Distribution of Western Flower Thrips Trapped on a Yellow Cylinder

Journal of Insect Behavior

Ben-Yakir, David; Van tol, Robert; Bovio, Marcella; Ribak, Gal

https://doi.org/10.1007/s10905-023-09838-3

J Insect Behav
https://doi.org/10.1007/s10905-023-09838-3

RESEARCH

Distribution of Western Flower Thrips Trapped on a Yellow Cylinder

David Ben-Yakir · Robert W. H. M. van Tol · Marcella Bovio · Gal Ribak

Received: 30 January 2023 / Revised: 16 July 2023 / Accepted: 28 July 2023

Abstract The Western flower thrips (WFT), *Frankliniella occidentalis*, is an important pest of many crops worldwide and a vector of viral pathogens. Studying the orientation and approach of flying WFT toward attractive targets can enhance the efficacy of monitoring this pest. Monitoring WFT in open fields using attractive colored traps mounted on a wind vane indicated that most trapped thrips were on the leeward of the traps. In this study, we determined the distribution of trapped WFT on cylindrical yellow traps under controlled conditions in a wind tunnel (24 ± 1 °C, 70 ± 4% RH, airflow speeds 0.19 m sec^{-1}). In each replicate, we released 150–250 WFT females, either upwind or downwind of the cylindrical yellow sticky trap. Each replicate lasted six hours. Overall, 79%±14 of the released WFT females flew actively and 59%±15 of those that flew were trapped. The vast majority of the thrips were trapped on leeward of the cylindrical yellow traps. Of the WFT females released downwind of the trap, 93%±3 ($N=6$) were trapped on the leeward, while of those released upwind of the trap, 81%±8 ($N=7$) were trapped on the leeward. A behavioral-biomechanical model simulating WFT flight towards the attractive yellow cylinders predicted that, as long as airflow speed is below the WFT flight speed, 71–84% of the WFT will be trapped on the leeward. The results of this study agree with the trapping distributions of WFT recorded in field studies. The results also suggest that, when airflow speed is below the WFT flight speed, most WFT approach visually attractive traps by actively flying upwind.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10905-023-09838-3.

D. Ben-Yakir (✉)
Institute of Plant Protection, ARO, The Volcani Center, P. O. Box 15159, 68 HaMakkabbim Road, 7505101 Rishon LeZion, Israel
e-mail: benyak@volcani.agri.gov.il

R. W. H. M. van Tol
Biointeractions and Plant Health, Wageningen University & Research, Droevendaalsesteeg 1, 6708 Wageningen, The Netherlands

Present Address:
R. W. H. M. van Tol
BugResearch Consultancy, Herendaal 1, 6228 GV Maastricht, The Netherlands

M. Bovio
Plant Breeding, Wageningen University & Research, PB 386, Droevendaalsesteeg 1, 6700 Wageningen, The Netherlands

G. Ribak
Faculty of Life Sciences, School of Zoology and Sagol School of Neuroscience, Tel Aviv University, 6997801 Tel Aviv, Israel

Published online: 08 August 2023

Keywords Western flower thrips · Wind tunnel · Airflow direction · Cylindrical sticky trap · Thrips flight

Introduction

The western flower thrips (WFT), *Frankliniella occidentalis*, is an important pest, and a vector of viral pathogens, of many crops worldwide (He et al. 2020). Therefore, the development of monitoring tools for this pest is of great importance for its management (Mouden et al. 2017; Reitz et al. 2020). Adult thrips fly at a low speed (Lewis 1997) but they can actively reach attractive targets, if the airflow speed is below 0.22 m sec^{-1} (Teulon et al. 1999; Davidson et al. 2012). Attractive colored sticky traps (yellow or blue) are commonly used for monitoring WFT (for e.g., Natwick et al. 2007). Little is known about the effects of wind direction and speed on the trapping of thrips using those traps. When we monitored thrips (*Thrips tabaci* and WFT) in open fields, using blue pole traps and blue sticky cards mounted on wind vanes, most thrips were trapped on the leeward (Ben-Yakir and Chen 2008). When we monitored WFT in alfalfa fields at low wind speed (<0.27 m sec^{-1}) using blue pole traps mounted on wind vanes, on average, 77% of trapped WFT were on the leeward of the traps (Ben-Yakir and Carvalho 2021). Studying the orientation and approach of flying WFT toward attractive cylindrical targets under controlled conditions may explain the behavioral basis of the observed distribution of thrips on pole traps in the field.

In this study, we determined the distribution of trapped WFT on cylindrical yellow traps under controlled conditions in a wind tunnel. We also developed a simulation model of WFT flight toward the cylindrical yellow trap to predict and explain the experimental distribution of the trapped WFT.

Materials and Methods

Wind Tunnel Study

This study was done during the summer of 2017 and the spring of 2022 in a wind tunnel designed for studying thrips flight toward attractive olfactory and visual cues (Smits et al. 2000). The wind tunnel is located at Wageningen Plant Research, Biointeractions and Plant Health, in the Netherlands. The design of the wind tunnel and the experimental setup are presented in Fig. 1. The walls of the wind tunnel are made of a clear glass. The experimental chamber was limited to the middle section of the tunnel (L = 100 cm; W = 120 cm; H = 80 cm; Fig. 1). The experimental chamber was illuminated from above using various LED lights that simulated the wavelength spectra of the natural sunlight without the UV portion (see S1 for details). During the experiments, the tunnel was maintained at 24 ± 1 °C, 70 ± 4% RH, and the airflow speed was 0.19 m sec^{-1}.

An upside down paper cup, covered with yellow Munix 2" cloth tape (the tape color has values of red, green and blue [RGB] of 210, 170, 0, respectively; https://en.wikipedia.org/wiki/RGB_color_model), served as the trap (Fig. 2 and Photo S2). The sides of

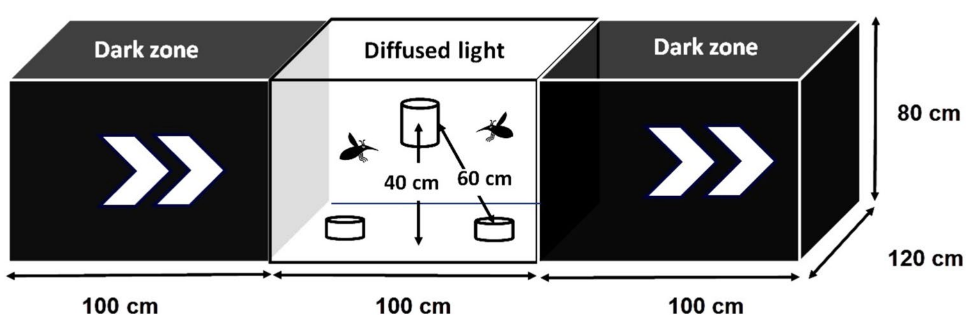

Fig. 1 The chamber used for the wind tunnel experiment. The cylinder in the middle of the chamber represents the yellow trap (see Fig. 2 for details). The two cylinders near the chamber's floor represent the release cups. On every replicate, thrips were released from one cup, located either upwind or downwind from the yellow trap The arrows indicate the direction of the airflow

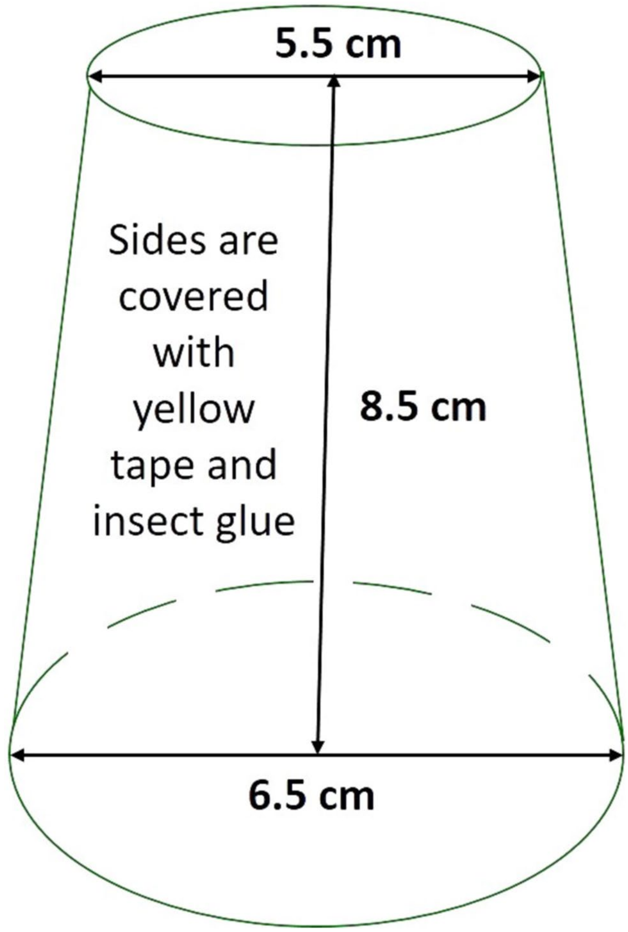

Fig. 2 The sticky yellow cup used for studying the trapping dynamic and the on-trap distribution of WFT in the wind tunnel

the yellow cup were covered with a layer of Stikem insect glue (Seabright Laboratories, USA) forming a trapping area of 140 cm^2. The trap was set in the middle of the assay chamber, 40 cm above the floor (Fig. 1). Preliminary experiments indicated that when the distance between the thrips' release point and the trap ranged from 35 to 60 cm, there were no significant differences in the thrips' trapping rates and their distribution on the trap. Similarly, there were no significant differences in the thrips' trapping rates and distribution if the thrips' release point was at same height of the trap, or 25 cm below the trap. Thus, thrips were released from 15 cm above the floor and 60 cm away from the trap. The thrips' release positions, downwind or upwind of the trap, were the two treatments (Fig. 1).

We used WFT females from a laboratory culture, maintained at 25 °C and 60–70% relative humidity (RH) with 16:8 light:dark periods, that was reared on potted flowering chrysanthemum (*Chrysanthemum morifolium* (syn. *Dendranthema grandiflora*). WFT females, of unspecified age and mating status, were collected with an aspirator shortly before the start of each replicate. We collected 150–250 WFT females for each replicate. The collected WFT were briefly anaesthetized with CO_2 and transferred to a release cup made of clear Plexiglas (d = 8 cm, h = 6 cm). After the transfer, the mouth of the release cup was covered with Parafilm M (Bemis, PM-996, USA). Then, the release cup was placed in the wind tunnel for one hour to acclimate the thrips. At the onset of the replicate, the release cup was uncovered and the thrips were free to fly away. Each replicate lasted six hours. Thus, during each replicate WFT were starved for up to 7 h (1 h acclimation plus 6 h per replicate). At the end of each replicate, the number of WFT trapped and their distribution on the trap (Fig. 3) were determined by examination under magnification.

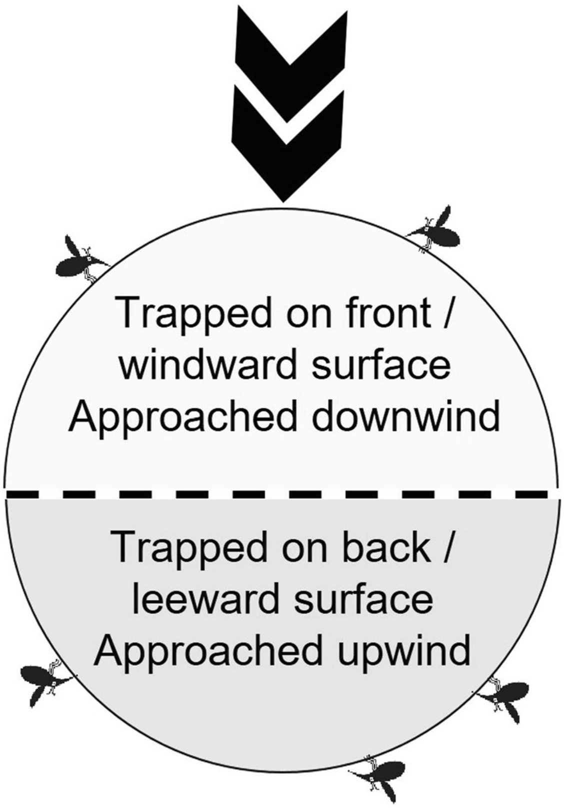

Fig. 3 The categories used for the location of WFT trapped on the cylindrical cup. The arrows indicate the direction of the airflow

WFT Flight Model

Using MATLAB software, we developed a simple model that simulated WFT flight to the yellow cup under similar conditions to those in our wind tunnel experiment. For this model, we had to determine the distance that WFT can visually resolve the attractive colored cup and start flying toward it (Land 1997). For insects with compound eyes, a mosaic of small images, each made by a single ommatidium, forms the view. Therefore, the number of ommatidia in the eye also determines its image resolving power. The number of the ommatidia in an eye determines the angle between them. Thus, the interommatidial (IO) angle can be used to estimate visual acuity of an insect (Land 1997). Using photos of thrips' eyes from the web site https://fineartamerica.com/featured/3-western-flower-thrips-adult-dennis-kunkel-microscopyscience-photo-library.html (S3) and information from Lewis (1997) we estimated that the IO angle of WFT is between 10° to 14°. The distance of resolution (D) for a visually contrasting object with a size R by an insect with an IO angle α can be calculated from the formula $D = (R/2) / \tan(\alpha/2)$ (Land 1997). In our model, R was 6 cm (the mean width of the yellow cup trap, Fig. 2), WFT IO angle α was either 10° or 14° and the calculated distance of resolution (D) was either 34.3 cm or 24.4 cm, respectively.

We also had to determine at what speed WFT fly toward the trap. Thrips flight speeds are estimated to range between 0.10 and 0.50 m sec^{-1} (Lewis 1997). In previous wind tunnel studies, WFT could not reach attractive targets at airflow speed of 0.22 m sec^{-1} (Teulon et al. 1999; Davidson et al. 2006, 2012). Our preliminary experiments in the wind tunnel indicated that at airflow speed of 0.09 and 0.19 m sec^{-1} about 50% of the released WFT females reached the traps. However, at airflow speed of 0.27 m sec^{-1} only 17% of them reached the trap. Thus, for this model, we assumed that the average WFT flying speed is 0.25 m sec^{-1}.

At each run of the model, 120 WFT were "released" every 3° on the perimeter of a horizontal circle with a radius of 34.3 cm (D). The simulated WFT are programmed to fly directly towards the center of the trap and change their flight direction in response to the displacement from their intended track by the airflow (termed drift). The instantaneous location of the "released" WFT flying toward the trap was determined every 0.5 msec. Each run of the model lasted six seconds, equal to the flight time needed for WFT "released" downwind to reach the trap, at an airflow speed 0.19 m sec^{-1}. Overall, the model was run six times at each of three airflow speeds and two estimated values of the WFT IO angle. At the end of each run, the number of WFT that reached the trap and the rate of WFT trapped on the leeward were determined.

Data Analysis

The categories used to determine the location of the WFT trapped on the cylindrical trap are illustrated diagrammatically in Fig. 3. We assumed that thrips trapped on the leeward approached the traps by flying upwind.

This experiment was done under controlled conditions and the thrips' release position, downwind or upwind of the trap, was the only variable analyzed. There were 7 replicates of upwind release and 6 replicates of downwind release (Table 1). Because the number of trapped thrips varied on each replicate, we expressed the thrips' distribution (windward vs. leeward) as a percent of the total number of the trapped thrips on the cup.

To analyze the effect of the thrips' release position on the thrips' distribution on the cup, we first transformed the percentages using arcsine to "stretch out" the close data points. Then, we used t-test (Excel Analysis ToolPak, Office 2016) to determine the significance of the release position on the distribution of the trapped thrips on the cup.

Results

Wind Tunnel Study

Most WFT were trapped 4 to 5 h after their release, with only a few trapped during the first 3 h after release. Overall, during this experiment 79%±14 of the WFT females flew away from the release cup and 59%±15 of those that flew away reached the traps.

Of the WFT females released downwind of the trap, 93%±3 ($N=6$) were trapped on the leeward of the yellow cup (Table 1). Of those released upwind of the trap, 81%±8 ($N=7$) were trapped on the leeward of the yellow cup (Table 1). The difference in the rates of WFT trapped on the leeward between thrips released downwind and upwind from the trap, was statistically significant (t-test, DF = 11, $P=0.005$) (Table 1).

WFT Flight Model

The model predicts that as long as WFT flight speed is faster than the airflow speed, 100% the "released" WFT will reach the trap and 71–84% of them will be trapped on the leeward (Table 2**).** The airflow drift of the flying thrips (Fig. 4) can explain the bias of the WFT toward the leeward of the cylindrical trap. At an airflow speed of 0.27 m sec^{-1}, which is faster than WFT flight speed, the model predicts that only about 19% of the thrips will reach the trap and of them only 24–29% will be trapped on the leeward (Table 2).

At all airflow speeds, the magnitude of the selected interommatidial angle (10° or 14°) had only minor effects on the numbers of WFT that are expected

Table 1. The effects of airflow direction at a speed 0.19 m sec^{-1}, and the location of WFT release, on the rates of WFT trapped on the leeward of a sticky yellow cup in a wind tunnel

Released	downwind		Released	upwind	
Experimental Date	No. WFT trapped [a]	% trapped on leeward [b]	Experimental Date	No. WFT trapped [a]	% trapped on leeward [b]
Mar-31-2022	67	88	Mar-25-2022	70	67
Sep-7-2017	77	92	Mar-28-2022	109	76
Mar-23-2022	68	92	Mar-24-2022	92	79
Mar-30-2022	116	95	Mar-29-2022	67	82
Jun-29-2017	73	96	Jun-14-2017	84	87
Apr-4-2022	143	98	Sep-6-2017	108	89
---	---	---	Apr-5-2022	87	90
Mean ± SD	N=6	93 ± 4 *	Mean ± SD	N=7	81 ± 8 **

[a] Out of 150–250 WFT females released

[b] Out of the WFT trapped

[*] Numbers followed by a different number of asterisks are significantly different (T-test, DF = 11, $P=0.005$)

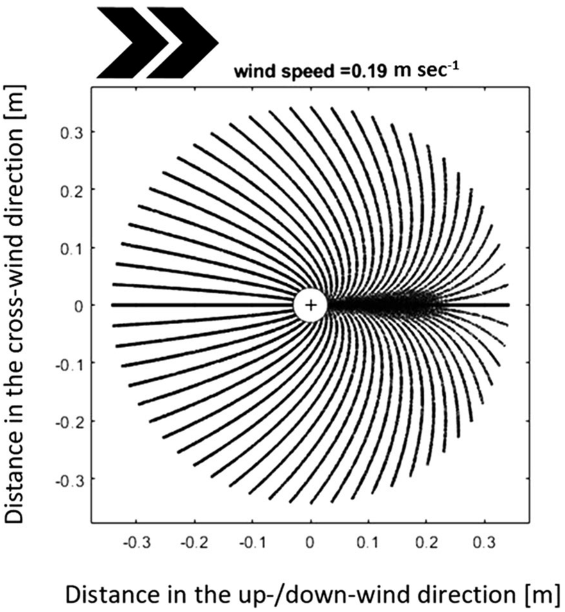

Fig. 4 Simulated 2D of the flight arena and flying paths of WFT toward the yellow cup in the wind tunnel. Each line represents the path of a single WFT flight from its release point to its landing on the yellow cup. Although 120 WFT were "released", only the paths of 60 thrips (every other one) are presented. WFT were assumed to fly at a speed of 0.25 m sec^{-1} toward the center ('+') of the cylindrical trap (circle). The axes indicate the distance and location (+ or -) in the arena relative to the center of the cylindrical trap. The airflow direction is from left to right (arrows) at a speed of 0.19 m sec^{-1}. The model parameters and predictions are presented in Table 2

to reach the trap and the rates of WFT that will be trapped on the leeward (Table 2).

Discussion

Thrips are weak flyers but they are able to fly upwind toward attractive targets in wind tunnels (e.g. Davidson et al. 2012). Evidence also suggests that thrips can reach attractive traps in open fields and migrate to new field crops by flying upwind (Irwin and Yeargan 1980; Hoddle et al. 2002; Nyasani et al. 2017; Pereira et al. 2020).

In previous wind tunnel studies, WFT could not reach the traps when airflow speed was 0.22 m sec^{-1} (Teulon et al. 1999; Davidson et al. 2006, 2012). However, in this study, some WFT females (17%) reached the trap even at airflow speed of 0.27 m sec^{-1}. Thus, it appears that different WFT populations can have different range of flight speeds.

In previous wind tunnel experiments, starved WFT were more responsive to attractive targets (Davidson et al. 2006). In this study, we also noted that starvation, at least up to seven hrs, increased the responsiveness of WFT to the yellow trap.

The results of this controlled wind tunnel study corroborate field observations on the distributions of trapped thrips during periods of low wind speed (Ben-Yakir and Chen 2008; Ben-Yakir and Carvalho 2021). Further, the model output helps to explain our experimental results and predicts that at

Table 2 Simulated effects of airflow speed and Interommatidial angle on the number of WFT "trapped", and the rate "trapped" on the leeward surface of an attractive colored cylindrical trap

Model input			Model output			
Airflow speed (m sec^{-1})	Trap diameter (cm)	WFT flight speed (m sec^{-1})	IO[a] angle 10° No. WFT trapped [b]	IO[a] angle 10° % trapped on leeward [c]	IO[a] angle 14° No. WFT trapped [b]	IO[a] angle 14° % trapped on leeward [c]
0.09			120	72	120	71
0.19	**6.0**	**0.25**	**120**	**84**	**120**	**81**
0.27			21	29	25	25

Data in bold font correspond to the simulation graph in Fig. 4

[a] IO = Interommatidial

[b] Out of 120 WFT "released"

[c] Out of the WFT trapped

airspeed of 0.19 m sec^{-1} 81–84% of the WFT will be trapped on the leeward of the trap (Table 2). The model thus provides a mechanistic explanation for the higher density of WFT in the leeward of traps, as recorded also in field monitoring with similar traps. When airflow speed was below the WFT flight speed, WFT movement was affected by their active flight toward the traps and their drift caused by the airflow across their line of flight. The combined effects of these forces may contribute to the higher rates of WFT that reach the leeward of traps by flying upwind. Other factors that may contribute to the higher rated if WFT trapped on the leeward are air vortices and a "windshield" effect on the downwind side of the cylinder. Flying upwind toward attractive visual targets was also reported for other small insects like aphids (Reynolds and Reynolds 2009), whiteflies (Byrne 1999; Isaacs et al. 1999) and parasitic wasps (Corbett and Rosenheim 1996).

In the model, we assumed that WFT flew directly towards the center of the trap. Under this assumption, the model predicts that at airflow speed 0.19 m sec^{-1} 100% of the WFT will reach the trap (Table 2). However, in preliminary studies, when we released the WFT at the higher visual distance of resolution (D = 34.3 cm), on the same plane as the trap, only about 50% of the released WTF reached the trap. This difference between the predicted and the observed results was partly because about 20% of the WFT remained in the release cup until the end of the replicates. Of the WFT that flew away from the release cup, only 62.5% reached the traps. Our flight behavior observations showed that most thrips did not fly directly from the release cup to the traps. The flying thrips appeared to hover up and down around the trap before landing on it. An Indirect flight path of WFT toward attractive optical targets has also been noted in other flight behavior studies conducted in this wind tunnel (Lopez-Reyes et al. 2023).

The distribution of trapped thrips on cylindrical colored traps may be used to distinguish between thrips that approached actively by flying upwind and those that reached the trap passively. The results of this study may help the design and operation of monitoring traps for thrips and other small weak flying insects.

Acknowledgements We like to thank Ms. Gerrie L. Wiegers, of the Biointeractions and Plant Health, Wageningen University & Research, for rearing the thrips used in the experiments done in 2017.

Author Contributions Authors 1 and 2 conducted the experiments.Author 1 analyzed the data.Author 4 developed the computer simulation model.Author 3 provided the thrips. Authors 1 and 4 wrote the manuscript.All authors read and approved the manuscript.

Funding This study was funded by the Nederland Ministry of Agriculture (Topsector Tuinbouw & Uitgangsma- terialen, program number KV 1605-075), Koppert Biological Systems, LTO Glastuinbouw Nederland (Stichting Programmafonds Glastuinbouw) and Lincoln University, Lincoln, New Zealand.

Data Availability The data that support the findings of this study are available in the 'Open Science Framework' under DOI: https://doi.org/10.17605/OSF.IO/EXT76 (Ben-Yakir et al. 2022).

Declarations

Competing Interests The authors declare no competing interests.

Conflict of Interest The authors declare that no competing interests exist.

References

Ben-Yakir D, Carvalho CJ (2021) Using wind vanes to study how thrips reach colored traps. Entomol Exp Appl 169:1061–1065. https://doi.org/10.1111/eea.13104

Ben-Yakir D, Chen M (2008) Studies of thrips migratory flights in Israel. Acta Phytopathol Entomol Hung 43:243–248

Ben-Yakir D, van Tol RWHM, Bovio M, Ribak G (2022) Data: Airflow direction affects the approach of western flower thrips to cylindrical colored traps. OSF June 22. https://doi.org/10.17605/OSF.IO/EXT76

Byrne DN (1999) Migration and dispersal by the sweet potato whitefly, *Bemisia tabaci*. Agric For Meteorol 97:309–316. https://doi.org/10.1016/s0168-1923(99)00074-x

Corbett A, Rosenheim JA (1996) Quantifying movement of a minute parasitoid,*Anagrus epos* (Hymenoptera: Mymaridae), using fluorescent dust marking and recapture. Biol Control 6:35–44. https://doi.org/10.1006/bcon.1996.0005

Davidson MM, Butler RC, Teulon DAJ (2006) Starvation period and age affect the response of female *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) to odor and visual cues. J Insect Physiol 52:729–736. https://doi.org/10.1016/j.jinsphys.2006.03.013

Davidson MM, Butler RC, Teulon DAJ (2012) Response of female *Frankliniella occidentalis* (Pergande) to visual cues and para-anisaldehyde in a flight chamber. J Insect Behav 25:297–307. https://doi.org/10.1007/s10905-011-9299-z

He Z, Guo JF, Reitz SR, Lei ZR et al (2020) A global invasion by the thrip, *Frankliniella occidentalis*: current virus vector status and its management. Insect Sci 27:626–645. https://doi.org/10.1111/1744-7917.12721

Hoddle MS, Robinson L, Morgan D (2002) Attraction of thrips (Thysanoptera: Thripidae and Aeolothripidae) to colored sticky cards in a California avocado orchard. Crop Protect 21:383–388. https://doi.org/10.1016/S0261-2194(01)00119-3

Irwin ME, Yeargan KV (1980) Sampling phytophagous thrips on soybean. In: Kogan M, Herzog DC (eds) Sampling methods in soybean entomology. Springer, New York, pp 283–304

Isaacs R, Willis MA, Byrne DN (1999) Modulation of whitefly take-off and flight orientation by wind speed and visual cues. Physiol Entomol 24:311–318

Land MF (1997) Visual acuity in insects. Annu Rev Entomol 42:147–177. https://doi.org/10.1146/annurev.ento.42.1.147

Lewis T (1997) Flight and dispersal. In: Lewis T (ed) Thrips as crop pests. CAB International, Wallingford, pp 175–196

Lopez-Reyes K, Lankheet MJ, van Tol RWHM et al (2023) Tracking the flight and landing behaviour of western flower thrips in response to single and two-colour cues. Sci Rep (accepted for publication). https://doi.org/10.1038/s41598-023-37400-w

Mouden S, Sarmiento KF, Klinkhamer PGL et al (2017) Integrated pest management in western flower thrips: past, present and future. Pest Manag Sci 73:813–822. https://doi.org/10.1002/ps.4531

Natwick ET, Byers JA, Chu CC et al (2007) Early detection and mass trapping of *Frankliniella occidentalls* and *Thrips tabaci* in vegetable crops. Southwest Entomol 32:229–238

Nyasani JO, Subramanian S, Orindi B et al (2017) Short range dispersal of western flower thrips in field-grown french beans in Kenya. Int J Trop Insect Sci 37:79–88. https://doi.org/10.1017/s1742758417000054

Pereira PS, Sarmento RA, Lima CHO et al (2020) Geostatistical assessment of *Frankliniella schultzei* (Thysanoptera: Thripidae) spatial distribution in commercial watermelon crops. J Econ Entomol 113:489–495. https://doi.org/10.1093/jee/toz253

Reitz SR, Gao Y, Kirk WDJ et al (2020) Invasion biology, ecology, and management of western flower thrips. Annu Rev Entomol 65:17–37

Reynolds AM, Reynolds DR (2009) Aphid aerial density profiles are consistent with turbulent advection amplifying flight behaviours: abandoning the epithet 'passive'. Proc Royal Soc B 276:137–143

Smits PH, Deventer Pv K, WJd (2000) Western flower thrips: reactions to odours and colours. Proc Exp Appl Entomol 11:175–180

Teulon DAJ, Hollister B, Butler RC et al (1999) Colour and odour responses of flying western flower thrips: wind tunnel and greenhouse experiments. Entomol Exp Appl 93:9–19. https://doi.org/10.1046/j.1570-7458.1999.00557.x