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Thrips species biodiversity and dynamic populations in an organic *Citrus* orchard in northeastern Tunisia

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Abstract
Thrips species diversity in a *Citrus* organic orchard in the region of Mograne in Northeastern Tunisia based on biodiversity parameters (Shannon index, dominance, and equitability) showed the existence of ten thrips species. Among those species, five are phytophagous: *Thrips tabaci*, *Thrips angusticeps*, *Frankliniella occidentalis*, *Limothrips denticornis*, and *Melanthrips fuscus*. The remaining species are predatory: *Aeolothrips tenuicornis*, *Aeolothrips fasciatus*, *Aeolothrips intermedius*, *Franklinothrips meaglops*, and one genus, *Haplothrips* sp. The most abundant species are *Aeolothrips intermedius* (55%) followed by *Thrips angusticeps* and *Haplothrips cottei* (the same percentage of 11%), *F. occidentalis* and *T.tabaci* (5% and 6%, respectively), *Aeolothrips fasciatus* and *Limothrips denticornis* (3% and 4%) then *Aeolothrips tennuicornis* and *Melanthrips fuscus* (the same percentage of 2%). The species *Franklinothrips megalops* is less abundant (1%)**.** The evolution of different thrips species revealed that the emergence reached high levels in March and April. Biodiversity indexes showed a case of lower dominance and higher equitability.

Keywords: Thrips, *Citrus*, biodiversity, phytophagous, predatory

1. Introduction
Thrips are minuscule insects that belong to the order of Thysanoptera. Those insects are divided into two suborders: Terebrantia and Tubulifera [1]. Thrips are serious pests that cause serious damage by sucking cell content or as vectors of different viruses to the host plants [2, 3, 4]. Cellular content sucking leads to the appearance of silver patches at the level of the pitted regions matching empty cells [1]. Many thrips' species cause serious damage to *Citrus* and transmit plant pathogens such as fungus, bacteria, and viruses [5]. M'Hafdhi *et al*., [6] added that thrips damages through stinging cellular content cause a blockage of the growth of the other cells inducing hence exploding and enlargement of fruits.
Studying thrips diversity and ecology is crucial to establishing Integrated Pest Management strategies to control them in *Citrus* crops [5, 7, 8]. The first report of thrips and their damage to *Citrus* in Tunisia occurred in 2008 in the Cap Bon region [9]. Thrips damages are reported increasingly in recent years, especially on fruits [10]. Moreover, Hached *et al*., [11] reported that Thomson Oranges are more sensitive to thrips attacks. Various works have been released to study thrips biodiversity and population dynamics occuring in *Citrus* crops in the Mediterranean basin and Tunisia [12, 13, 14, 5]. Elimem and Chermiti [5] found 12 thrips species with an abundance of *Frankliniella occidentalis*, *Melanthrips fuscus*, *Thrips tabaci, and Pezothrips kellyanus* and the predatory thrips such *Aeolothrips tenuicornis*, *Aeolothrips fasciatus*, and *Franklinothrips megalops*. Belaam-Kort and Boulahia-Kheder [10] reported 14 species of thrips in *Citrus* orchards like *T. major*, *P. kellyanus*, and, *F. occidentalis*. Belaam-Kort *et al.* [11] found that *F. occidentalis*, *P. kellyanus*, and *F. occidentalis* were more abundant in *Citrus* orchards on Navel oranges with the presence of predatory species such *Scolothrips longicornis*, *Aeolothrips* spp and *Franklinothrips* spp. A recent inventory in January 2022 published by Elimem *et al*. [15] has shown different thrips species on *Citrus* orchards in the Cap Bon region such *as F. occidentalis*, *Thrips* spp, *Limothrips cerealium*, *Pezothrips kellyanus*, and predatory thrips such as *Aeolothrips* spp and *Franklinothrips* spp. In Tunisia, studying the evolution of population dynamics of thrips species inventoried confirmed that their emergence occurred in spring and reached its maximum in May [5, 16]. The population dynamics of thrips species are related to the phonological status of host plants affecting their distribution, occurrence in the different parts of plants, and even their sex ratio [17, 5, 18, 19, 20].

A preliminary study of the various species in northeastern Tunisia published by Elimem *et al*. [7] reported the occurrence of four thrips species: *F. occidentalis*, *T. tabaci*, *T. angusticeps*, and *P. kellyanus.* The study has also demonstrated that the population dynamics of these thrips' species are related to abiotic parameters such as relative humidity and temperature.
This study aims to give an inventory of Thysanoptera species found in a *Citrus* orchard in the region of Mograne from the governorate of Zaghouane in northeastern Tunisia; studying their biodiversity and monitoring their populations' dynamics.

2. Materials and methods

2.1 Experimental site

This work was carried out from January 13, 2021, to June 16, 2021, in a *Citrus* orchard of the Higher School of Agriculture of Mograne (36°25'46.05"N 10°05'37.00"E, elevation 146 m) belonging to the governorate of Zaghouane in northeastern Tunisia. The experimental plot contains multiple species such as Thomson's navel, Valencia late, Maltese, clementine, tangerine, mandarins and pomelo.

2.2 Sampling methods

The experimental plot was divided into 10 micro-plots. Ten trees were sampled weekly and randomly from each micro-plot. Fruits and twigs of 30 cm in length were chosen from the four quadrants of each tree. Moreover, a light beating of the sampled trees was performed and the fallen specimens on a white tissue were collected by aspiration using a simply manufactured aspirator. The collected insects were conserved in small containers of a solution of 40% alcohol for further identification.

2.3 Thysanoptera mounting and identification

All the specimens collected were mounted according to Bournier [1] protocol. Later, the identification was based on different identification keys: Mound *et al*. [21], Mound and Walker [22], Palmer *et al*. [23] and, Mound and Kibby [24].

2.4 Biodiversity indexes of the Thysanoptera fauna

The bio-ecological study was based on four be ta diversity indexes. Measurement of the different diversity indexes was done using the software PAST® (Paleontological Statistics). These indexes are:

Specific Richness (Rs) [25, 26]: Which is the number of species or attributes present. It is the simplest and the most commonly used index to represent diversity.

Shannon Weaver diversity index (H') [27, 28]: This is an informative index evaluating the spatial and temporal diversity of a given population in a biotope or a set of biotopes.
The formula of this index is:

$$H' = -\sum pi * Ln\ (pi)$$

Where pi is the proportion of individuals belonging to the species. H' varies between 0.5 for low diversity and 4.5.

Dominance (D) and Equitability (E) [28, 29]
Dominance is expressed by:

$$D = (n * 100)/N$$

Where D is the dominance, n is the number of individuals belonging to the best represented species and N is the total number of individuals in a given sample.
Equitability is the ratio of the actual diversity observed and the theoretical maximum diversity. It is expressed by the following formula:

$$E = H'/Ln(N)$$

An equitability value under 0.6 characterizes a disturbed environment.

Dominance classification
According to Kucharczyk *et al*. [30] and Elimem and Chermiti [5], thrips species are classified according to their dominance into: eudominants (> 10%), dominants (5.1 to 10%), subdominants (2.1 to 5%), recedents (1 to 2%) and, subrecedents (< 1%).

3. Results

3.1 Identification of thrips fauna in the *Citrus* orchard

During the monitoring period of thrips fauna, a total of ten specimens were reported belonging to four different families. The different phytophagous and predatory species identified are listed in table 1.

Table 1: Phytophagous and predatory species identified in the *Citrus* orchard

Order	Sub-Order	Family	Genus	Species
Thysanoptera	Terebrantia	Thripidae	*Thrips*	*tabaci*
				angusticeps
			Frankliniella	*occidentalis*
			Limothrips	*denticornis*
		Aeolothripidae	*Aeolothrips*	*tenuicornis*
				intermedius
				fasciatus
			Franklinothrips	*megalops*
		Melanthripidae	*Melanthrips*	*fuscus*
	Tubulifera	Phlaeothripidae	*Haplothrips*	*sp*

Concerning the abundance of the different species, *Aeolothrips intermedius* was the most abundant (55%), followed by *Thrips angusticeps* and *Haplothrips cottei* (the same percentage 1of 1%), *F. occidentalis* and *T. tabaci* (5% and 6%, respectively), *Aeolothrips fasciatus* and *Limothrips denticornis* (3% and 4%, respectively) then *Aeolothrips tennuicornis* and *Melanthrips fuscus* (the same percentage of 2%). The species *Franklinothrips megalops* is less abundant

with a percentage of 1%. According to the classification of Kucharczyk *et al*. [30], the results (Table 2) demonstrate the species *A. intermedius*, *T. angusticeps* and *Haplothrips cottei* are eudominant. *T. tabaci* and *F. occidentalis* are dominant, *A. fasciatus* and *L. denticornis* are sub-dominant. *A. tenuicornis*, *Melanthrips fuscus*, and *Franklinothrips megalops* are recedent species.

Table 2: Thrips species frequency and dominace in the *Citrus* orchard ((+ + + + +): Eudominant, (+ + + +): Dominant, (+ + +): Sub-dominant, (+ +) Recedent, (+): Subrecedent)

Species	Frequency (%)	Dominance
T. angusticeps	11.48	+ + + + +
T. tabaci	5.90	+ + + +
A. fasciatus	3.23	+ + +
A. tennuicornis	1.77	+ +
A. intermedius	54.81	+ + + + +
H. cottei	10.90	+ + + + +
F. occidentalis	5.17	+ + + +
M. fuscus	1.76	+ +
L. denticornis	3.68	+ + +
F. megalops	1.29	+ +

3.2 Biodiversity parameters

The evaluation of the basic biodiversity parameters (Figure 1) has shown low values for dominance and Shannon indexes. However, the equitability index was close to 1 indicating that all the species are equally abundant, hence the population is homogeneous. These results explain the near or equal percentages of the abundance of the different species identified in the field (Table 2).

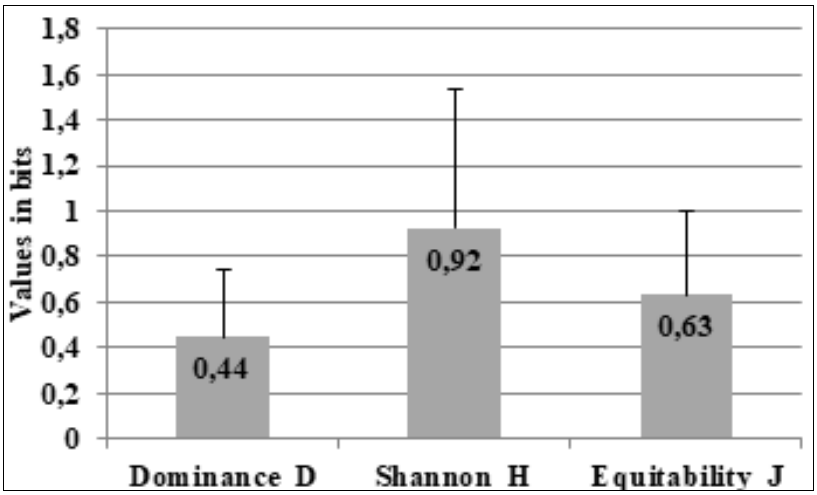

Fig 1: Biodiversity indexes in the *Citrus* orchard

3.3 Thysanoptera populations' monitoring

Thrips spp (Thysanoptera; Thripidae)

Two species of the genus *Thrips* have been caught: *T. angusticeps* Uzel (1895) and *T. tabaci* Lindemann (1889). The emergence of the two species took place at the beginning of February and the first week of March. *Thrips* spp populations registered four peaks in March and April. Population peaks of *T. angusticeps* occurred on March 10, April 7 and 28, and May 19, 2021. Population peaks of *T. tabaci* occurred on March 03 and 31, and May 05 and 19, 2021. The highest averages of caught adults were observed on March 31, 2021, for *T. tabaci*, and on April 07 and 28, 2021 for *T. angusticeps* (Figure 2).

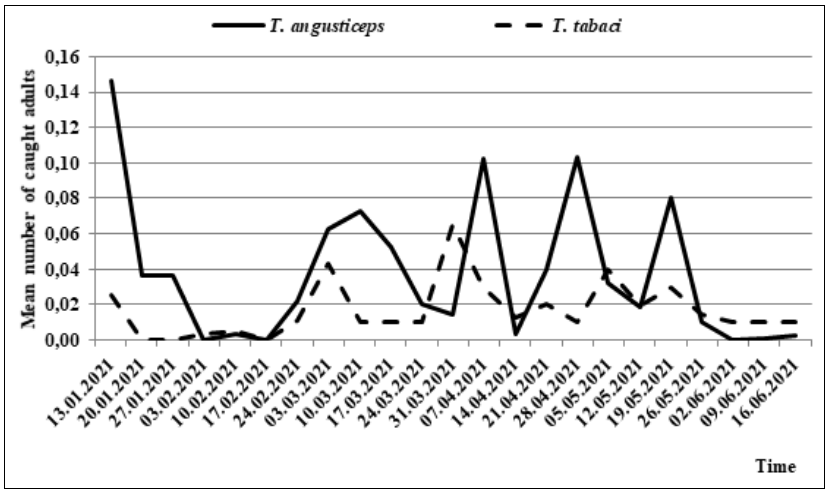

Fig 2: Monitoring of *T. angusticeps* and *T. tabaci* in the *Citrus* orchard

***Aeolothrips* spp (Thysanoptera; Aelothripidae)**

In our study, the majorities of *Aeolothrips* species emerge towards the start of spring and reach high peaks in April. *Ae. tennuicornis* populations appeared in the first week of February. Its population density increased at the end of March. The highest peak of *Ae. tennuicornis* was observed in April. *Ae. intermedius* population density peaks were observed in March, April, and June. *Ae. fasciatus* was abundant throughout the study period with the highest averages recorded during March and April (Figure 3).

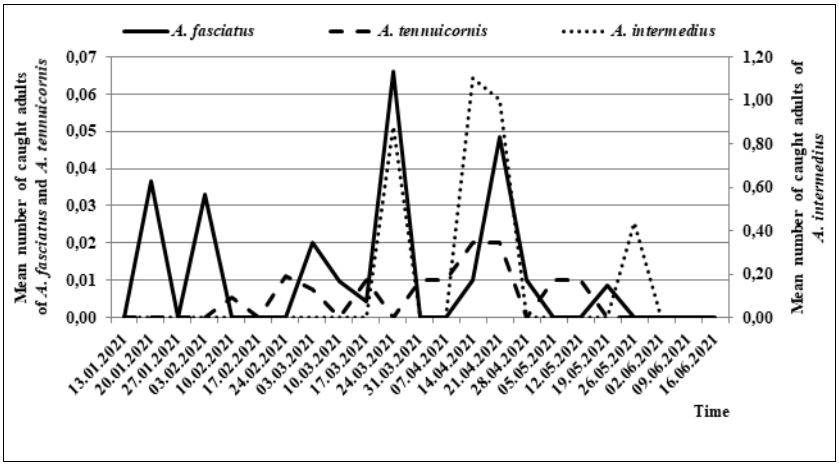

Fig 3: Monitoring of *Aeolothrips* spp. in the *Citrus* orchard

***M. fuscus* (Thysanoptera: Melanthripidae); *F. occidentalis* and *L. denticornis* (Thysanoptera: thripidae)**

M. fuscus population has begun with a peak on March 31, 2021, and a second one on April 28, 2021. During our study, *F. occidentalis* was less frequent with one peak registered on March 10, 2021. *L. denticornis*, which attacks mainly cereals, was observed during all the study period starting from March (Figure 4).

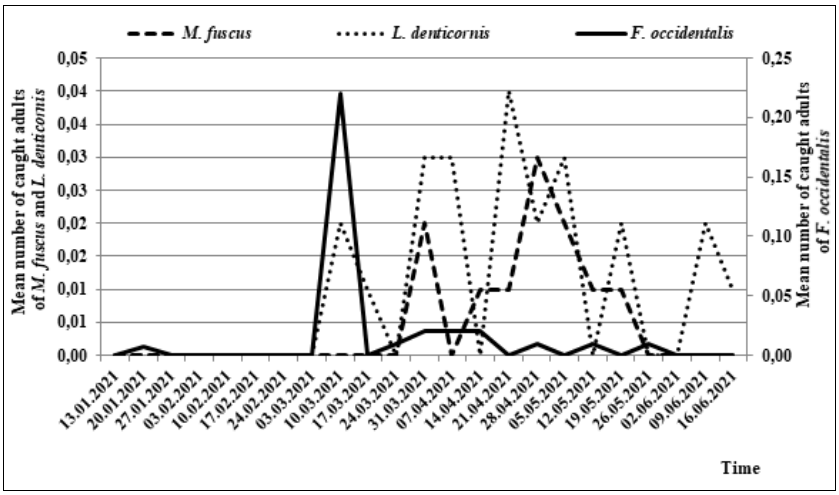

Fig 4: Monitoring of *M. fuscus, L. denticornis* and *F.occidentalis* in the *Citrus* orchard

***Haplothrips* sp (Thysanoptera; Phlaeothripidae)**

The monitoring of *Haplothrips* sp. populations has shown that they appear towards the end of February and reach high levels in March, April, and May. Their populations start to decline by the end of May and the start of June (Figure 5).

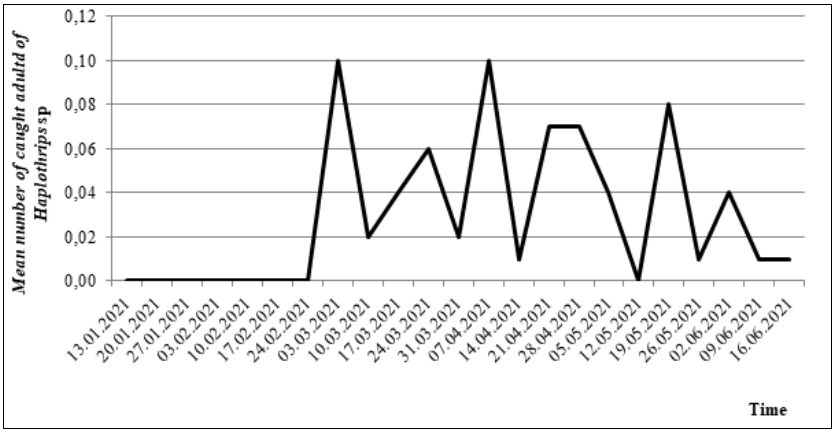

Fig 5: Monitoring of *Haplothrips* sp in the *Citrus* orchard

***Franklinothrips megalops* (Thysanoptera; Aelothripidae)**

The survey of *F. magalops* population density has revealed one peak occurring toward the end of February and the beginning of March (Figure 6).

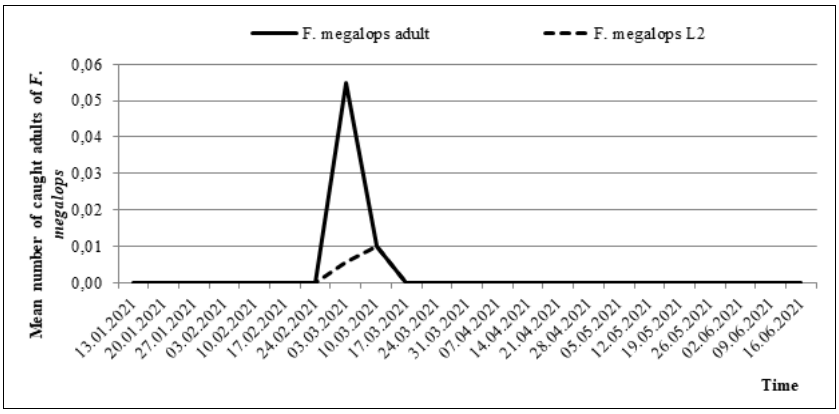

Fig 6: Monitoring of *F. megalops* in the *Citrus* orchard

4. Discussion

Thrips species identified in the *Citrus* orchard are *T. angusticeps* and *T. tabaci*. These species have been found in different studies on *Citrus* in several regions of Tunisia [5, 31, 7, 11]. *T. tabaci* is a cosmopolitan polyphagous species having different botanical hosts [22, 1, 32]. Belaam-Kort and Boulahia-Khedher [14] showed that *T. tabaci* is among the most abundant *Thrips* species on *Citrus* in North and Northeast of Tunisia. Elimem and Chermiti [5] reported the same findings in *Citrus* orchards located in the Center of Tunisia. *T. angusticeps* is also polyphagous and cosmopolitan [1, 32]. Several studies have demonstrated that this pest has a large geographical distribution in different localities in Tunisia with high population levels [9, 14, 5]. *F. occidentalis* has been mentioned in our study. This species is polyphagous. It can attack multiple ornamental, vegetable, and tree crops [1, 33, 17, 34]. Moreover, *F. occidentalis* is present in *Citrus* orchards in Tunisia and the Mediterranean basin [12, 9, 13, 5].

According to Belaam-Kort and Boulahia-Khedher [14, 10] and Elimem and Chermiti [5], *M. fuscus* is among the most frequent Thysanoptera species on *Citrus* in the North, Northeast, and the coastal regions of Tunisia. In Spain, Navarro *et al.* [12] confirmed these findings. The species we identified were also signaled by Belaam-Kort and Boulahia-Khedher [10] and Belaam-Kort *et al.* [8] that revealed the presence of *L. cerealium* in *Citrus* orchards in different regions of Cap-Bon, Bizerte, and Morneg. *Aeolothrips* species feed on flowers, small arthropods, and pollen [24, 35]. They are mainly small predators of phytophagous thrips [36]. The species found in our study are *Ae. intermedius*, *Ae. tenuicornis* and *Ae. fasciatus.* The first species was identified in *Citrus* orchards by Belaam-Kort and Boulehia-Khedher [10]. The second and the third species were detected by Elimem and Chermiti [5]. For *the Haplothrips* genus, their phytophagous species are not economically serious. Some species of *Haplothrips* are predators [1, 32]. Elimem *et al.* [16] have indicated that *Haplothrips* are predators of mites. *F. megalops* is an obligate predator of small arthropods [37]. That's why it is used as biological control agent against phytophagous thrips species [38, 39]. The evolution of the different thrips species is not similar. Thus, the highest numbers of caught insects have occurred in March, April and May. That is due to favorable climatic conditions during spring and the phenological status of *Citrus* trees (flowering). These results confirm those of Elimem and Chermiti [5] affirming that the eudominant species such *as F. occidentalis*, *T. tabaci*, and *P. kellyanus* reach high averages during March, April, and May. According to Belaam-Kort and Khedher-Boulehia [10], the highest densities of immatures and adults of thrips on *Citrus* take place during spring at flowering.

Eventually, our study confirms findings of thrips species on vine orchard. These results affirm that the evolution of thrips number is related to phenological stages of the host plant. They also described a low dominance and high equitability of thrips species in the field [16].

The emergence of *T. tabaci* and *T. angusticeps* started at the end of February and reached high peaks in April and May confirming results find by Elimem and Chermiti [5] in Tunisia and Navarro *et al*. [12] in Spain. Concerning *F. occidentalis*, our results are similar to those of Elimem and Chermiti [5] that demonstrated that the number of thrips individuals in *Citrus* orchards increased in February and March and reached high peaks in April and May. The evolution of the population dynamics of *M. fuscus* in *Citrus* organic fields has also been studied by Elimem and Chermiti [5]; they indicated that this species can be detected during the coldest months from September to February and decrease in spring and hot summer. These results do not match our findings because *M. fuscus* was detected during the hottest moths of the study period (end of March and end of April). That can probably be explained by the regional and climatic conditions, knowing that the study of Elimem and Chermiti [5] was done on the coast and our study in a montanious region. Cereal thrips *L. denticornis* was present throughout the study period. Koppa [40] has indicated that the first generation of this pest occurs in mid-June. The second generation starts in spring. It seems like the occurrence of this species is related to the presence of weeds from the grass family.

For the predatory species, the results concerning *Aeolothrips* spp confirm those of Elimem *et al.* [16] on grapevine orchards. Authors found that the highest populations were observed in April confirming then findings of Navarro *et al*. [12] and Elimem and Chermiti [5]. Results concerning *Haplothrips* sp populations do not confirm those of Larsson [41] stating that *Haplothrips* spp starts their proliferation during the end of May and June. The peak of *F. magalops* individuals occurred simultaneously with the emergence of the majority of phytophagous thrips. Our findings are confirmed by Elimem and Chermiti [5] affirming that the presence of this pest is related to its prey.

5. Conclusion

Ten thrips species were detected in an organic *Citrus* orchard in Northeastern Tunisia: *T. tabaci*, *T. angusticeps*, *F. occidentalis*, *L. denticornis*, and *M. fuscus* which are phytophagous thrips; and, *Ae. tenuicornis*, *Ae. fasciatus*, *Ae. intermedius*, *F. meaglops*, and one genus, *Haplothrips* sp. which are predatory. Monitoring the different thrips species revealed that the emergence reached high levels in March and April.

Biodiversity was studied using three beta diversity indexes (Shannon index, dominance, and equitability). The most abundant species was *Ae. intermedius* and *F. megalops* was the less abundant specie**.** Biodiversity indexes revealed low dominance and high equitability. This study is necessary to develop Integrated Pest Management strategies against Thysanoptera pests.

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