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RESEARCH ARTICLE

Investigating population dynamics and evaluating damage incurred by Thripidae (Thysanoptera) species in citrus orchards of Northeastern Morocco: an exemplary analysis in Berkane

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ABSTRACT

Thrips are significant pest of crops, vegetables, and fruiting trees, and various species of thrips can infest citrus at fruit formation as well as new leaf sprouts. Thrips presence and damage can significantly reduce the export value of fruits, making them a major concern for citrus growers. Field studies were conducted to investigate the biodiversity and abundance of citrus thrips on an early fruiter citrus cultivar in experimental and commercial orchards of Morocco. In this study, we investigated the abundance, economic importance, dynamics, and seasonal fluctuations of citrus thrips in relation to citrus phenology. We identified four species of thrips that infest citrus orchards, including *Frankliniella occidentalis*, *Pezothrips kellyanus*, *Scirtothrips sp*, and *Aeolothrips sp*. Our results showed that the quantitative peak of thrips occurred during the blooming stage, and that the number of thrips caught on sticky traps during bloom could be a suitable predictive method for estimating final fruit damage. The population dynamics of thrips species were found to depend on several biotic and abiotic factors, including temperature, rainfall, and chemical interventions. We also observed that some citrus varieties were more susceptible to thrips attacks than others, with Washington navel and Maroc late being the most infested orchards with infestation rates of 32% and 24%, respectively. Our findings provide

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important insights into the abundance, economic importance, and seasonal fluctuations of citrus thrips, which can inform the development of effective control strategies to mitigate their damage in citrus orchards.

Introduction

Thrips, belonging to the order Thysanoptera, are small insects that are notorious for causing damage to horticultural and ornamental crops directly through feeding and oviposition, as well as indirectly as vectors of plant viruses (de Avila et al. 1993; Ullman et al. 2002; Mound 2005; Reitz 2009; Ripa et al. 2009; Bosco and Tavella 2010; Shrestha et al. 2012; Raen et al. 2013; Li et al. 2016; Silveira and Haro 2016; Dianzinga et al. 2020; Nachappa et al. 2020; Tan et al. 2022). While all citrus cultivars are susceptible, the economic ramifications of citrus thrips are most pronounced in the context of San Joaquin navel oranges, satsuma mandarins, and various desert citrus varieties. Citrus thrips inflicts damage upon fruit by puncturing epidermal cells, resulting in scabby, grayish, or silvery lesions on the rind. Notably, second-instar larvae are the primary culprits in causing harm. These larvae predominantly feed at the calyx end beneath the sepals of nascent fruit and exhibit a larger size compared to their first-instar counterparts. The resultant scarring, often smoother than calyx-end lesions, is accentuated at the stylar end, a phenomenon consistently observed in conjunction with calyx-end scarring. Notably, stylar-end scarring is more frequently observed in mandarin varieties (encompassing true mandarins, hybrids, satsumas, and clementines) than in sweet oranges (Deguine et al. 2021). These pests are challenging to control through Integrated Pest Management (IPM) programs due to their resistance to common insecticides (Morse and Hoddle 2006; Li et al. 2016; Bhuyain and Lim 2020) and cryptic habits that allow them to colonize plants undetected (Kirk 2017; He et al. 2020; Sampson et al. 2021). Thrips can survive in a range of environments, including plant litter and living or dead tree bark (Mirab-Balou et al. 2017; Mahmoudi et al. 2023). With a wide host range that includes citrus, cereals, onions, garlic, and broadleaved crops, thrips are a serious economic threat to various crops worldwide (Okajima and Masumoto 2014; 2022). The feeding injury caused by thrips can result in scarring of rind tissue and subsequent blemish injury that leads to the rejection of fruit in the fresh market (Baker et al. 2011; Colloff et al. 2013). Citrus thrips prefer to feed on navel oranges in California, resulting in rind blemish injury that also leads to fruit rejection (Jeppson 1989; Childers and Nakahara Childers and Ueckermann 2014). Thrips are also known to oviposit on different parts of plants, causing further damage (Bournier 1983; Elimem and Chermiti 2014). In addition to their phytophagous feeding habits, some thrips species are predators of small insects and mites (Bournier 1983; Loomans and van Lenteren 1995; Elimem et al. 2011).

The population dynamics of thrips are influenced by a range of abiotic and biotic parameters, including temperature, relative humidity, daylight, and other pests (Elimem and Brahim 2009; Elimem et al. 2011; Mohamed Elimem et al. 2022). Despite the presence of beneficial insects, Moroccan research studies have applied control methods for citrus pests with little consideration for their impact on beneficial insects (Smaili et al. 2020; Assouguem et al. 2022; Ndlela et al. 2022). However, the outbreak of new citrus pests such as whiteflies, leafhoppers, ants, and thrips has induced Moroccan citrus producers to adopt the IPM strategy to avoid significant yield losses (Smaili et al. 2020; Haddad et al. 2021; el Handi et al. 2022). Confusion between the leaf blotch disease and possible thrips damage has also led to losses of up to 15% in packaging stations in Berkane (Khfif et al. 2022). Thus, detailed knowledge about thrips species composition, meteorological conditions, migration behavior, and citrus cultivar susceptibility is necessary to facilitate susceptible production and prevent yield losses.

This research aimed to uncover the diverse array of thrips species present in citrus orchards located in northeastern Morocco. Through observing the interaction between these tiny insects and their host plants, the study sought to shed light on the dynamic relationship between thrips and citrus plants' phenology. Finally, the research aimed to evaluate the extent of damage caused by thrips on various citrus varieties. By delving into the fascinating world of thrips and citrus plants, this study sought to uncover crucial information that can inform and guide agricultural practices in the region. With its comprehensive inventory of thrips species, in-depth analysis of their relationship with citrus plant phenology, and assessment of the damage caused by thrips, this research promises to contribute significantly to the field of agriculture and inspire future studies in the area.

Materials and methods

Study area

In 2021, field trials were conducted in the stunning and bountiful Berkane province of the Northeastern Kingdom of Morocco. This region, known for its diverse terrain of plains and mountains, is a hub of citrus production, attracting farmers and researchers alike. The study took place in four local orchards, each located in Northeastern Morocco, as illustrated in Figure 1. Berkane's Mediterranean climate, characterized by hot summers, was the perfect environment for this investigation. At an elevation of 185.82 meters (609.65 feet) above sea level, Berkane experiences a yearly temperature of 18.91 °C (66.04 °F), which is −2.55% lower than Morocco's averages. The region typically receives around 34.36 millimeters (1.35 inches) of precipitation, with 71.37 rainy days (19.55% of the time) annually, according to Weather and Climate data for 2023.

During the experimental period of this research, which took place between March and August 2021, the thrips population was closely monitored in four different orchards, each home to a variety of citrus species such as Clementine Berkane, Nules, Washington navel, and Maroc late. These orchards, located approximately ten kilometers from Madagh in the Zniber Domains (Riad de la Clémentine), and the Washington navel orchard at the Benamer Domain, just three kilometers away from Madagh. To ensure that insect pests did not cause any yield losses throughout the growing season, pesticides were frequently applied to the sprayed orchards (Table 1).

Chemical treatment in orchards

With its picturesque setting and rich diversity of citrus species, the Berkane province provided an ideal location for this study, which sought to deepen our understanding of thrips populations and their impact on

Figure 1. Location of field experiments in berkane province.

Table 1. Pesticides applied for each selected orchard.

Orchard	Chemical treatments	Date of application
Clementine berkane variety	Acetamiprid	10th March
	Spirotetramat	6th June
Nules variety	Acetamiprid	10th March
	Spirotetramat	6th June
Washington navel variety	Lambda cyhalothrin	25th April
	Pyriproxyfen + Acetamiprid	10th June
Maroc late variety	Abamectin	05th March
	Imidacloprid	14th May
	Spirotetramat	13th June

citrus farming in this region. By conducting field observations in several orchards and closely monitoring the thrips population over several months.

Population fluctuation of thrips on blue sticky traps

To accurately assess the population fluctuations of adult thrips, blue traps glued in polyvinyl chloride (PVC) with dimensions of 10*25 cm were strategically placed at a rate of four traps per orchard with a surface of 2 hectares for each orchard selected (Figure 2). These traps were initially installed on February 25th, 2021, for the Clementine Berkane and Nules varieties, and in April for the oranges. The traps were checked and replaced weekly, and they were positioned at a height of 1-1.5 meters in the southern canopies of four randomly selected trees. At the time of trap hanging, the tree phenology was in the bud swell stage, with flower buds measuring 0.2 inches (5.08 mm) in length. Any adult thrips caught on these blue traps were counted and examined in the laboratory using a binocular. Due to the sticky nature of the traps, it was nearly impossible to separate intact thrips from the adhesive material, so only the total number of adult thrips was recorded. The flight activity of adult thrips was estimated by averaging the number of adults caught on the four traps for each orchard on every sampling date.

Between March 3rd and April 12th 2021, an inventory sampling was carried out in all four orchards during the blooming period of citrus trees to study the thrips population. Thrips were collected using the zig-zag technique, and four trees per plot were randomly selected. One branch per orientation was beaten using the beating technique (Čirjak et al. 2022), causing all insects present on the struck branch to tumble

Figure 2. Installation of blue sticky traps to monitor the thrips population dynamics on citrus.

onto a white support. This includes thrips, which were collected inside tubes to prevent their repeated hovering and jumping. The adult thrips were then extracted from the tubes using a fine brush and stored in plastic vials containing a mixture of ethyl alcohol, acetic acid, and glycerin for later identification. The specimens were identified using different identification keys from the literature (Stannard 1968; Pitkin 1976; Mound 1981; 1991; Mound and Palmer 2009; Mirab-Balou et al. 2017; Rachana et al. 2023), and proper identification was ensured by using the Ceti Magnum Binocular Fluorescence Microscope at different magnifications. The microscopic preparation of thrips adult specimens followed the protocol of Mound and Tree (Mound and Palmer 2009; Mirab-Balou et al. 2017; Boparai et al. 2020; Hached et al. 2020; Alloui-Griza et al. 2022; Čirjak et al. 2022).

Damage assessment

This portion of the study aimed to assess the damage of thrips in citrus orchards. To achieve this, each orchard was divided into four sub-orchards, and 25 trees were randomly selected from each sub-orchard or 100 trees from the whole orchard. These selected trees were marked with a blue band to ease the identification process.

Data management and statistics

The data on thrips collected from the blue sticky traps were analyzed using Microsoft Excel 2016 to study the fluctuations and dynamics of thrips populations on different citrus varieties. To plot the curves of the dynamics of thrips populations on each variety, the captures of thrips species were calculated as the average of individuals captured in the four traps installed in each orchard of the selected variety during the entire study period. To determine the infestation of fruits by thrips, it is crucial to conduct sampling and calculate the average percentage of infested fruits. The collected data were processed using the Minitab 16 Statistical software (Munich, Germany). The infestation rate indicates the proportion of fruits attacked out of all observed fruits, and it was calculated using the following equation:

$$\textbf{Infestation rate} = \frac{\textbf{Number of fruits attacked}}{\textbf{Total number of fruits observed}} * 100$$

The meteorological data were recorded daily at INRA of Qualipole of Berkane, which is far 10 km from field sites, using a GP2 Data Logger (Delta-T Devices Ltd.)

Results

Species identification

This study marks the first comprehensive collection of thrips species and their potential for damage across various citrus cultivars in the Berkane region of Morocco. A total of four thrips species were identified and classified under the sub-order Terebrantia, consisting of three phytophagous species and one predatory species (*Aeolothrips* sp) (Table 2).

The collected information sheds new light on the occurrence and abundance of these thrips' species and their impact on citrus orchards, providing valuable insights for growers and researchers alike. The identified species are presented in Figure 5 (1, 2, 3, and 4). Two types of thrips damage were observed in the orchards: i) silvery partial or complete ring at the base of the fruit or fruit peduncle and ii) marbling, more or less developed (Figures 3 and 4). The ring depreciation was caused by *Pezothrips kellyanus*, a species that infests all citrus species and orange varieties. On the other hand, the marbling scars were likely caused by *Frankliniella occidentalis* and *Scirtothrips* sp., which are major species found in citrus orchards on flowers and fruits in Northeastern Morocco. The fruits were not harvested but were continuously monitored on the tree, and the injury rating was not conducted using a scale. Instead, any fruit with russeting or silvering injury larger than 0.2 inches (5.08 mm) was considered as damaged.

The thrips species identified in Tunisia are consistent with those found on citrus in other Mediterranean countries such as Spain, Turkey, Cyprus, and Italy, according to several studies (Vassiliou 2010; Navarro Campos 2013). For instance, a study conducted by Elimen and Chermiti (Elimem and Chermiti 2013) found that *Frankliniella occidentalis*, *Pezothrips kellyanus*, and *Thrips tabaci* were the most prevalent species on different citrus species during the monitoring period. Similarly, (Attia et al. 2022) found that *Thrips major* Uzel and *Frankliniella occidentalis* Pergande were the most abundant species during 2012 and 2013 in the Takelsa region. The species *F. occidentalis, T. major, T. tabaci, T. angusticeps,* and *P. kellyanus* are among the most commonly found thrips species in Mediterranean citrus orchards. However, only *P. kellyanus* causes feeding damage on citrus fruits in Cyprus (Vassiliou 2010). Worldwide, more than 40 thrips

Table 2. The species of thrips identified in the citrus orchards surveyed.

Sub-order	Family	Subfamily	Species
Terebrantia	Thripidae	Thripinae	*Frankliniella occidentalis*
			Pezothrips kellyanus
			Scirtothrips sp.
	Aeolothripidae	Aeolothripinae	*Aeolothrips sp.*

Figure 3. Wind marks do not normally extend from the calyx and can be longitudinal or arc-shaped (see diagrams above) small circular areas or islands of clean tissue are usually visible on wind-damaged fruit. The edges of the scars also tend to be irregular.

species have been identified in association with citrus, and in Florida, for example, an inventory of thrips species in 7 citrus orchards showed 36 species, including 7 predators (Childers and Nakahar). The low biodiversity observed in our study may be attributed to sampling only on citrus, while other herbaceous plants were not considered in this study.

Monitoring of the citrus thrips population dynamics

Clementine Berkane variety

On the Clementine Berkane citrus variety, our study identified three distinct peaks in thrips migration (Figure 6a) that were associated with the phenological stages of the host plant. The first peak, which occurred on

Figure 4. Thrips marks tend to be longitudinal, with damage extending from the calyx (see figures above Figure 3 D, F). Feeding damage to fruit is recognizable as a ring of damaged tissue (Figure 3 A, C) or 'halo' at the stem end (kelly's citrus thrips), or as russet or grey scarring or bleaching between touching fruit (Figure 3 G).

15th April 2021, marked the first individuals that had restarted their activity after winter, and had a total number of about 69 individuals. This peak corresponds to the petal fall of the trees and the proliferation of thrips with host plant leaf staggering. The first generation of thrips on Clementine Berkane starts on 04th March 2021 and ends on 29th July 2021. The mean average number of emerging adults from plant fields was estimated as one generation, with the intervals of the peaks equivalent to the developmental durations at various temperatures (Figure 6a).

Nules variety

Thrips populations were monitored to identify their activity patterns in relation to the phenological stages of citrus orchards, with the appearance of a single peak marking the first generation of individuals after overwintering (Figure 6b). The total thrips number was 88 individuals, which coincided with the beginning of fruit citrus growth. During the study period, thrips activity increased as the average air temperature rose above 17 °C, peaking in mid-May when the bloom period ended and the fruit growing period began. However, the number of thrips caught by traps decreased during the fruit development period in all orchards, including the Nules variety. The study results showed that the quantitative peak of thrips occurred during the blooming stage, and correlation analysis indicated that the daily population dynamics were significantly positively correlated with daily maximum wind velocity and negatively correlated with daily mean temperature and daily minimum temperature. The findings suggest that the abundance of thrips on citrus orchards, including the Nules variety, is closely related to the phenological stages of the host plant.

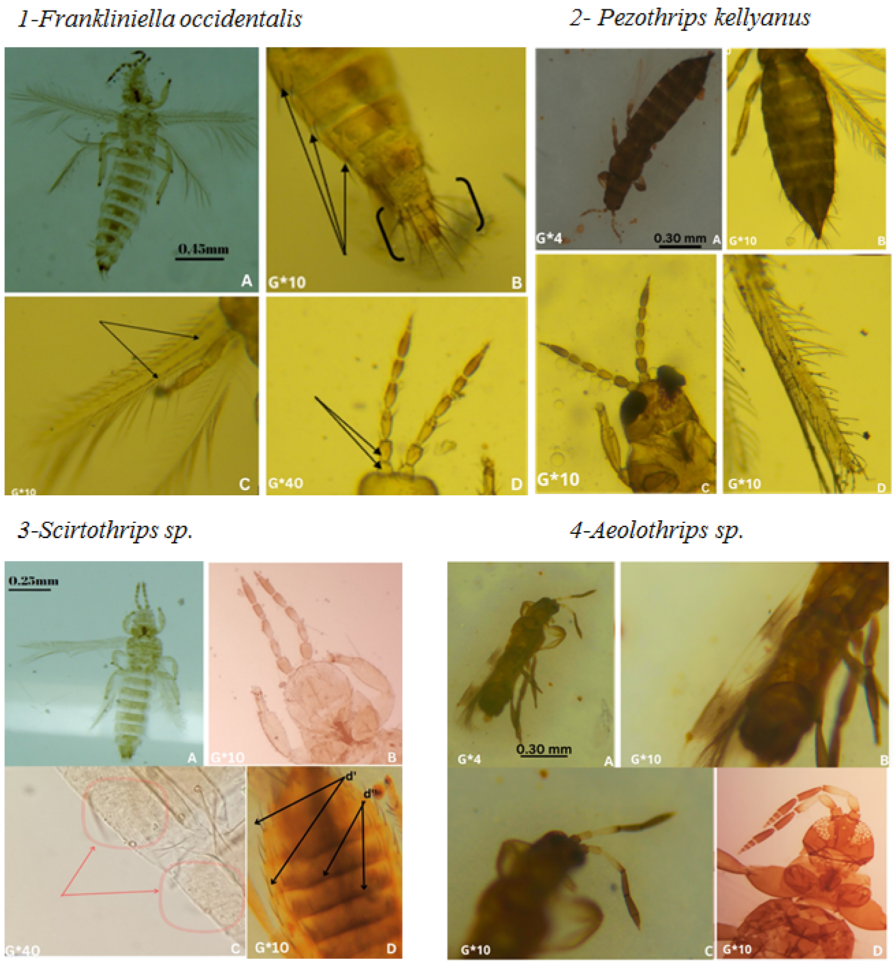

Figure 5. Species of thrips identified on citrus in the triffa plain.1- frankliniella occidentalis, A: Taxonomical criteria: B: Presence of complete peign at the VIII tergite. C: Wings with 2 complete lines of bristles. D: antennal segment I clearer than II; 2- pezothrips kellyanus, A: Taxonomical criteria, B: Abdominal tergite VIII with postero-marginal peign interrupted in the Middle. C: the antennae are mostly dark compared to the the junctions of the segments which are transparent; 3- scirtothrips sp., A: Taxonomical criteria. B: Antenna with 7 to 8 dark segments. C: Several parallel lines of minuscule microtrichia attached laterally to the abdominal tergites. D: dark bands on the underside of the abdomen; 4- aeolothrips sp., A: Taxonomical criteria, B: Wide foreword with very pronounced veins, with several transverse bands. D: Antenna with 9 articles and absence of long bristles on the pronotum.

Washington navel variety

The occurrence and abundance of thrips captured by blue traps on different citrus varieties were monitored in the Berkane region of Morocco, and the results were depicted in Figure S1. The first generation of thrips started on 28th April 2021 and continued until 28th July 2021, with the peak observed on 26th May 2021 with a mean capture of 28 individuals. The observed single peak in thrips development on each citrus variety

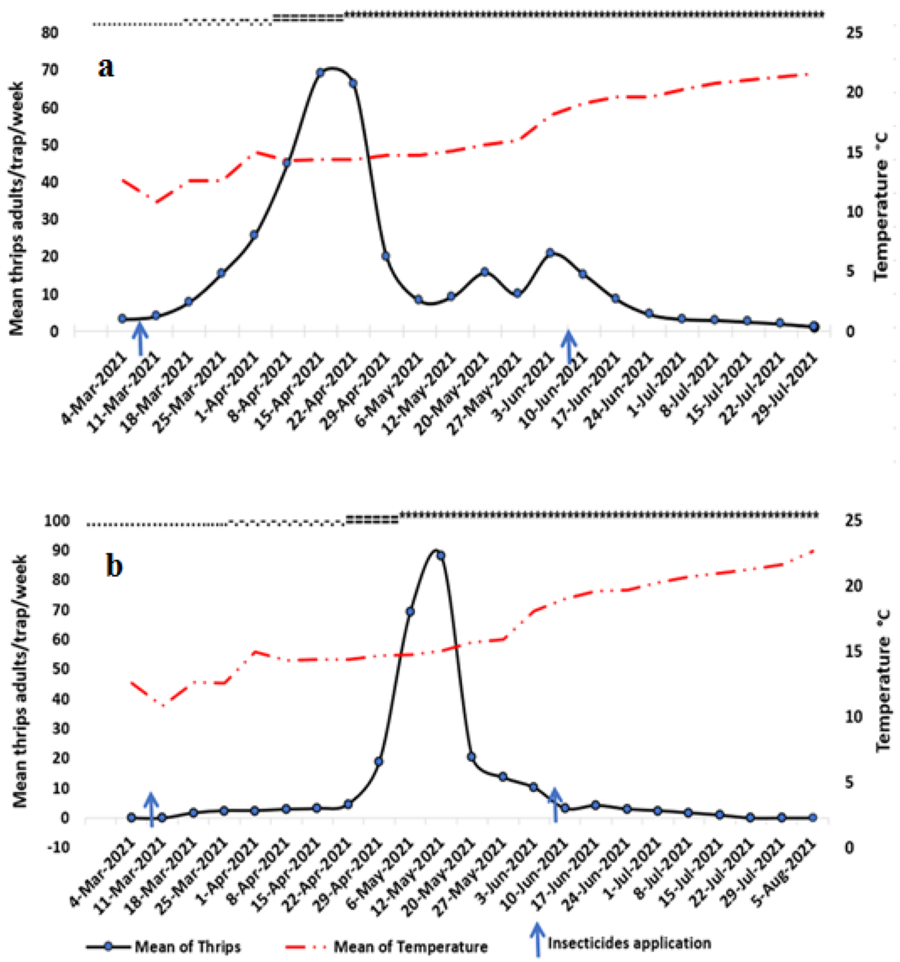

Figure 6. Temporal changes in mean number of thrips adults for (a) the clementine berkane, (b) the citrus variety nules during 2021 (….bud burst + start of bloom;.-.-.-.-.-full bloom; ===petal fall; ****fruit growing).

may be due to the application of chemical treatments during the blooming stage, which usually involves the combination of gibberellic acid with other phytosanitary products.

Maroc late variety

On 28th April 2021, the blue traps captured the first individuals of thrips, marking the onset of the first generation of thrips which lasts until 04th August 2021 (Figure S1). The peak of the first generation occurred on 19th May 2021 with an average capture of 59 adults. A study on the dynamics of thrips showed two adult peaks followed by a larval peak that coincided with blooming and the start of fruit set. These findings are consistent with previous studies which suggest that *P. kellyanus* develops predominantly during spring blooming (April to June) and gradually declines until it disappears in the absence of flowers, with a single generation per year. The presence of ripe fruits and new flowers in Berkane orchards provides a suitable environment for thrips to migrate from overwintering sites in mature fruits to new citrus flowers, where they cause damage. This discovery reinforces the importance of implementing pest management strategies during the blooming period to control the spread of thrips and minimize crop damage.

Thysanoptera populations' monitoring thrips spp (thysanoptera; thripidae)

Clementine Berkane variety

Three species of thrips belonging to family Thripidae were identified in the study: *Frankliniella occidentalis*, *Scirtothrips* sp., and *Pezothrips kellyanus*. These species emerged from overwintering at the end of February and the first week of March. Four peaks in thrips populations were observed in April and June, with *Frankliniella occidentalis* and *Scirtothrips* sp. showing two peaks each. The first peak of *Frankliniella occidentalis* was observed on 15th April 2021 with a total of 182 adults, and the second peak occurred on 3rd June 2021 with 56 adults. For *Scirtothrips* sp., the first peak was observed on 22nd April 2021 with 88 adults, and the second peak was observed on 3rd June 2021 with 27 adults (Figure S2a). *Pezothrips kellyanus*, on the other hand, had a single generation of low importance that spread from 25th March 2021 to 29th April 2021 with a maximum of 14 individuals captured on 15th April 2021 (Figure S2a).

Nules variety

According to recent population monitoring studies, *Frankliniella occidentalis* typically emerges in late March and reaches peak levels in April and May, but their populations tend to decline by the end of May and beginning of June (Figure S2b). Similarly, *Scirtothrips sp*. populations have been observed to begin with a peak on May 12th, 2021. In contrast, *Pezothrips kellyanus* was found to be less frequent, with only one peak registered on the same date (Figure S2b). These results provide valuable insights into the temporal dynamics of these thrips species and can help inform management strategies to control their populations.

Washington navel variety

The survey conducted on *Pezothrips kellyanus* population density revealed a prominent peak towards the end of May (Figure 7a). Furthermore, Figure 7a also highlighted the abundance of *Pezothrips kellyanus*, *Scirtothrips* sp, and *F. occidentalis*. Notably, *Pezothrips kellyanus* and *Scirtothrips* sp exhibited only one generation, with the highest number of captures recorded towards the end of May. Conversely, *Frankliniella*

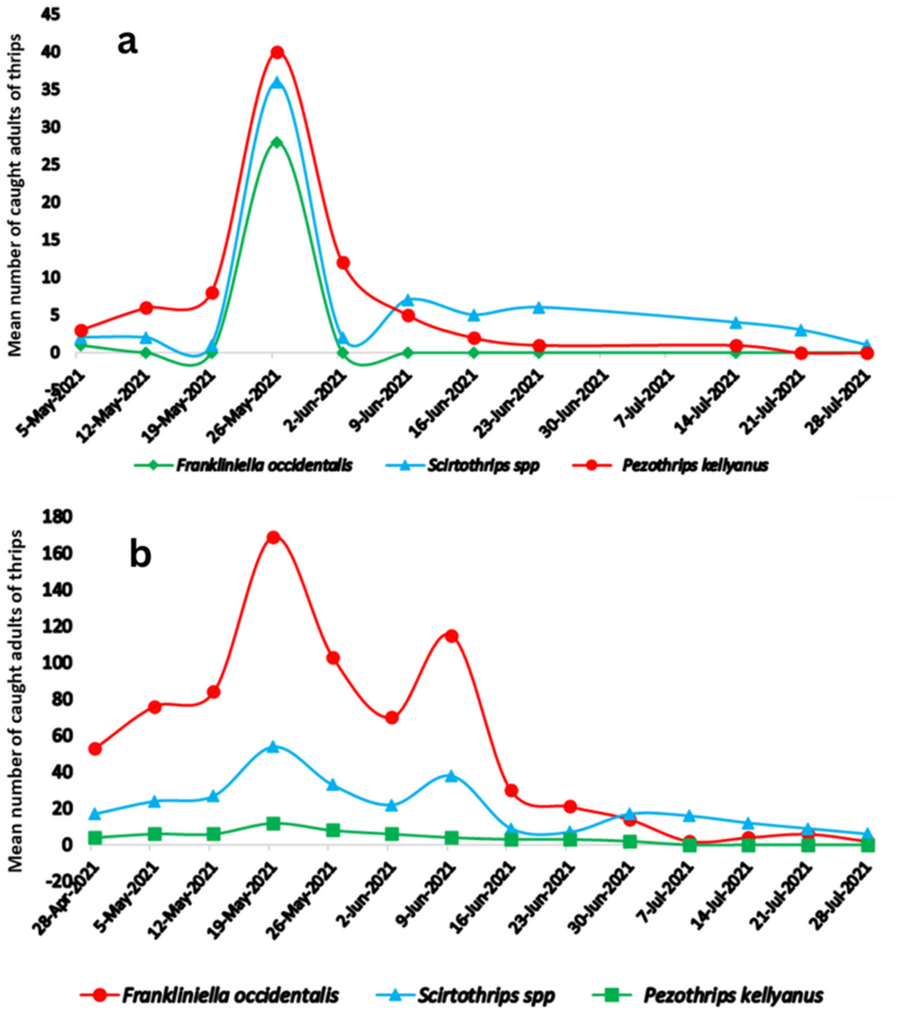

Figure 7. Monitoring of the several species of thrips on citrus varieties. (a) Washington navel variety, (b) maroc late variety.

occidentalis displayed two generations, with the first observed before the start of May until 19th May 2021, and the second spanning from 19th May 2021 to 02nd June 2021, with a peak of 28 individuals on 26th May 2021 (Figure 7a).

Maroc late variety

Regarding the Maroc Late variety, our observations revealed that *F. occidentalis* was the most abundant species, with two flights during the year 2021. The first flight occurred between 28th April and 7th July, with a peak of 169 individuals on 19th May, while the second flight was between 7th July and 28th July, with a peak of 7 individuals on 21st July. In contrast, *Scirtothrips* sp exhibited only one generation, which spanned from

28th April 2021 until the start of August, with a peak of 54 individuals on 19th May 2021. *Pezothrips kellyanus* carried out one generation, with the highest capture number of 12 adults on 19th May 2021 (Figure 7b). These findings underscore the importance of implementing effective management strategies to minimize the damage caused by these species to the crops.

Thrips damage to fruit

The analysis of Figure 8 reveals that the Washington navel variety was the most heavily attacked (32%), followed by Maroc late (24%), Clementine Berkane (13%), and Nules (11%). The feeding activity of thrips individuals intensified on the ovary at the end of the bloom period when flower parts desiccate and are shed. Feeding scars appeared on the ovary and grew with the fruit's swell. These results suggest that thrips attacks affected the Washington navel and Maroc late varieties more than others, as the pest population exceeded threshold levels in these two orchards during the petal fall and early fruit set period. The poorly maintained Washington navel orchard harbored many host plants for thrips, which may explain the low thrips captures during the monitoring period. However, a diversity of natural enemy species such as mites, lacewings, ants, and ladybirds were observed on these two varieties. Conversely, the Maroc late variety was well-maintained, and the absence of host plants could significantly explain the relatively higher thrips captures by the sticky blue traps. In addition, orange varieties are more susceptible to thrips, which is consistent with studies reporting significant damage caused by these pests in California, Arizona, and South Africa (Bedford 1998; Tanigoshi and Moreno 2012; Navarro Campos 2013). Young twigs, leaves, and leaf buds are also fed upon by citrus thrips, resulting in non-economic types of injury to the trees (Jeppson 1989).

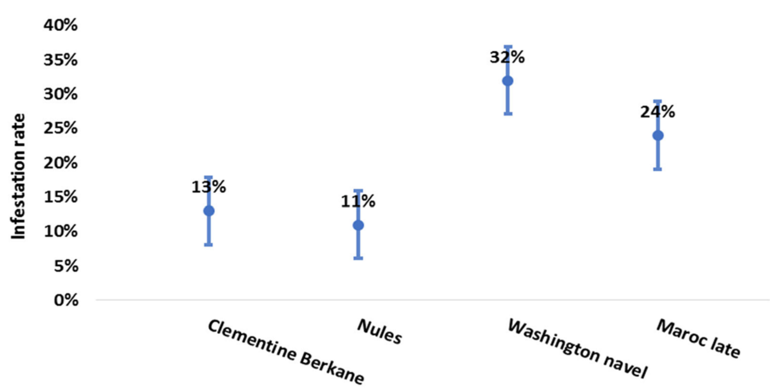

Figure 8. Infestation rate by thrips on the four varieties during 2021.

Regarding the Berkane Clementine and Nules varieties, the infestation rate was lower compared to the other two varieties. These two plots suffered fewer attacks, as seen in the percentage of infested fruits, where the damage at the level of the median and stylar part of the fruit, causing marbling, was most frequently observed during the field study Figure 2,3). According to Boulahia-Kheder and Belaam-Kort (2017) (Belaam-Kort and Boulahia-Kheder 2017), only calyx damage is specific to *P. kellyanus*, and calyx and stylus damage on the same fruit is specific to *Scirtothrips* sp. The fruits that show damage to the stylar part are the most common, according to observations during fruit monitoring, and are caused by the genus *Scirtothrips*. In accordance with our results, Belaam-Kort (2020) (Belaam-Kort 2020) showed that Thomson oranges were more sensitive than Maltaise oranges to thrips damage, with 68.04% and 42.92% of attacked fruits, respectively. In addition, Koutti and Bounaceur (2013) (Koutti and Bounaceur 2013) demonstrated that the thrips attack rate on Thomson oranges could reach 32%, while it did not exceed 14% and 8% on Clementine and Washington navel, respectively. On particularly sensitive species such as bergamots and lemons, the damage caused by some species such as *Pezothrips kellyanus* reached 59% and 45% on lemons (Belaam-Kort and Boulahia-Kheder 2017). Moreover, (Elekcioğlu 2013) showed the susceptibility of lemons to thrips damage compared to Washington navel.

Discussion

This study investigates the impact of various environmental factors on the population growth of thrips in citrus orchards in northeastern Morocco. The study found that the abundance of thrips species and economic damage to citrus crops are influenced by air temperature and the phenological stage of the citrus host plant. Additionally, precipitation events were found to suppress the growth of thrips populations, causing mortality of a large proportion of these pests. The flight activity of thrips is highly correlated with air temperature, and the abundance of thrips caught on sticky traps increased during the blooming stage of citrus trees. Thrips caught on sticky traps increased in orchards showing high densities of thrips during citrus blooming stages and had higher fruit damage. The study also found that the quantitative peak of thrips occurred during the blooming stage, and *F. occidentalis* was persistently present in the citrus groves. This meticulous methodology allowed for a precise evaluation of thrips populations and their behavior, providing valuable data for further analysis and interpretation.

The findings of the study are consistent with previous studies that have investigated the impact of environmental factors on the population growth of thrips. For example, Raza et al. (2015) (Raza et al. 2015) found that the population of thrips increased with an increase in temperature. Similarly, Rhainds et al. (2007) and Gopal et al. (2018) also found a positive correlation between temperature and the population growth of thrips (Rhainds et al. 2007; Gopal et al. 2018). Murai (2000) (Murai 2000) suggested that temperature and relative humidity may fluctuate the population and rate of population elevation of thrips may be intrinsically influenced. Dry weather was found to favor thrips population growth, while precipitation events could suppress the growth of thrips populations (Morsello et al. 2008).

Thrips are active as adults on plants, especially on weeds, and the populations increase during spring. The results of the study suggest that thrips adults overwinter on weeds (*Cynodon dactylon*, *convolvulus* spp, *Cyperus rotundus*, *Chenopodium album, solanum* spp) in adjacent fields and then migrate to citrus orchards in early spring during the blooming period of citrus trees. Low numbers of adults were recorded on sticky traps before bud burst in March, indicating that air temperatures were probably too low (10–17 °C) for flight activity during this period. However, the flight activity increased during March to April as the mean daily air temperature increased. Thrips caught by traps decreased in all orchards during the fruit development period, peaking in May, including the Nules variety. The findings suggest that the abundance of thrips on citrus orchards, for example on the Nules variety is closely related to the phenological stages of the host plant. Furthermore, the synchronism of adult immigration periods to citrus orchards with reference to its emergence in the fields of surrounding host plants suggested that most adults on citrus trees immigrated from surrounding host plants, with the number of emerging adults differing among plant fields and periods

The current study focused on *F. occidentalis*, which is a dominant thrips species in citrus groves. This thrips species has a constant presence in citrus groves, probably due to its high polyphagy and genetic adaptability of its populations. *F. occidentalis* is also capable of preying on some small arthropods present in the same habitat. The damage caused to fruit by *Frankliniella occidentalis* is not well defined, although this species feeds abundantly on flowers.

The impact of temperature on thrips population growth is noteworthy, as the study found that the population of thrips increased with an increase in temperature. This is consistent with the findings of Raza et al. (2015) (Raza et al. 2015), who reported a higher thrips population on different varieties due to favorable environmental conditions or varietal response. Citrus thrips prefer to feed on navel oranges in California, resulting in rind blemish injury that also leads to fruit rejection (Childers and Nakahara 2006). These findings are consistent with those reported in Tunisia by Belaam-Kort (2020), who indicated that *P. kellyanus* develops mainly in spring during blooming (April to June) and gradually decreases until it disappears in the absence of flowers, giving a single generation per year. These results are also in line with other studies (Rhainds et al. 2007; Gopal et al. 2018; Raut et al. 2021), which have shown that temperature and relative humidity can fluctuate the population and rate of population elevation of thrips. Murai (2000) (Murai 2000) further notes that temperature and relative humidity can intrinsically influence thrips population growth.

Trap captures may not reflect the actual number of thrips in the orchards due to environmental factors such as precipitation events, which can have suppressive effects on the growth of local populations of thrips developing during late winter and early spring, as shown by Morsello et al. (2008) (Morsello et al. 2008).

Therefore, it is important for citrus growers to monitor the phenological stage of their citrus trees and implement appropriate pest management strategies, such as timely and targeted insecticide applications, to minimize the damage caused by thrips and other pests. Additionally, the results of this study may be useful for developing integrated pest management strategies that take into account the influence of environmental factors on the population growth of thrips in citrus orchards. Furthermore, the synchronism of adult immigration periods to citrus orchards with reference to its emergence in the fields of surrounding host plants suggested that most adults on citrus trees immigrated from surrounding host plants, with the number of emerging adults differing among plant fields and periods.

Conclusions

This investigation delves into the nuanced dynamics and population fluctuations of thrips within orchards spanning the blooming to fruit growth stages, elucidating the intricate interplay of temperature and rainfall on the migratory patterns and damage proclivities of these insects. Despite being a relatively obscure insect group in Morocco, thrips wield considerable potential for inflicting substantive harm upon citrus crops, thereby endowing this study with both scientific gravitas and societal pertinence.

The inquiry discerns that ambient air temperature significantly governs the migratory trajectories and damage predisposition of thrips populations within their habitats. Temperature emerges as a pivotal determinant, exerting a discernible influence on thrips proliferation, with elevated temperatures correlating positively with augmented thrips abundance. Conversely, rainfall exerts an immediate suppressive effect on thrips numbers, although thrips ensconced within fruit petals exhibit heightened resilience against direct rain splash and insecticidal interventions. This acquired knowledge furnishes citrus cultivators with a predictive framework for enhanced thrips infestation management, particularly amid climatic conditions marked by elevated temperatures or increased rainfall.

Moreover, taxonomic distinctions reveal that divergent thrips species partake in the ring scarring of citrus across different cultivars, underscoring the imperative of comprehending species distribution for effective thrips mitigation in citrus production. The findings of this study furnish novel insights into thrips, an insect cohort that remains relatively obscure in the Moroccan context. The research trajectory extends to the exploration of control modalities, notably emphasizing biological interventions and preventive strategies, aimed at curbing thrips populations and precluding escalation in damage thresholds. This assumes heightened significance within the context of Morocco's economy, wherein citrus production constitutes a substantial sector.

In summation, this inquiry into thrips possesses scientific import in unraveling the intricacies of population dynamics, damage propensities, and the modulatory impact of temperature and rainfall in citrus cultivation. Simultaneously, its societal relevance is underscored by the provision of actionable intelligence to citrus agriculturists for more adept management and prophylaxis against thrips incursions, thereby averting economic losses. The ongoing exploration of control methodologies, particularly those rooted in biological and preventive paradigms, positions the study as a catalyst for fostering sustainable and efficacious citrus production.

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Author's contributions

Conceptualization, YB. and MS.; methodology, YB, KK, ME and MEJ.; software, YB and KK; validation, YB, KK and ME; formal analysis, YB, KK and MS.; investigation, YB.; data curation, YB., KK., and MS Writing—original draft preparation, YB and KK; writing—review and editing, KK, ME, BT, MS, RL, BT, and MEJ; supervision, YB, KK, MS and MEJ.; project administration, MS; funding acquisition, MS. All authors have read and agreed to the published version of the manuscript.

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Data availability statement

The datasets supporting this article are available from the corresponding author upon reasonable request.

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