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Within plant vertical distribution of *Frankliniella occidentalis* Pergande (1895) (Thysanoptera; Thripidae) on greenhouse pepper crop: effects of climatic conditions and implications for populations surveillance and control programs

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Abstract – Within plant vertical distribution of Frankliniella occidentalis Pergande (1895) (Thysanoptera: Thripidae) on greenhouse pepper crop: effects of climatic conditions and implications for populations surveillance and control programs
Frankliniella occidentalis Pergande (1895) (Thysanoptera; Thripidae) is a cosmopolitan polyphagous thrips species which occurs on many cultivated host plants causing relevant economic damages. Survey of within pepper plants vertical distribution of F. occidentalis as function of pepper plant strata (upper, medium and lower) and climatic conditions (temperature, relative humidity and photoperiod), showed that during the cold season(11 to 17°C), the pest populations were evenly distributed within different host plant strata. However, with the increase of temperature (20°C) and photoperiod, medium and lower stratum presented more or less similar thrips numbers while population density in the upper stratum was significantly higher. Regarding larvae, the upper stratum presented the highest densities with no significant differences among studied strata. Correlation between average thrips numbers and different strata heights showed that highest thrips densities were observed at approximately 80 cm above ground level.

Keywords: thrips, plant stratum, sex ratio, vertical distribution.

Résumé – Distribution verticale de *Frankliniella occidentalis* Pergande (1895) (Thysanoptera ; Thripidae) sur cultures protégées de piment, effets des conditions climatiques et implications sur la surveillance des populations et les programmes de lutte
Frankliniella occidentalis Pergande (1895) (Thysanoptera ; Thripidae) est une espèce de thrips cosmopolite et polyphage associée à de nombreuses plantes cultivées pouvant causer des dommages économiques importants. Le suivi de la distribution verticale de *F. occidentalis* en fonction des différentes strates de la plante hôte (supérieure, moyenne et basale) et des conditions climatiques (température, humidité relative et la photopériode) sur cultures protégées de piments a montré que pendant la saison froide (11 à 17 °C), le ravageur était réparti uniformément sur la plante hôte. Cependant, avec l'augmentation de la température (20 °C) et de la photopériode, la strate moyenne et la strate basale ont affichés des densités de populations similaires tandis que les populations de thrips au niveau de la strate supérieure étaient significativement plus élevées. En ce qui concerne les larves, la

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couche supérieure a présenté les densités les plus élevées sans pour autant montrer des différences significatives. La corrélation entre le nombre moyens de thrips et les différentes hauteurs de strates a révélé que les densités de thrips les plus fortes se situent à environ 80 cm au-dessus du niveau du sol.

Mots clés : Thrips, strate végétale, sex-ratio, distribution verticale.

1. Introduction

Frankliniella occidentalis (Pergande1895) (Thysanoptera; Thripidae), known also as the Western Flower Thrips (WFT) is a polyphagous thrips species associated with many cultivated plants belonging to several botanical families (Lewis 1973) including tree species, vegetable crops such as cucumber, eggplant, melon, bean, pepper, tomato and strawberry (González-Zamora and Garcia-Marí 2003; Papadaki et al. 2008), and ornamental cultures such as chrysanthemum, orchids, rose (Rosa L. spp.), Gypsophila spp. Dendranthema grandiflora etc (Chau and Heinz 2006 ; Yudin et al. 1986). As suggested by its vernacular name, this species originates from the west of the United States, more precisely California. In the sixties, its dispersion was limited to the northwest of the United States, Canada and Mexico. Thereafter, it has spread starting from 1970 to many countries in different continents such as Europe, Africa, Asia and Oceania (Chau and Heinz 2006 ; Kirk and Terry 2003 ; Lacasa et al. 1996).
F. occidentalis may cause many damages on its host plant. On rose crops for example, it is especially on flowers that damages are the most important. Generally, symptoms consist of yellow spots and distortions of attacked organs (Brun 2004). Feeding larvae and adults leave scars on leaves and white spots petals of flowers becoming brown, then dry and perforate. Feeding scars affect flower buds and may prevent them from fully deployment. Attacked sepals become curly and slightly discolored (Brun 2004).
On pepper crops, F. occidentalis is responsible of serious damages which ultimately lead to severe economic losses. On attacked organs, discoloration can be observed evolving into necrosis and chlorosis. Attacked leaves and fruits acquire a brownish silvery appearance and become deformed. Egg laying activities can cause some damages expressed by a reaction of leaf tissue surrounding the egg (Belharrath et al. 1994 ; Fery and Schalk 1991 ; Frantz and Mellinger 2009 ; Tommasini and Maini 2002). The WFT is still considered as a quarantine organism is many countries due to its ability to transmit viruses such as the Tomato Spot Wilt Virus (TSWV) (Belharrath et al. 1994).
The biotic potential, population dynamics, morphological and biological characteristics and bio-ecology of F. occidentalis are governed by many abiotic parameters such as temperature, relative humidity and photoperiod as well as biotic parameters, more specifically the phenology of the host plant (Bournier 1983; Chaisuekul and Riley 2005 ; Elimem and Chermiti 2009 ; Elimem et al. 2011; Fraval 2006; Loomans and Van Lenteren 1995; Whittaker and Kirk 2004). In this perspective, Lacasa (1990) indicates that WFT populations often attack the upper parts of host plants where they stay till harvesting. On many crops, bordering plants are often reported as the first and the most attacked and infested zones of the culture.
In this context, this work aimed at studying within plant vertical distribution of F. occidentalis in protected pepper crops and the possible interaction with temperature as the most important climatic parameters governing the bio-ecology of the pest.

2. Material and methods

2.1. Experimental sites

The study was carried out in two 500 m² pepper crop greenhouses located in the governorate of Monastir (Central Eastern coast of Tunisia) (Figure 1). The first greenhouse (G1) is located in the region of Moknine (35°37’45.39’’N 10°55’57.41’’E, elevation: 1m) during 2009, and the second one (G2) belongs to the region of Bekalta (35°36’16.50’’N 11°00’16.69’’E, elevation: 6m) during 2010. Both greenhouses were formed by four rows that each of which is formed by two lines of the pepper variety “*Chargui*”. The inter-row distance is about 1 m. Both greenhouses were protected with insect-proof.

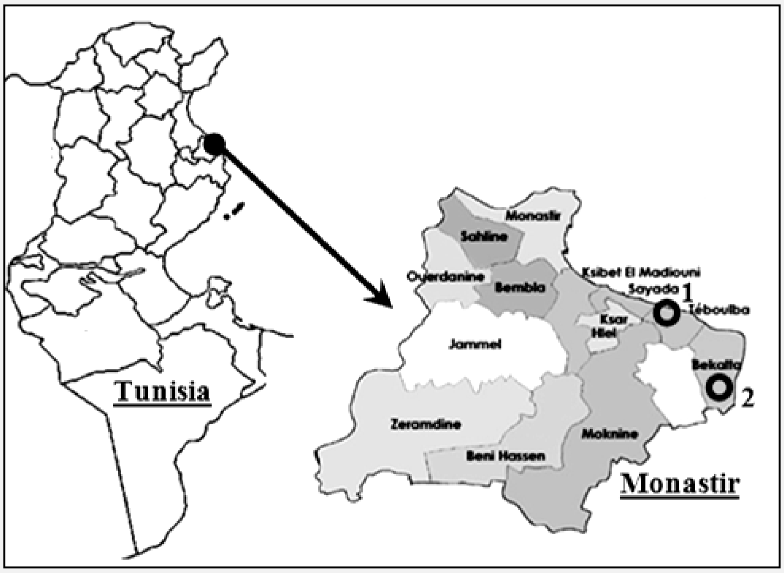

Figure 1. Geographical localization of the experimental sites in the governorate Monastir and in Tunisia (Legend: 1, region of Teboulba; 2, region of Bekalta).

2.2. Host plant height measurement

Ten pepper plants were selected since the beginning of the study and marked in each greenhouse. The follow-up of the height of each stratum was considered as follow: the upper stratum is equal to the total height of the pepper plant (apical leaves and shoots included).The lower one is the length of the stem while the medium stratum was calculated according to the following formula:

$$\mathbf{HMS = (TH - SL) / 2 + SL}$$

Where HMS is the height of the medium stratum, TH is the total height of the plant and SL is the stem length from the ground level to the first ramification (Figure 2).

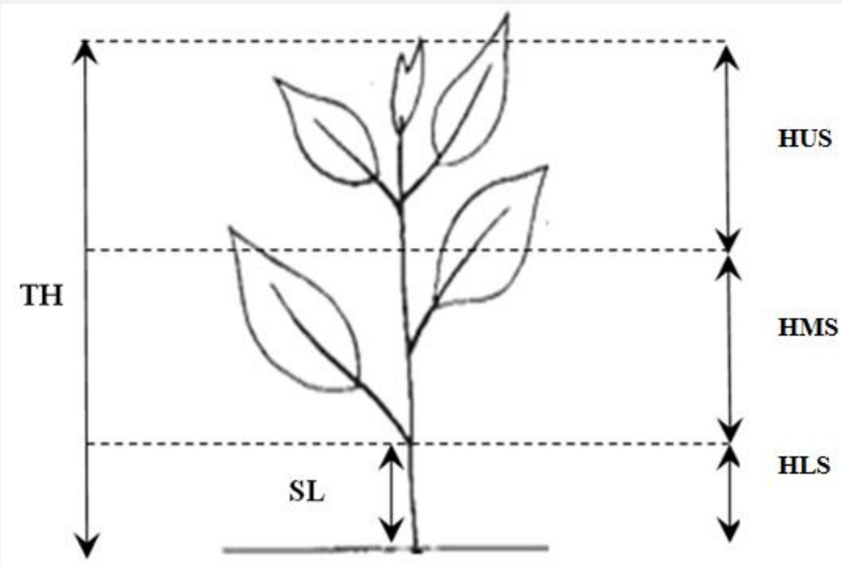

Figure 2. Different strata of the pepper plant (Legend : TH, Total Height; SL, Stem Length; HUS, Height of the Upper Stratum; HMS, Height of the Medium Stratum; HLS, Height of the Lower Stratum).

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2.3. Flowers' sampling

Adults' population monitoring on the host plant flowers was done through a weekly flowers sampling in both studied greenhouses using the same sampling method. In each greenhouse, the four rows have been divided into five blocks each, making thus a number of 20 sampling units. From each sampling unit, a pepper plant was randomly selected from which three flowers were sampled from the different plant strata (upper, medium and lower). Pepper plants used for sampling were marked not to be used in the following samplings. Each sampled flower was placed in a plastic bag on which the numbers of sampling unit and the stratum were marked.

2.4. Climatic parameters monitoring

Temperature and relative humidity were weekly monitored with a data logger (Spectrum technologies, USA). Photoperiod data was taken from the National Institute of Meteorology of Tunisia (NIMT 2010).

2.5. Statistical analysis

Statistical analyses were performed using the statistical software GraphPad Prism version 5.0 (GraphPad Prism, USA). The number of thrips in different plant strata were subjected to analysis of variance (ANOVA) and means of thrips numbers in different strata were separated using the Beffironi post hoc test at p=5% level of significance.

3. Results and Discussion

3.1. Monitoring of climatic conditions

The monitoring of temperature in the greenhouse ''G1'' in Moknine in 2009 showed that during the early study period till the end of March, the highest and the lowest average temperature values were respectively 14.17 and 11.70°C registered on February 26th and March 12th 2009. This parameter increased gradually till reaching values around 25°C reported on May 28th 2009 (Figure 3). Regarding relative humidity, average values were high during February and March to decrease later to 73.13% on May 14th 2009 (Figure 3). In greenhouse ''G2'' in Bekalta during 2010, mean temperature values were about 17.47°C on February 17th 2010 and reached 21.44°C on March 10th 2010. This parameter increased considerably reaching 26.53°C on May 05th 2010 (Figure 4). Relative humidity in this biotope was between 60 to 65% during February and March. It decreased since April to lower values ranging from 37 to 40% (Figure 4). Concerning, photoperiod, this parameter increased steadily during the study period with 276 and303 hours/month respectively on May and June during 2009 and 2010 (Table 1).

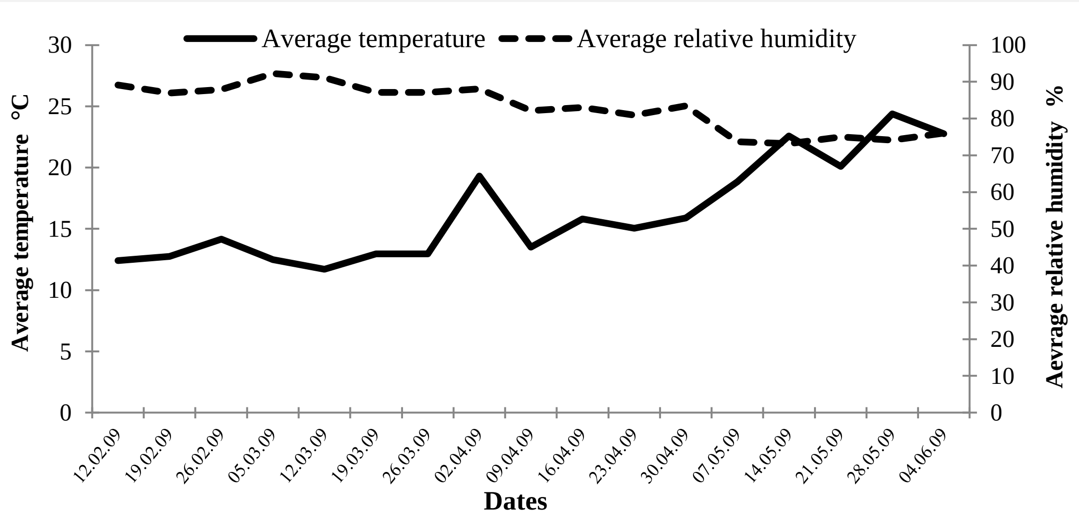

Figure 3. Mean temperature and relative humidity in the pepper crop greenhouse ''G1'' in the region of Moknine (Monastir, Tunisia) in 2009.

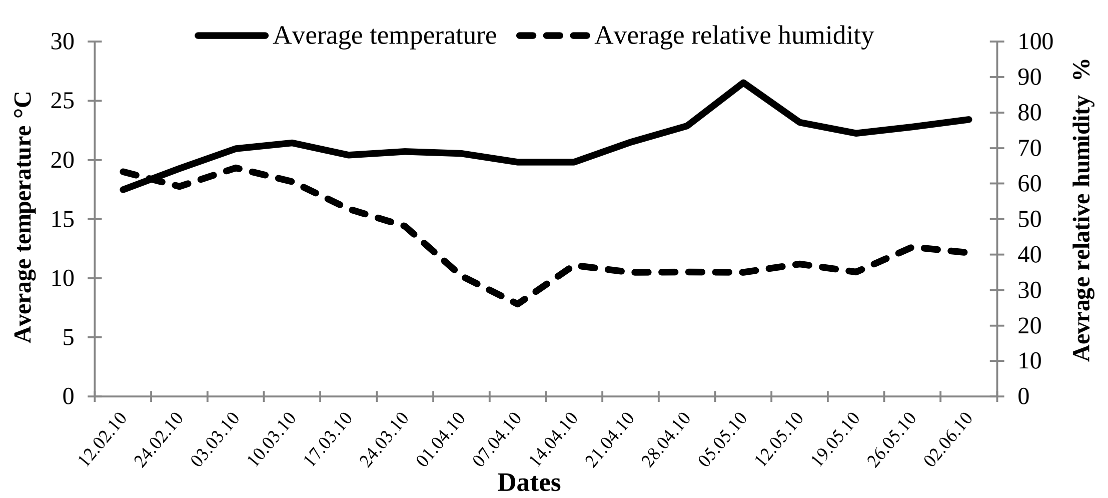

Figure 4. Mean temperature and relative humidity in the pepper crop greenhouse ''G2'' in the region of Bekalta (Monastir, Tunisia) in 2010.

Table 1. Temporal evolution of the Photoperiod (in hours) during the different months of both study periods during 2009 and 2010 in the governorate of Monastir (NIMT* 2010).

Months	**February**	**March**	**April**	**May**	**June**
Photoperiod					
(Hours/month)	179	208228	276	303	

*NIMT,National Institute of Meteorology of Tunisia.

3.2. Host plant height measurement

Measurements of different pepper plant strata in both greenhouses are shown in Table 2.

Table 2. Height of the different strata of pepper plants in greenhouses ''G1'' and ''G2'' (cm) (Means with the same letter within the same column are not significantly different, Duncan test at $p \leq 0.05$).

		Greenhouses	
		''G1'' (cm)	**''G2'' (cm)**
	Upper stratum	85,333 ± 29,360 a	89,616 ± 32,602 a
Strata	**Medium stratum**	51,383 ± 18,569 b	53,525 ± 20,204 b
	Lower stratum	17,433 ± 7,827 c	17,433 ± 7,827 c

3.3. Vertical distribution of *F. occidentalis* in pepper crop

The monitoring of F. occidentalis in the different strata of pepper plants in two greenhouses ''G1'' in 2009 and ''G2'' in 2010 showed the prevalence of the pest populations in the upper stratum throughout the period of the study except in March 12th 2009 in the greenhouse "G1" where the density of thrips per flower in the medium stratum exceeded that of upper stratum (Figures. 5 and 8). Conversely, the difference between the upper layer and the other two strata was low in the cold season. This difference increased with the rising of the temperature. This phenomenon was observed from the period of mid-March 2009 in the greenhouse ''G1'' and the end of March 2010 in the greenhouse ''G2''.

The pattern of the adult population followed the same pattern of that of the total population of the WFT (Figures. 6 and 9). As for larvae, despite that their populations were similar in the three considered strata in both studied habitats; the upper stratum presented the highest larval densities (Figures. 7 and 10). In the same context, the correlation between the numbers of different developmental stages of F occidentalis with plants height showed that the highest thrips densities were observed 80 cm above the

soil level corresponding to the upper stratum of plants (Figures. 11,12 and 13). The results showed also that the highest cumulative densities of the total population of thrips is significantly concentrated in the upper stratum of the pepper plants (Table 3 and 4) representing 44 % in the greenhouse ‘’G1’’ and 42.33 % in the greenhouse ‘’G2’’. Both males and females were also concentrated in the upper stratum whereas; larvae did not show significant differences among different strata even though the upper stratum showed highest occupation percentage.
Statistical analysis showed significant differences between the upper layer and the middle and the lower ones in the greenhouse ‘’G 1’’ but not in the greenhouse ‘’G 2’’. Regarding the males, the top stratum of the pepper plant presented a significant difference with the other two in both studied greenhouses.

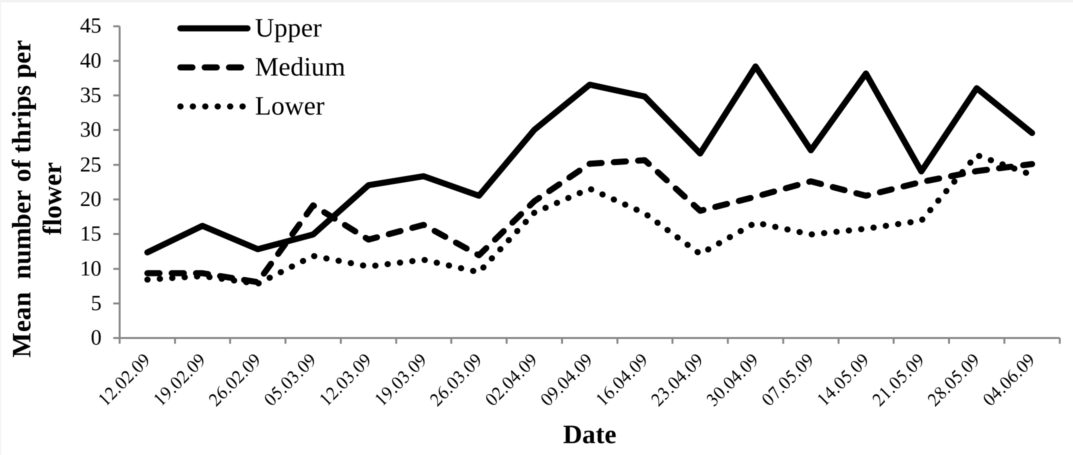

Figure 5. Pattern of the average number of thrips in the different strata of pepper plants in the greenhouse ‘’G1’’ in Moknine in 2009.

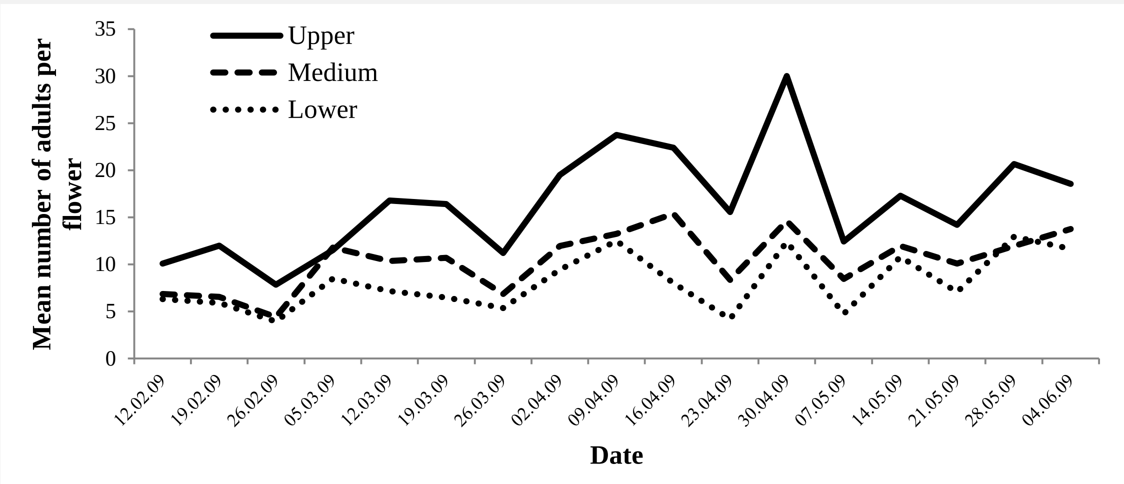

Figure 6. Pattern of the average number of adults of *F. occidentalis* in the different strata of pepper plants in the greenhouse ‘’G1’’ in Moknine in 2009.

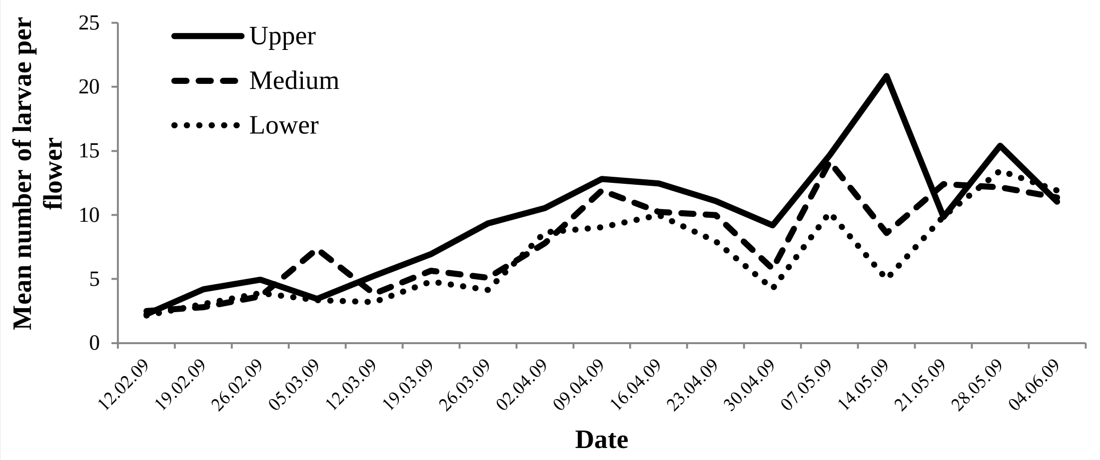

Figure 7. Pattern of the average number of *F. occidentalis* larvae in the different strata of pepper plants in the greenhouse ''G1'' in Moknine in 2009.

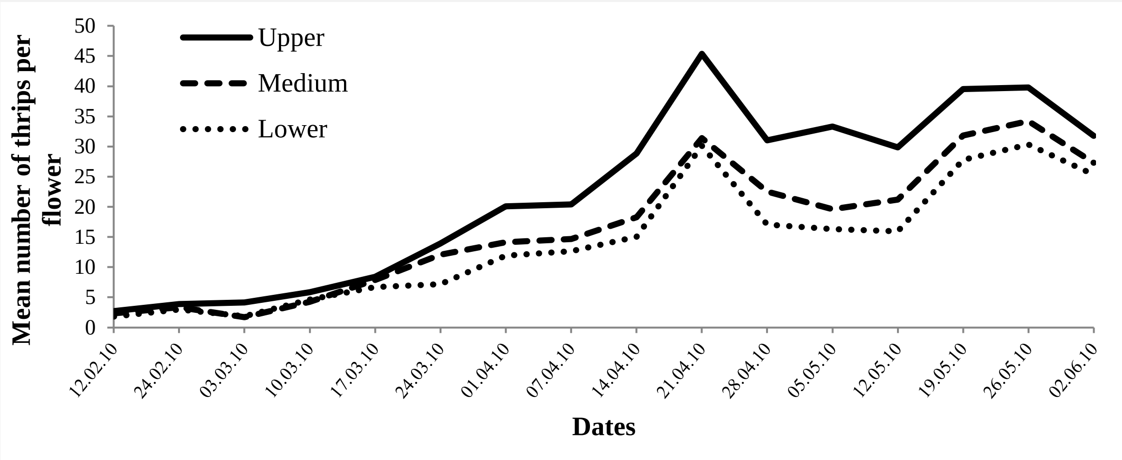

Figure 8. Pattern of the average number of thrips in the different strata of pepper plants in the greenhouse ''G2'' in Bekalta in 2010.

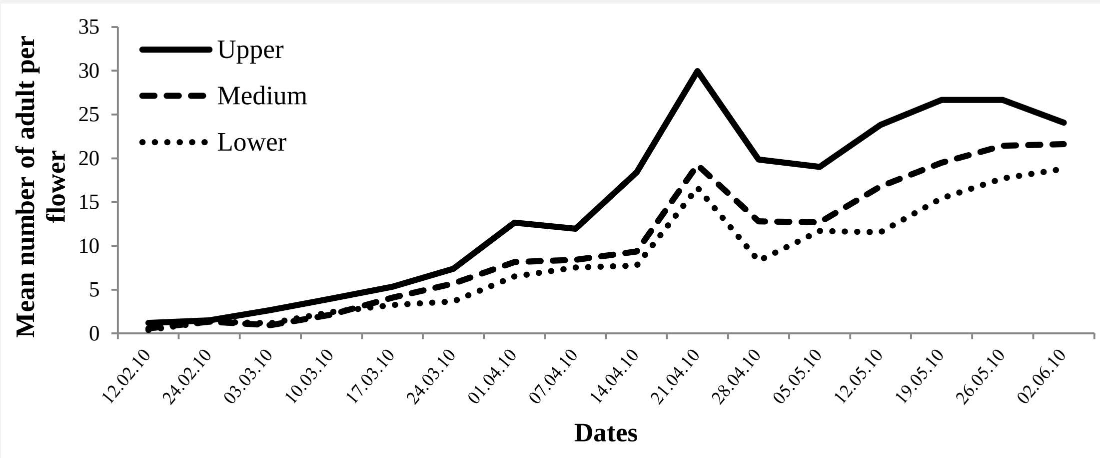

Figure 9. Pattern of the average number of adults of *F. occidentalis* in the different strata of pepper plants in the greenhouse ''G2'' in Bekalta in 2010

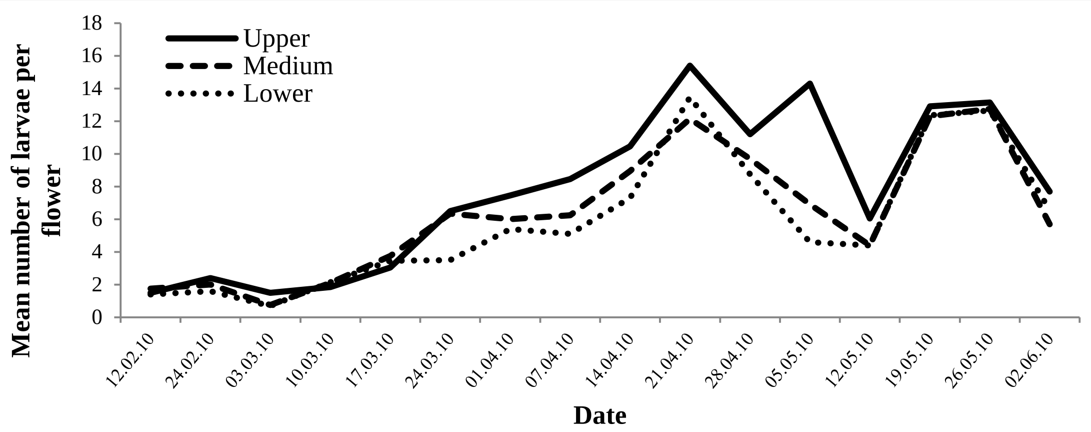

Figure 10. Pattern of the average number of larvae of *F. occidentalis* in the different strata of pepper plants in the greenhouse ''G2'' in Bekalta in 2010

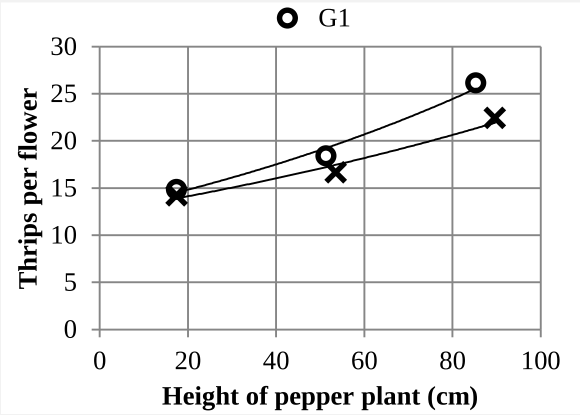

Figure 11. Relationship between the number of thrips per flower and the height of the stratum.

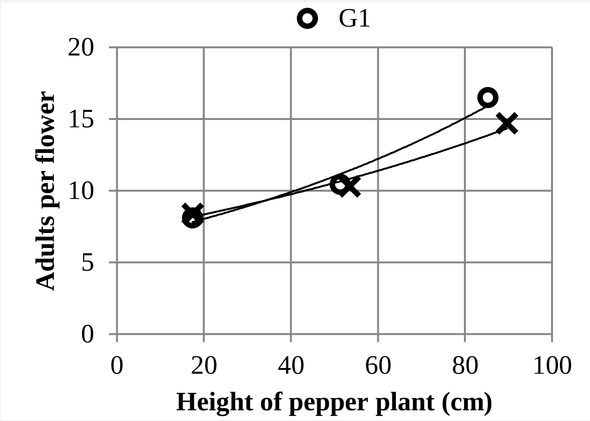

Figure 12. Relationship between the number of adults of *F. occidentalis* and the height of the stratum.

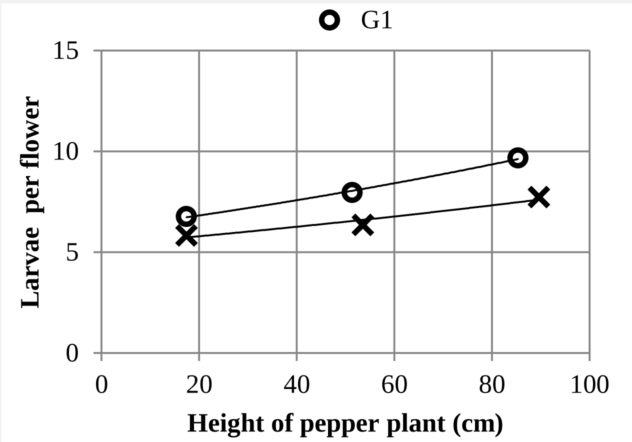

Figure 13. Relationship between the number of larvae of *F. occidentalis* and the height of the stratum.

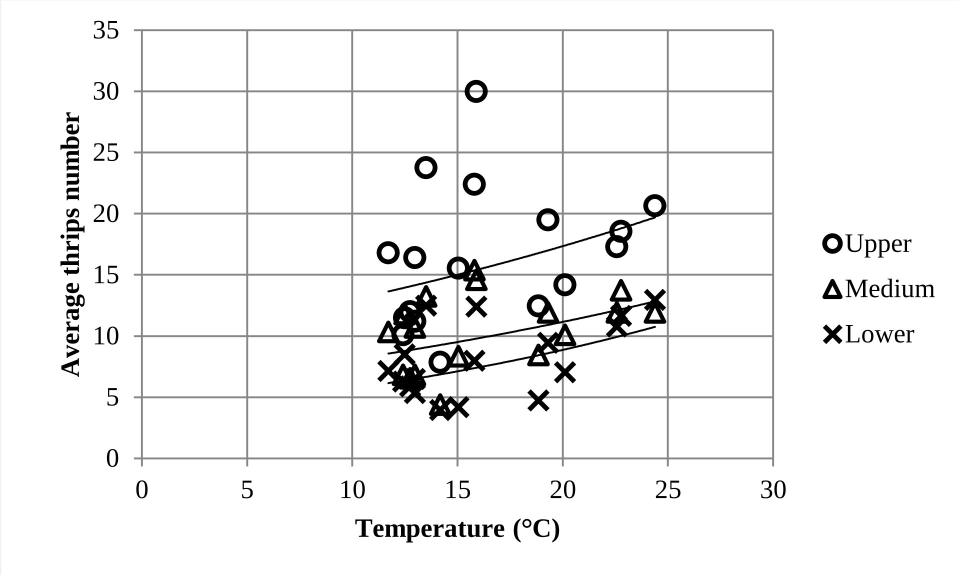

Figure 14. Relationship between temperature and average thrips number in each stratum in the greenhouse ''G1'' in the region of Moknine in 2009.

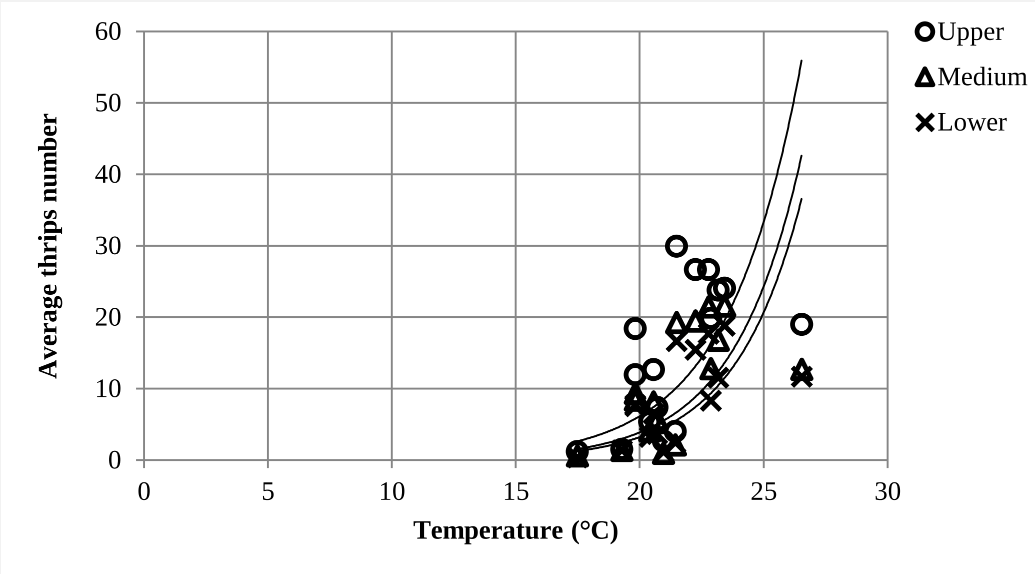

Figure 15. Relationship between temperature and average thrips number in each stratum in the greenhouse ''G2'' in the region of Bekalta in 2010.

Table 3. Accumulated number of different thrips instars and their percentage of occupation of the different strata of pepper plants in the greenhouse ''G 1'' in Moknine in 2009. (Means with the same letter within the same line are not significantly different, Duncan test at $p \leq 0.05$, df = 2, F = 2.529).

	Upper	Medium	Lower	% Upper	% Medium	% Lower
Females	15,173 ± 5,465 a	9,702 ± 3,069 b	7,573 ± 2,995 b	46,739 ± 4,604 a	30,039 ± 3,304 b	32,450 ± 10,796 b
Males	1,308 ± 0,355 a	0,723 ± 0,228 b	0,508 ± 0,125 c	51,479 ± 5,009 a	28,341 ± 4,613 b	20,179 ± 4,944 c
Adults	16,482 ±5,660 a	10,426 ± 3,116 b	8,082 ± 3,032 b	47,052 ± 0,303 a	29,957 ± 3,021 b	22,990 ± 3,807 c
L1 larvae	5,452 ±3,613 a	4,264 ± 2,455 ab	3,444 ± 2,177 b	40,494 ± 10,631 a	32,640 ± 6,941 ab	26,864 ± 7,903 b
L2 larvae	3,805 ± 2,214 a	3,322 ± 1,915 a	3,139 ± 1,726 a	36,790 ± 5,169 a	31,252 ± 7,795 ab	32,444 ± 2,456 b
Total larvae	9,664 ± 4,861 a	7,958 ± 3,732 a	6,761 ± 3,546 a	39,461 ± 8,154 a	32,883 ± 6,108 ab	27,654 ± 4,998 b
Total thrips	26,147 ± 8,937 a	18,385 ± 5,891 b	14,844 ± 5,509 b	44,009 ± 4,923 a	31,032 ± 3,793 b	24,958 ± 3,026 c
Sex-ratio	0,093 ± 0,027 a	0,108 ± 0,057 a	0,087 ± 0,047 a	-	-	-

Table 4. Accumulated number of different thrips instars and their percentage of occupation of the different strata of pepper plants in the greenhouse ''G2'' in Bekalta in 2010. (Means with the same letter within the same line are not significantly different, Duncan test at $p \leq 0.05$, df=2, F=18.812).

	Upper	Medium	Lower	% Upper	% Medium	% Lower
Females	13,640 ± 9,354 a	9,784 ± 7,157 ab	7,940 ± 4,956 b	43,992 ± 4,654 a	30,863 ± 2,653 b	25,143 ± 3,958 c
Males	1,184 ± 0,639 a	0,637 ± 0,387 b	0,484 ± 0,313 b	52,071 ± 11,731 a	26,719 ± 8,680 b	21,208 ± 8,253 b
Adults	14,690 ± 10,052 a	10,303 ± 7,606 ab	8,387 ± 5,265 b	45,269 ± 5,498 a	29,797 ± 3,658 b	24,932 ± 3,578 c
L1 larvae	3,9715 ± 2,717 a	3,284 ± 2,105 a	2,950 ± 2,126 a	37,379 ± 7,031 a	33,023 ± 5,012 a	29,596 ± 8,265 a
L2 larvae	3,771 ± 2,368 a	3,156 ± 1,906 a	2,931 ± 2,036 a	37,515 ± 6,775 a	33,073 ± 5,698 ab	29,410 ± 5,796 b
Total larvae	7,740 ± 4,796 a	6,362 ± 3,906 a	5,834 ± 4,091 a	38,927 ± 6,752 a	32,267 ± 3,694 b	28,804 ± 4,830 b
Total thrips	22,431 ± 14,414 a	16,665 ± 10,962 a	14,221 ± 9,926 a	42,336 ± 4,498 a	31,122 ± 3,238 b	26,540 ± 2,803 c
Sex-ratio	0,130 ± 0,115 a	0,078 ± 0,050 b	0,071 ± 0,042 b	-	-	-

The obtained results are consistent with those of Seal and Stansly (2000) who reported that in the case of *Scirtothrips dorsalis* Hood (1919) on pepper, the most infested leaves are those located in the upper part of the plants, followed by those of the medium stratum followed by the lower ones. Similarly, Atakan and Bayram (2011) indicate that in the case of *F. occidentalis* on cotton, the highest population was recorded on sticky traps placed near the upper part of the host plant. This indicates that the upper stratum is a representative sampling part in order to better quantify the density of the populations of the WFT. Sticky traps should be consequently placed at this level. In the same context, Lacasa (1990) indicated that the WFT often colonizes the upper parts of the plant where it remains until the end of the crop cycle, which generally coincides with the increase of temperature. Similarly, Brødsgaard (1989) reported that the density of *F. occidentalis* is positively correlated to the height of the traps installed above the host plant. Although adult thrips can fly, they are not good flyers. Several species use their wings to be transported with the wind (Bournier 1983; Kaas 2005). However, Lewis (1973)reported that many thrips species are able to fly for several hours. Furthermore, thrips flight is influenced by temperature and the photoperiod. This explains the fact that, during the cold period, the differences detected between thrips numbers found in the three strata are more or less similar despite the dominance of the upper layer. In this study, the increase of the temperature and the photoperiod starting from March in 2009 and 2010 resulted in increased differences between the upper and the other two strata. In the case of *Thrips palmi* Karny (1925), Seal and Stansly (2000) demonstrated that the infestation starts in the lower leaves, before migrating to the medium and upper parts of the plants during the warm season. This is consistent with the results found in the case of the WFT where the difference between the top layer and the rest of the plant started to become more important with the rise of the temperature and the photoperiod enhancing the flight activity and therefore the infestation.

Bournier (1983) noted that the majority of thrips species, including *F. occidentalis*, perform a swarm migration when temperature is suitable, resulting in the contamination of other parts of the host plant or even neighboring cultures. He also noted that migration usually starts at temperatures around 20 °C

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which is consistent with the results of this study where the difference between the upper layer and the other two started to become more important by mid-March in Bekalta and the end of March in Moknine, periods where average temperatures were around 20°C (Figures. 14 and 15). In the same context, Elimem and Chermiti (2014) mentioned the preference of *F. occidentalis* towards of some pepper variety. This preference is accentuated with the increase of the temperature, generally ranging from 20 to 22 °C. Indeed, the temperature enhances the development and biotic potential of this pest (Brødsgaard 1989; Loomans and Van Lenteren 1995) and promotes its flight (Bournier 1983) and consequently its migration. On the other hand, the phenology of the host plant may also play an important role in the spatial distribution of *F. occidentalis*. According to Bournier (1983) and Fraval (2006) the wide range of phytophagous thrips species feed on the cell contents of the tender parts of host plants such as young leaves and bloomed flowers usually located in the upper part of the host plant, which also explains the high density of *F. occidentalis* at this level of the plant.
In this study, some differences in the distribution of both sexes of *F. occidentalis* were observed among strata translated into a predominance of females in the three levels of pepper plants, which is consistent with the results found by Elimem and Chermiti (2009) and Higgins and Myers (1992) where populations of WFT were female biased. In this context, Mateus *et al.* (2003) reported a higher number of males than females on *Dianthus* spp. and strawberry crops flying on top of the host plants. In addition, Gillespie and Vernon (1990) indicate that on cucumber the sex-ratio of *F. occidentalis* depends on the height of traps. Terry and Schneider (1993) found that males of *F. occidentalis* can mate several times over a period of 1 to 2 hours while females have periods of several days during which they reject males attempting to mate. This creates a competition between males seeking receptive females which induce a strong flight activity. This could explain the higher effective of males in the upper parts of the host plants. Furthermore, Bryan and Smith (1956) noted that females of this species are relatively inactive shortly before oviposition. Higgins and Myers (1992) and Terry and Kelly (1993) confirmed that on other crops, males proportion is higher on traps than on different sampled parts of the host plant.

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