected. For each tree, inflorescences were collected from one outer flowering shoot in four different cardinal directions: North, South, East and West, with each shoot measuring approximately 30 cm in length. A total of four inflorescences from each tree were tapped onto a white tray (40×30×7 cm) for 5 s., resulting in a total of 40 inflorescences for the entire experiment. Thrips individuals were collected from four different directions of each tree using a suction tube or fine brush. The adults and larval thrips extracted from each sample tree were transferred into one 2 ml plastic tube containing ethyl alcohol (60%); thus, a total of 10 samples were collected from each lemon grove for each sampling date. During the fruit formation period, a limited number of flowers were observed on the

plants. As thrips are primarily concentrated on flowers, 30 cm long fruiting shoots with one flower (with an average of 3–4 fruits on the shoots) were considered for sampling during this period. The sampling method for the fruiting shoots was similar to that of used during the flowering period, after which thrips were collected and stored in the plastic tubes. Sampling commenced on April 2nd, 2018 (13 weeks) and April 5th, 2019 (12 weeks), and it continued until mid to late June. The termination of sampling was determined by a significant decrease in the number of flowers in both sampled groves and the absence of thrips on the fruits. The sampling process for the two trials, i.e. two lemon groves, was carried out between 10:00 am–12:00 pm.

Thrips preparation and diagnosis

In a previous study conducted on lemon trees within the same geographic area, 11 thrips species were identified (Atakan et al., 2021). Among these species, notable ones include *T. hawaiiensis*, *F. occidentalis*, *Thrips tabaci* Lind., and *Thrips major* Uzel (Thysanoptera: Thripidae). Since *T. hawaiiensis* was the most common and main thrips species accounting for 98% of total adult populations (Atakan et al., 2021), the current study, therefore, revolved around this particular species. The thrips individuals were evaluated at the Entomology Laboratory of the Department of Plant Protection, Faculty of Agriculture, Çukurova University, Turkey. The species of the thrips were identified through the following procedure: Thrips individuals (adults and larvae) were initially placed in AGA liquid for 2 days to soften their bodies (i.e. maceration), facilitating the preparation of the specimens. After the initial step, the thrips individuals were transferred to glass petri dishes containing 10% NaOH solution on a hot plate set at 45 °C. The specimens were left in the solution until a slight color change occurred and their wings opened. The insects' bodies were emptied by gently stroking their dorsal and ventral sides with a fine-tipped needle at a 90% ethyl alcohol medium. The individuals were then placed in a Hoyer's mounting medium for microscopic slides. The microscopic thrips slides were subsequently kept at a temperature of 45 °C for approximately 3 weeks. The identification of the samples was carried out as described in Nakahara (1994), zur Strassen (2003) and Vierbergen et al. (2010).

Determination of damage to fruits due to *Thrips hawaiiensis*

To assess the possible damage caused by thrips feeding in both lemon orchards, a population follow-up was conducted once fruiting began to occur. The samplings were carried out for four times at 7–15 day intervals, beginning on May 7th, 2018, and four times at 7–10 day intervals between May 24th and June 21th, 2019. Throughout the sampling period, 10 trees were randomly chosen from each orchard at each sampling date. The orchards were examined, and the number of damaged fruits exhibiting irregular or halo-shaped appearance, as well as silvery-bronzed and scarred surfaces, was recorded (Fig. 1). A total of 10 young fruits were examined from each selected tree, amounting to 100 fruits in total for the entire orchard.

Identification of alternative wild hosts of *Thrips hawaiiensis* in lemon grove

This study was conducted in a lemon grove located in the Kocahasanlı district, where thrips populations were monitored and weed growth was more prevalent. Following the thrips sampling, five plants of each weed species were randomly selected from the area between the middle two rows of trees in the grove. The selection was based on the plants being in the flowering period and having a coverage rate of more than 10% of flowers (Atakan & Uygur, 2005). These weed species were *Daucus carota*, *Calendula*



Fig. 1 Damage symptoms on the young lemon fruits due to *Thrips hawaiiensis*

arvensis, *Crepis commutata*, *Epilobium parviflorum*, *Galium aparine*, *Ochtodium aegyptiacum*, *Malva sylvestris*, *Medicago polymorpha*, *Mercurialis annua* and *Verbascum obtusifolium*. The chosen area spanned approximately 2 m wide and 30 m long. To collect thrips from the weed plants, the upper half of each plant was gently shaken over a white container for 5 s. The thrips that fell into the container were collected using a suction tube and transferred into 2 ml plastic bottles containing 1.5 cm³ of ethyl alcohol. Thrips individuals (adult and larval thrips) from both plants were stored in a single tube, and they were sorted and categorized in the laboratory based on their morphological characteristics, such as adults and larvae. They were then counted and identified using the predetermined preparation techniques.

Climatic data

Daily temperature data, including minimum, maximum, and average temperatures were obtained from the Alata Horticultural Research Institute of the Ministry of Agriculture, Mersin, Turkey (36° 37' 36.66" N and 34° 20' 16.35" E). The institute is located approximately 5 to 10 km away from both lemon sampling groves. To determine the cumulative effect of temperature on thrips development, the sum of degree-days was calculated. This calculation involved summing the daily average temperatures that exceeded the development threshold of 10.4 °C (Murai, 2001; Lin et al., 2021), starting from 1st January to 1st July for both experimental years.

Statistical analyses

Comparisons between the average numbers of different biological stages of *T. hawaiiensis*, including larva, adult female, and adult male individuals, were made based on three different phenological periods of lemon trees. At each sampling site, for each of the three different phenological periods i.e. flowering (early-mid April), petal falls (mid-late April) and fruiting (late April-late June), the 3 sampling dates representing the highest pest densities across the various biological stages were selected. One-way analysis of variance (ANOVA) was conducted, and Tukey test ($P < 0.05$) was performed to determine significant differences. Given that the data exhibited a normal distribution based on the Shapiro-Wilk test,

a comparison of the means was done using the normal data. Due to the similarities in tree age, flowering and fruit formation periods as well as population density patterns of adults and larvae in both sampling locations, the data were combined over the locations. Subsequently, a comparison was made regarding their distributions in various plant parts for each sampling year. The relationship between the rates (%) of fruit damage caused by thrips feedings and sum of degree-days (DD) was calculated for the Barbaros and Kocahasanlı locations in 2018 and 2019. To achieve this, a total of 20 samplings at weekly intervals, commencing on January 1st, were interpreted using parametric analysis based on Pearson's correlation coefficients, considering the average temperatures above the thrips' development threshold, with significance level set at $P < 0.05$. All analyses were performed using the SPSS statistical software program (SPSS, 2016).

Results

Population development and damage of thrips on young fruits

In Barbaros district, the density of adult female *T. hawaiiensis* reached its highest point (1.94 individuals/inflorescence) at 465 degree-days (DD) on May 21th, 2018 (Fig. 2). In the last two sampling dates (after June 11th), the density of adult female individuals remained below 1 individual at 868–972 DD. The density of adult male individuals was consistently low, ranging between 0.20 and 0.50 individuals/inflorescence throughout the sampling period. The combined density of adult males and females reached 0.68 individuals/fruit at 358 DD on May 14th (Fig. 3). In Kocahasanlı district, the highest density of adult female individuals (1.81 individuals/inflorescence) was observed two weeks prior to that of Barbaros at 294 DD on May 7th, 2018 (Fig. 2). The density of adult females remained at approximately one individual between 358 and 656 DD. After June 4th, the density of adult females dropped below 1 individual. The larval density peaked at 358 DD on May 14th in Kocahasanlı with 1.82 larvae/fruit. However, the density of adult individuals remained very low at 465 DD. In 2019, high levels of adult female densities were recorded at 576 DD and 674 DD (2.56 and 2.26 individuals/inflorescence, respectively) on May

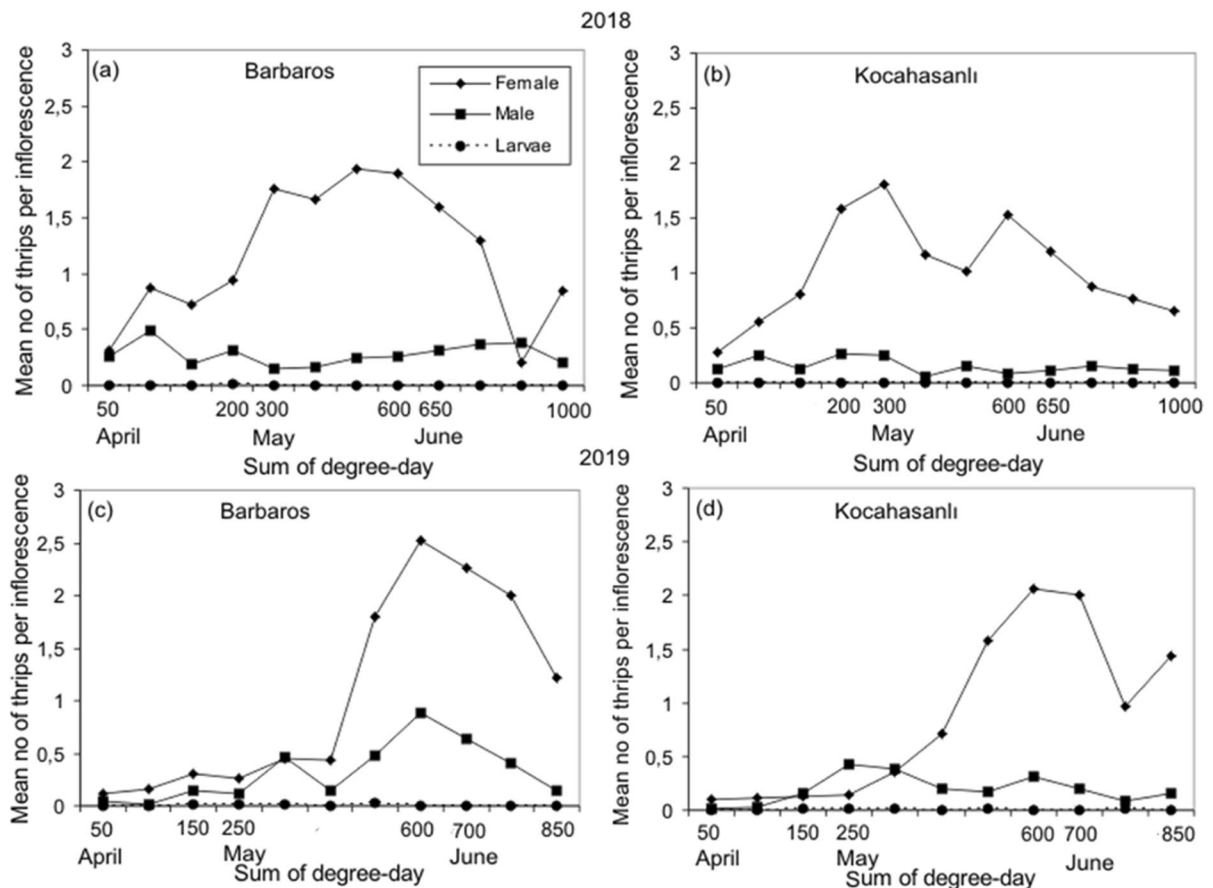


Fig. 2 Mean numbers of different stages of *Thrips hawaiiensis* in inflorescences of lemon trees in Barbaros and Kocahasanlı during districts 2018–2019, according to sum of degree-days (DD)

31th and June 7th in Barbaros. During this period, the density of adult male individuals increased to 0.88 and 0.64 individuals/ inflorescence, respectively. In Barbaros, adult individuals were not found in most of the sampling dates, but the highest adult density was recorded at 784 DD on June 14th. Similarly, in Kocahasanlı, the highest density of adult female individuals was recorded as 2 individuals/ inflorescence during the same period. In this region, the highest density of adult individuals in fruits was approximately one individual at 579 DD on May 31th (Fig. 3). Larval densities in flowers were consistently very low, with 0.01 larval individual/ inflorescence observed in many sampling dates. No larvae were recorded on fruits in 2019 (Fig. 3).

Overall, adult thrips individuals were mostly recorded during the fruit formation period (Table 1). In both regions, a significant number of female

individuals were recorded in flowers, especially during fruiting period (2018: $F=497.450$, $df=2,27$, $P<0.0001$; 2019: $F=43.722$, $df=2,27$, $P<0.0001$).

The damage caused by *T. hawaiiensis* on young fruits is presented in Table 2. The first damaged fruits were detected on May 7th, 2018, in Kocahasanlı, coinciding with the increase in adult individuals (1.81 adult female individuals/inflorescence) and reaching 294 DD. The incidence of scarred fruits increased and reached its highest level at 765 DD with 19.4% in Barbaros and 27.2% in Kocahasanlı. During this time, there were either no or very few adult or larval individuals present in the fruits in both regions (Fig. 3). The first scarred fruits were recorded at 493 DD on May 24th, 2019 (Table 1). The highest incidence of scarred fruits was observed on June 21th, with a rate of 21% or 23.4% when the sum of effective temperatures reached 886 DD. At this time, the density of

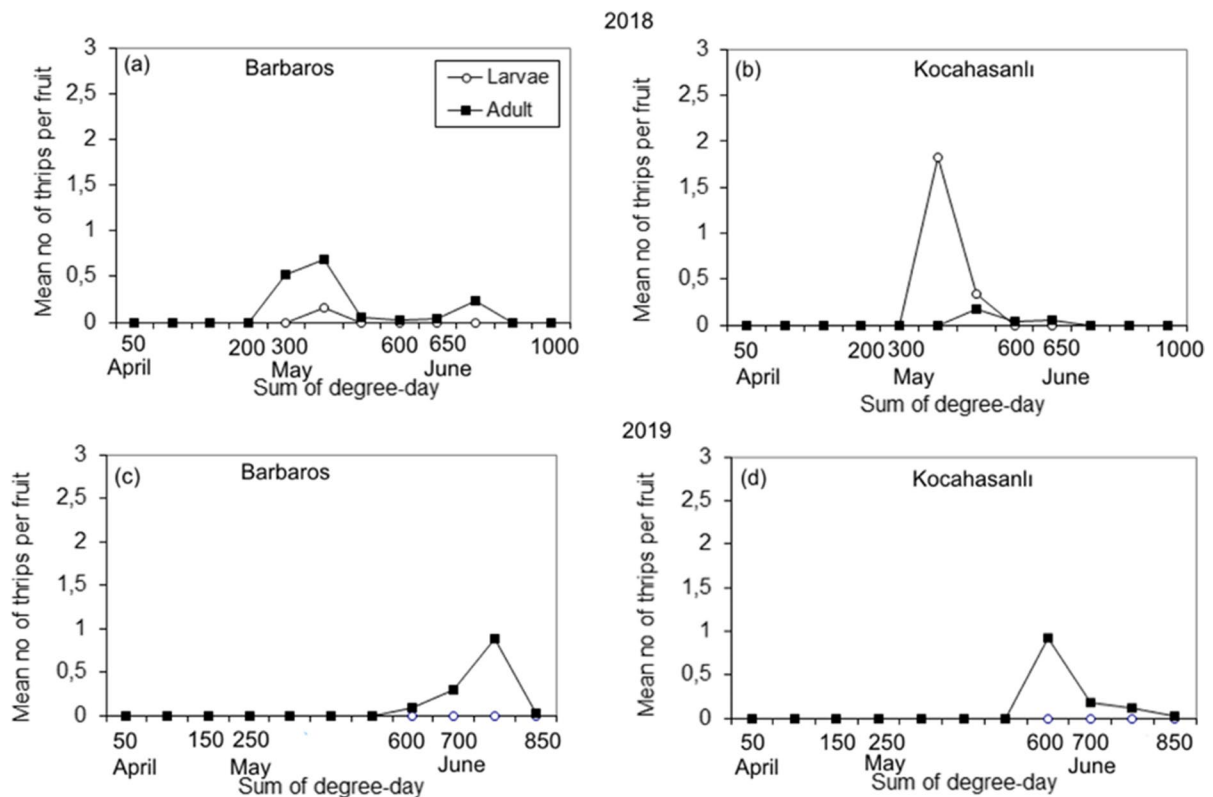


Fig. 3 Mean numbers of different stages of *Thrips hawaiiensis* on young fruits of lemon trees in Barbaros and Kocahasanlı districts during 2018–2019, according to sum of degree-days (DD)

Table 1 Seasonal mean numbers of various stages of *Thrips hawaiiensis* according to phenology of lemon trees during 2018–2019

Year	Insect stage	Mean number of thrips per flower ^{a,b}		
		Flowering	Petal fall	Fruiting ^c
2018	Female	0.27 ± 0.03a	1.39 ± 0.22a	12.93 ± 0.38a
	Male	0.07 ± 0.01b	0.52 ± 0.13b	1.69 ± 0.19b
	Larvae	0 ± 0b	0.03 ± 0.01b	0.01 ± 0.01c
2019	Female	0.28 ± 0.08a	0.48 ± 0.06a	12.01 ± 1.09a
	Male	0.05 ± 0.04b	0.16 ± 0.05b	2.67 ± 0.38b
	Larvae	0 ± 0b	0.02 ± 0.01b	0.05 ± 0.02c

^aSince the average number of individuals in the phenological periods of the lemon trees of different periods of *Thrips hawaiiensis* was similar, the sample regions were combined

^bMeans with the same letters in the columns within the same year are not statistically different according to Tukey's HSD test ($P > 0.05$)

^cIn random sampling, there was an average of 1 flower in fruiting shoots

adult individuals was below 0.5, and no larvae were found (Fig. 3). When considering all sampling dates together, the highest incidence of scarred fruits was 21% or 23% (Table 3).

Relationship between damage caused by *Thrips hawaiiensis* and seasonal climate fluctuation

In April 2018, the temperature ranged from 15 to 20 °C, while May and June temperature ranges were 21–25 °C and May 26–29 °C at the sampling time. In contrast, during April 2019, temperature fluctuations were 13–17 °C, followed by 18–22 °C in May, and 23–26 °C in June (Fig. 4). While the average temperatures in both locations in 2018 were above the development threshold of the insect in winter and early spring, temperatures remained below 10 °C for many days in 2019, particularly during the January–February period (Fig. 4).

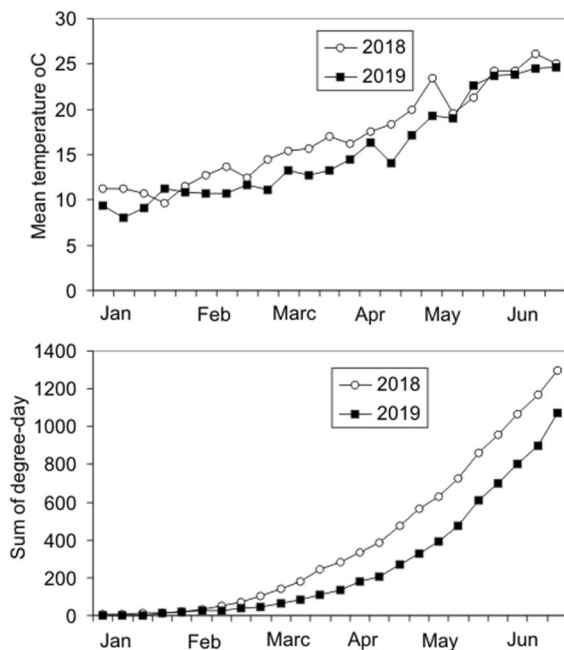
In 2018, a statistically significant relationship was found between the percentage of damage caused by

Table 2 Damaged rates of young lemon fruits according to the sampling dates and degree-days (DD) in Barbaros and Kocahasanlı districts during 2018–2019

Year	Sampling date	Barbaros		Kocahasanlı	
		Damage (%)	Sum of degree-day	Damage (%)	Sum of degree-day
2018	7 May	0	294	3.0	294
	14 May	2.5	358	7.5	358
	28 May	17.2	564	23.6	564
	11 June	19.4	765	27.2	765
2019	24 May	1.2	493	4.6	493
	31 May	1.4	579	5.0	579
	14 June	10.0	784	10.0	784
	21 June	21.0	886	23.4	886

Table 3 Seasonal average population densities in lemon flowers and fruits, and damage rates of young lemon fruits due to *Thrips hawaiiensis* in Barbaros and Kocahasanlı districts during 2018–2019

Year	Barbaros			Kocahasanlı		
	Mean number of thrips ($\pm$ SE)		Damage (%)	Mean number of thrips ($\pm$ SE)		Damage (%)
	Flower	Fruit		Flower	Fruit	
2018	9.55 $\pm$ 1.63	0.01 $\pm$ 0.01	17	7.36 $\pm$ 1.33	0.01 $\pm$ 0.01	23
2019	9.01 $\pm$ 2.33	0.06 $\pm$ 0.02	21	6.71 $\pm$ 1.64	0.03 $\pm$ 0.01	23

**Fig. 4** ^a Mean weekly temperatures and ^b sum of degree-days calculated as the sum of the daily mean temperature above 10.4 from January to June in 2018 and 2019. Mean temperature values obtained from the weather station located in the Erdemli, Mersin, Turkey

thrips and the sum of degree-days (DD) as of January 1 in both Barbaros ($R(20)=0.72$, $P<0.001$) and Kocahasanlı districts ($R(20)=0.78$, $P<0.001$). The case was also similar for 2019 in both Barbaros ($R(20)=0.77$, $P<0.001$) and Kocahasanlı ($R(20)=0.84$, $P<0.001$). These findings indicated that there was a strong positive correlation between the extent of damage caused by the thrips and the accumulation of degree-days from January 1st. Thus, higher degree-day accumulations were associated with a higher percentage of damage caused by the thrips.

Alternative wild host plants

Based on the observations, it was found that adults and larvae of *T. hawaiiensis* were present on Field marigold (*Calendula arvensis*), Wild carrot (*Daucus carota*) and Mullein (*Verbascum obtusifolium*) (Table 4). These three weed species were found to be common outside the sampling area and shared a common characteristics of abundant flowering. In addition, very few *T. hawaiiensis* adults were observed on *Ochrodium aegyptiacum*, which has yellow flowers and was commonly found in spring in the region

Table 4 Secondary weed hosts of *Thrips hawaiiensis* that naturally grow in the lemon orchard in Kocahasanlı district during 2018–2019

Scientific name	Common name	Mean number of thrips per plant			
		2018		2019	
		Adult	Larvae	Adult	Larvae
Apiaceae					
<i>Daucus carota</i>	Wild carrot	10.08 ± 1.83	2.26 ± 0.23	15.68 ± 1.83	2.80 ± 0.42
Asteraceae					
<i>Crepis commutata</i>	Confused Hawk’s-beard	0.90 ± 0.26	0.07 ± 0.07	1.38 ± 0.26	0.10 ± 0.07
<i>Calendula arvensis</i>	Field marigold	0	0	0.75 ± 0.27	0.12 ± 0.06
Brassicaceae					
<i>Ochtodium aegyptiacum</i>		0.15 ± 0.08	0	0.59 ± 0.08	0
Euphorbiaceae					
<i>Mercurialis annua</i>	Annual mercury	0	0	0	0
Fabaceae					
<i>Medicago polymorpha</i>	Bur clover	0	0	0.04 ± 0.04	0
Malvaceae					
<i>Malva sylvestris</i>	Large flowered mallow	0	0	1.32 ± 0.55	0
Onagraceae					
<i>Epilobium parviflorum</i>	Hoary willowherb	0.03 ± 0.03	0	0.05 ± 0.05	0
Rubiaceae					
<i>Galium aparine</i>	Catch weed bedstraw	0	0	0	0
Scrophulariaceae					
<i>Verbascum obtusifolium</i>		NS ^a	NS	14.68 ± 3.24	2.74 ± 0.56

^aNS: Not sampled in year 2018

(Table 4). These findings suggest that these weed species may serve as alternative hosts for *T. hawaiiensis*, providing a source of food and potential breeding sites. The abundance of flowering in these weeds may attract thrips and contribute to their population dynamics.

Discussion

The study findings indicated that the first appearance of damage caused by *T. hawaiiensis* on lemon fruits was observed between nearly 300 and 800 degree-days (DD) during the fruit development period in both sampling areas over the two years. The larval populations were found to be very low in the sampled flowers and fruits. The damage to the fruits, characterized by halo spots, increased in mid- to late June when the density of adult populations decreased. Throughout the developmental phase (fruiting) of the lemon trees in both sampling orchards, there were higher population densities

of adult individuals, particularly females, compared to adult males and larvae (Figs. 2 and 3). According to Fu et al. (2019), adult females demonstrated a longer lifespan than their male counterparts. In the current study, it is thought that female adults could play a more significant role in causing damage. This finding contrasts with a previous study by Navarro-Campos et al. (2013) who reported that second instar larvae of *P. kellyanus* were mainly responsible for the citrus fruit damage. In the current study, the first signs of fruit damage were observed 3–5 weeks after the flower petals fell. The highest density of second stage larvae was recorded in Kocahasanlı district in 2018, which correlated with higher damage in that sampling area. Similar studies in Spain have reported fruit damage occurring in the 5th week after petal fall (Navarro-Campos et al., 2013). Additionally, damage caused by *Scirtothrips citri* (Moulton, 1909) (Thysanoptera: Thripidae) on citrus fruits was associated with the activity of second instar larvae (Rhodes & Morse, 1989). In 2018, the highest rate of scarred fruits was observed in Kocahasanlı with

a rate of 27%. In 2019, the damage rate in May was slightly lower compared to that of 2018, which may be attributed to lower average temperatures in January and February and milder spring months (Fig. 3). Climatic conditions could have a significant effect on thrips species, such as *P. kellyanus*, *S. citri*, and *T. hawaiiensis*. These factors should be considered in thrips control efforts in citrus orchards (Schweizer & Morse, 1997).

The observed damage patterns and population dynamics of *T. hawaiiensis* in the study area were influenced by various factors such as temperature, the presence of alternative or secondary host plants, citrus flowering patterns, and pest control practices. The abundance of flowering weeds outside the sampling area may have provided additional food sources and potential breeding sites for *T. hawaiiensis*. The timing and severity of damage were influenced by the density and behavior of adult thrips, as well as the suitability of young fruits for thrips feeding. The size of the lemon groves in both regions varied between 0.1 and 0.3 ha, and the groves were generally neglected. The proximity of the groves to each other and the potential use of insecticide applications in the surrounding area may have affected the population density of *T. hawaiiensis*. The abundant population of *T. hawaiiensis* in the lemon orchards led to the falling of flowers, resulting in a low number of pre-adult stage individuals that could develop into adult. Control applications against the citrus thrips through various groups of insecticides are implemented in the locations beginning from the flowering period. Therefore, even if the sampled groves were not sprayed, it could be possible that insecticide applications in the surrounding areas affected the population density of *T. hawaiiensis*. Similarly, a previous study done in 2015, when *T. hawaiiensis* was the first time recorded, reported intense damages on the lemon fruits, and the rates of stained and scarred fruits reached 70% in many orchards (Atakan et al., 2015). This issue indicated the significant impact of *T. hawaiiensis* on fruit quality and the need for effective control measures to mitigate the resulting damages. It is important to note that specific attributes of the insecticide applications, such as the timing, frequency, and types of insecticides used, were not provided. However, the implementation of insecticide control measures suggested that the management of *T. hawaiiensis* was considered a priority in the sampled orchards.

The higher damage observed in the Kocahasanlı district could be attributed to the presence of these two conditions that could contribute to the relatively greater damage caused by *T. hawaiiensis*. Studies conducted in Spain by Navarro-Campos et al. (2011) have highlighted that isolated lemon trees with ripe citrus fruits and Jasmin plants could serve as alternative hosts for the reproduction of *P. kellyanus*. Similarly, Vassiliou (2010) emphasized the importance of lemon trees in settlements near citrus orchards in Cyprus as feeding and sheltering sites for *P. kellyanus* populations. Although this study did not specifically investigate alternative host cultivars for *T. hawaiiensis* in the sampling regions, it was observed that *T. hawaiiensis* fed on *Daucus carota* and *Verbascum obtusifolium*, as indicated in Table 4. Further research and studies are need to be conducted to confirm the role of unharvested ripe fruits and alternative host plants in the population dynamics and damage caused by *T. hawaiiensis* in the region.

The study conducted in the two districts over the two years revealed that *T. hawaiiensis* exhibited a similar population trend. When the winter months were milder and the spring months were warmer, the population of *T. hawaiiensis* increased more rapidly during the critical development period of the plants, particularly during the formation of young fruits. As a result, the symptoms of damage appeared in a shorter time. Conversely, cool weather, especially in the spring, delayed the population increase and the occurrence of damage, resulting in a relatively lower damage to young fruits. Therefore, temperature, especially in the spring, played a significant role in the population dynamics of *T. hawaiiensis*. However, it was observed that the temperature increase in June did not contribute significantly to the increase in the population of *T. hawaiiensis*. This may be attributed to the very low flower density and the limited reproductive capacity of this thrips species, due to the dense adult population in the flowers, i.e. affecting mating, resulting in a scarcity or absence of larvae. The presence of mature green fruits alongside newly formed young fruits in lemon orchards has been observed to increase thrips damage in young fruits. Ripe and twin fruits were particularly important in providing feeding and sheltering sites for the pest. The relationship between temperatures (degree-days) during the period of fruit damage and the population structure of *T. hawaiiensis* can provide valuable insights for controlling this pest.

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Author contributions EA was responsible for the experimental design; EA was responsible for the experiments; EA was responsible for the insect (thrips) identifications and data analysis; EA was writing the paper. EA approved the final manuscript.

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Data availability Not applicable.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

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