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Plant odours with potential for a push–pull strategy to control the onion thrips, *Thrips tabaci*

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Abstract

We compared the efficacy of four plant essential oils to repel onion thrips, *Thrips tabaci* (Lindeman) (Thysanoptera: Thripidae), in the presence of an attractive odour, ethyl *iso*-nicotinate in a pasture field. Four horizontal white sticky plates were placed adjacent to (directions: N, S, E, W) a central horizontal white plate (C). After 24 h, in the treatment combination where the four plates were sprayed with essential oil surrounding a central sticky plate sprayed with ethyl *iso*-nicotinate, fewer onion thrips were found on the plates treated with sweet marjoram [*Origanum majorana* L. (Labiatae)] or clove basil [*Ocimum gratissimum* L. (Labiatae)] (87 and 71% less, respectively) compared to the control treatment of four water-sprayed plates surrounding a central plate with ethyl *iso*-nicotinate. We also compared the distribution of onion thrips on the plates. Relative thrips numbers on each plate were compared with similar (N, S, E, W, and C) plates in the control treatment. There were relatively lower thrips numbers on the south (23% reduction) and west (26% reduction) *O. majorana*-treated plates and higher numbers (37% increase) on the central attractant-treated plate indicating a short-distance push–pull effect. When four plates were sprayed with the thrips attractant surrounding a central sticky plate sprayed with an essential oil or water (control), only *O. majorana* reduced the number of thrips on the attractant-sprayed plates (62% reduction). The distribution of thrips on the different plates within this treatment combination did not change substantially when compared to the distribution in the water-control treatment. Other essential oils tested (wormwood [*Artemisia arborescens* L. (Compositae)]) and tea tree [*Melaleuca alternifolia* (Maiden. & Betche.) Cheel. (Myrtaceae)]) were not effective in any of the treatments. It appears that *O. majorana* is a promising thrips repellent which could be used for further testing in a push–pull system with the attractant ethyl *iso*-nicotinate. The field setup used also proved to be a valuable tool for evaluating the potential of repellents to control onion thrips.

Introduction

While insects use plant odours to find suitable host plants, many plants have developed counter strategies to defend themselves against these insects. One direct defence is the production of deterring or toxic compounds, and the release of associated repellent volatiles. Volatile plant odours released are usually a complex mixture of general leaf volatiles, found in most plant species, and more specific components that are shared by several plant species. Orientation to these plant odours by insects involves the analysis of this complex mixture for host recognition (Visser, 1986). While many insects use a specific blend and ratio of volatiles to find their host plant (Städler, 1992), a negative selection by the insect for specific plant odours associated with unsuitable host plants within the complex of odours play a role in selection or avoidance of plant species as well (Dickens et al., 1992; Städler, 1992; Hayes et al., 1994; Poland et al., 1998). This avoidance is not always based on selection and learning of the insect species alone but can also involve an induced defence mechanism by plants after attack of the insect, which makes them unattractive for the insect (Franceschi et al., 2005), or to attract natural enemies (Dicke et al.,

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1990; Turlings et al., 1995; Takabayashi & Dicke, 1996; Sabelis et al., 1999; van Tol et al., 2001).

The use of unattractive plant odours to repel or deter pest insects from crops has resulted in several commercial pest-control products in recent years (Isman, 1999, 2000, 2006; van Tol et al., 2006). An important source of repellents are the essential oils extracted from aromatic plant species for use in food flavouring and the perfume industry (Coppen, 1995). These odours have been extensively tested for safety and toxicity and have shown no detrimental impact on beneficial insects, and are therefore considered to be an interesting potential new means of crop protection (Plimmer, 1993; Isman, 1999, 2006).

Although several essential oils are repellent to thrips species in the laboratory (Koschier et al., 2000, 2002; Kogel & Koschier, 2002; Koschier & Sedy, 2003), the efficacy in the field is usually low (WJ de Kogel & RWHM van Tol, unpubl.). Offering insects a choice between more attractive host-plant odours (pull) and host plants with repellents (push) may improve the effectiveness of the formulated repellents in the field. In a push–pull or stimulo–deterrent diversionary strategy (SDDS) (Pyke et al., 1987; Miller & Cowles, 1990), the harvestable crop is protected by host-masking agents, repellents, antifeedants, or oviposition deterrents. At the same time, aggregative semiochemicals, including host-plant attractants and sex pheromones, stimulate colonization of pests on trap crops or entry into traps where pathogens can be deployed (Pickett et al., 1997). An initial demonstration of the push–pull strategy in the field was achieved with the pea and bean weevil, *Sitona lineatus* L. (Smart et al., 1994). The 'pull' component was the aggregation pheromone of the weevil, and the 'push' component involved an antifeedant extract from the Indian neem tree, *Azadirachta indica* A. Juss.

In this paper we studied the interaction between an attractant for onion thrips, *Thrips tabaci* Lindeman (Thysanoptera: Thripidae), and several potential repellent plant essential oils to determine the possibilities for use in a push–pull strategy. In a pasture field in New Zealand, we conducted a trial in which we assessed the distribution of thrips over a horizontally placed white sticky plate sprayed with the onion thrips attractant ethyl *iso*-nicotinate (patent reference: Davidson et al., 2005), surrounded by plates sprayed with essential oils, as well as an essential oil-sprayed plate, surrounded by attractant-sprayed plates. By comparing total thrips catches and thrips caught per plate within each treatment relative to water treated plates (control), we were able to provide detailed data about push–pull effects compared to overall repellence of the different essential oil – attractant combinations tested. This enabled us to select specific attractant–repellent combinations potentially suitable in a push–pull strategy.

Materials and methods

Trap design

A round white plate (diameter 23 cm) glued with a brush-on formulation of Tangle Trap (20% petroleum distillate formulation; Tanglefoot company, Grand Rapids, MI, USA) was placed horizontally on the grass and surrounded by four identical sticky plates in contact with the central plate in the four cardinal directions (N, S, W, and E; see also Figures 2 and 3). Attractant, repellent, and water (1 ml) were applied by spraying each plate with a 25-ml perfume sprayer. The onion thrips attractant used was 98% pure ethyl *iso*-nicotinate (Aldrich) (patent reference: Davidson et al., 2005). As potential repellents, we tested pure plant essential oils of *Artemisia arborescens* (ATL International, London, Ontario, Canada; main components 33% α-thujone, 7% β-thujone, 20% camphor, and 15% 1,8-cineole), *Origanum majorana* (ATL International; main components 62% 1,8-cineole and 21% linalool), *Ocimum gratissimum* (ATL International main components 75% eugenol, 8% germacrene D, and 8% β-ocimene), and *Melaleuca alternifolia* (ATL International; main components 41% terpinen-4-ol, 21% γ-terpinene, and 10% α-terpinene). The compound identification and composition of the essential oils was determined by gaschromatography coupled with mass-spectrometer analysis (GC-MS) at Plant Research International (Wageningen, The Netherlands). The traps were placed horizontally in the field to minimize the influence of vision (colour) relative to olfaction. Both position and colour (white horizontal plates) were chosen to minimize catches of other insects and other thrips species as well. Unpublished results (RWHM van Tol) showed that differences in the number of onion thrips caught between treatment (thrips attractant) and control is larger for horizontal than vertical white plates. White colour has been shown to be the most attractive colour for onion thrips (Kirk, 1984) and appears to play an essential role in the last part of the thrips orientation (landing) to an odour source during flight (RWHM van Tol, unpubl.).

Field experiment

The test was performed from 15 March (start 11:00 hours) to 16 March (end 15:00 hours) 2005 in a pasture field at Lincoln, New Zealand. The grass was mowed several days before the start of the test. Each treatment consisted of five plate traps (one central plate surrounded by four plates) in four replicates (four block experimental setup) placed 10 m apart. Four different essential oils, a water control, and the thrips attractant ethyl *iso*-nicotinate were tested in different combinations. One control treatment consisted of a central plate sprayed with ethyl *iso*-nicotinate surrounded by four plates sprayed with water. The other control treatment consisted of a central plate sprayed with water surrounded by four plates sprayed with ethyl *iso*-nicotinate. There were no essential oil or control treatments performed without the attractant because pretesting showed that plates without attractant caught almost no thrips at all, thereby being unsuitable for testing pure repellence effect of the essential oils in this field setup. The repellent treatments were identical in setup as the control treatments whereby the central plate or the four surrounding plates sprayed with water were sprayed with an essential oil instead and tested in conjunction with attractant-treated plates. This resulted in the following two control and eight essential oil-treatments tested in fourfold:

1. A central attractant-treated plate surrounded by four water-treated plates (control treatment for treatments 3–6).

2. A central water-treated plate surrounded by four attractant-treated plates (control treatment for treatments 7–10).

3–6. A central attractant-treated plate surrounded by four essential oil-treated plates (3 = *A. arborescens*; 4 = *O. majorana*; 5 = *O. gratissimum*; 6 = *M. alternifolia*).

7–10. A central essential oil-treated plate surrounded by four attractant-treated plates (7 = *A. arborescens*; 8 = *O. majorana*; 9 = *O. gratissimum*; 10 = *M. alternifolia*).

The plates were fixed into position in the field with a 10-cm long nail through the centre of the plate into the ground, after treating the plates with Tangle Trap. Each plate was evenly sprayed with 1 ml of water, ethyl *iso*-nicotinate or essential oil at 11:00 hours on 15 March, immediately after placing the five plates of each treatment combination in the field. The sprayings were repeated on 16 March at 11:00 hours. Weather conditions (temperature, sunshine, and wind direction and speed) during the test period were obtained from the nearby weather station located in Lincoln. Temperatures during daytime varied between 17 and 19 °C with a continuous cloudy sky. Prevailing wind direction during this period was northeast, with wind speed varying between 5 and 8 m s^{-1}. At the end of the test period, plates were covered with plastic wrap and stored cool (4 °C) until counting. After counting, thrips of the different treatments were removed and identified to species level per plate for two replicates. The species composition differed depending on the repellent–attractant combination tested. The percentage *T. tabaci* of the total thrips number caught is shown in Table 1. Other thrips species found were *Anaphothrips obscurus*, *Aptinothrips rufus*, and *Thrips obscuratus*. There was no correlation found between the treatments and numbers of these species. Data of thrips numbers were corrected per plate for other species than *T. tabaci* before analysis.

Table 1 Percentage *Thrips tabaci* of total thrips number (n) caught on white sticky plates in the different essential oil–attractant combinations

R(C)-4A[1]	Total (%)	n	R^2 (%)	n	$4A^3$ (%)	n
Control	79.5	30	62.5	4	83.3	26
Artemisia arborescens	70.5	29	20.0	4	76.9	25
Origanum majorana	67.7	15	50.0	2	70.4	13
Ocimum gratissimum	71.4	29	50.0	2	74.0	27
Melaleuca alternifolia	64.9	27	66.7	2	64.7	25
A-4R(C)[1]	Total	n	A^2	n	$4R^3$	n
Control	87.8	40	84.6	7	88.3	33
Artemisia arborescens	76.5	38	77.8	7	76.0	31
Origanum majorana	55.6	15	75.0	6	50.0	9
Ocimum gratissimum	71.4	17	60.5	6	77.3	11
Melaleuca alternifolia	88.5	41	92.9	11	86.4	30

[1]R(C)-4A, Plate sprayed with plant essential oil (R) or control (C) surrounded by four plates sprayed with ethyl *iso*-nicotinate (A); A-4R(C), Plate sprayed with ethyl *iso*-nicotinate (A) surrounded by four plates sprayed with plant essential oil (R) or control (C).
[2]R, centre plate sprayed with plant essential oil; A, centre plate sprayed with ethyl *iso*-nicotinate.
[3]4A, four plates sprayed with ethyl *iso*-nicotinate surrounding one plate sprayed with plant essential oil; 4R, four plates sprayed with plant essential oil surrounding one plate sprayed with ethyl *iso*-nicotinate.

Statistical analyses

All data were analysed with generalized linear models (GLM) with binomial distribution and logit link to equalize variances (GenStat 8.11, 2005). Because of a large position*treatment interaction, analyses were performed for each position separately. After the analyses, t-tests were performed for all pairwise comparisons of the treatments. Percentage reduction of *T. tabaci* presented in the figures is based on comparison of thrips numbers caught on the plates in the essential oil-treatments to the thrips numbers caught on the plates in the control treatments (see treatment description before in this section).

Results

The reduction of thrips per treatment (Figure 1) within the tested attractant–essential oil combinations shows that the reduction in thrips numbers caught on plates sprayed with essential oil of *O. majorana* is 86.9% ($P<0.001$) and with *O. gratissimum* 70.5% ($P<0.001$) when the essential oil-sprayed plates surround a central plate sprayed with the onion thrips attractant ethyl *iso*-nicotinate. No effect was found for the other two tested plant essential oils. Fewer thrips (62.3% reduction, $P<0.001$) were also found on the ethyl *iso*-nicotinate-treated plates surrounding a central

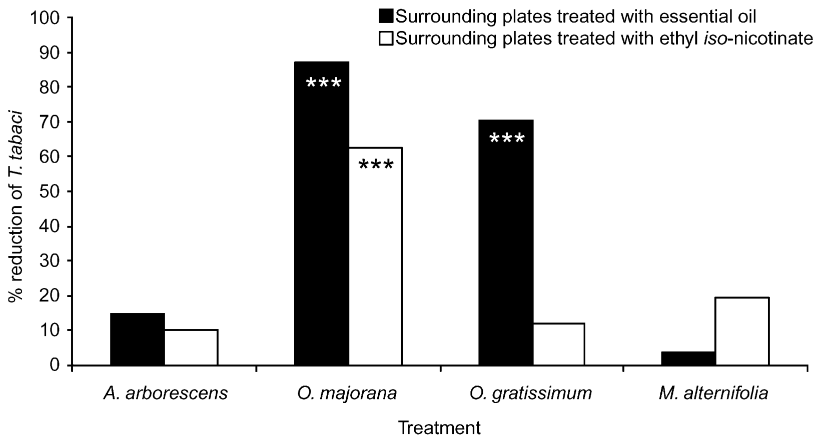

Figure 1 Percentage reduction of female *Thrips tabaci* relative to a control on four sticky white-coloured plates placed horizontally in a pasture field at the four cardinal directions (N, S, E, W), sprayed with 1 ml essential oil per plate (black bars), surrounding a central plate sprayed with 1 ml of the onion thrip attractant ethyl *iso*-nicotinate (n = 4) and four surrounding plates sprayed with 1 ml ethyl *iso*-nicotinate per plate (white bars) surrounding a central plate sprayed with 1 ml of essential oil (n = 4). Control treatment for black bar values shown in Figure 2A (average number *T. tabaci*: 34 ± 11) and for white bars in Figure 2B (average number *T. tabaci*: 25 ± 5). Bars marked with three asterisks present significantly different percentage thrips on the surrounding plates relative to the control treatments at P<0.001.

plate sprayed with *O. majorana*. No reduction on surrounding attractant plates was found for any of the other tested essential oils. There were no significant effects found on the central plates for any of the tested attractant–repellent combinations.

The prevailing wind direction during the period that thrips were presumed to be active (daytime) was northeast with wind speeds varying between 5 and 8 m s^{-1} and temperatures of 17–19 °C. Overall analysis on compass direction of surrounding plates (n = 20) showed that most thrips were caught on the downwind side plates [west (8.5) > south (5.4) > centre (3.6) > north (2.6) = east (1.8); values between brackets present average number of *T. tabaci* per plate; all differences significant at P = 0.05]. Whether attractant plates surrounded one centrally placed water-sprayed plate or water-sprayed plates surrounded one centrally placed attractant-sprayed plate did not influence the position of thrips on sticky plates (Figure 2). Overall, the two water–attractant combinations (control) did not differ in the total number of thrips caught [water-treated central control plate surrounded by four attractant plates (24.8 thrips) = central attractant-treated plate surrounded by four water-treated control plates (34.3 thrips), P = 0.076]. The total thrips caught on the surrounding plates were also similar [surrounding attractant plates (22.6 thrips) = surrounding water-control plates (28.2 thrips), P = 0.217] but significant more thrips (P = 0.009) were caught on the central plate sprayed with attractant surrounded by control plates (6.1 thrips) than on the central water-control plate surrounded by attractant plates (2.3 thrips).

We also compared the distribution of onion thrips on the plates. Relative thrips numbers on each plate were compared with similar (N, S, E, W, and Central) plates in the control treatment. When a central attractant-treated plate was surrounded by four plates treated with essential oil of *O. majorana*, the distribution of thrips on the different plates compared to the control changed significantly (Figure 3). Relatively fewer thrips were found on the west plate (26% reduction, P = 0.004) and south plate (23% reduction, zero *T. tabaci* on plates sprayed with *O. majorana*) sprayed with *O. majorana* and significantly more thrips on the central plate treated with ethyl *iso*-nicotinate (37% increase, P<0.001). For *O. gratissimum* there was a near significant reduction on the west plate sprayed with essential oil (15% reduction, P = 0.07) and an increase on the central attractant-treated plate (12% increase, P = 0.07) and the east plate sprayed with *O. gratissimum* (9% increase, P = 0.03). For *M. alternifolia* there was a relative increase of thrips on the central plate treated with ethyl *iso*-nicotinate (10% increase, P = 0.03) and a significant reduction on the south plate treated with *M. alternifolia* (12% reduction, P = 0.002). Essential oil of *A. arborescens* surrounding ethyl *iso*-nicotinate gave no clear change in the distribution of thrips on the plates relative to the central attractant plate.

The species composition on the sticky plates differed depending on the essential oil-attractant combination tested. Next to *T. tabaci* we found *Anaphothrips obscurus*, *Aptinothrips rufus*, and *Thrips obscuratus*. The percentage *T. tabaci* of the total thrips number caught is shown in

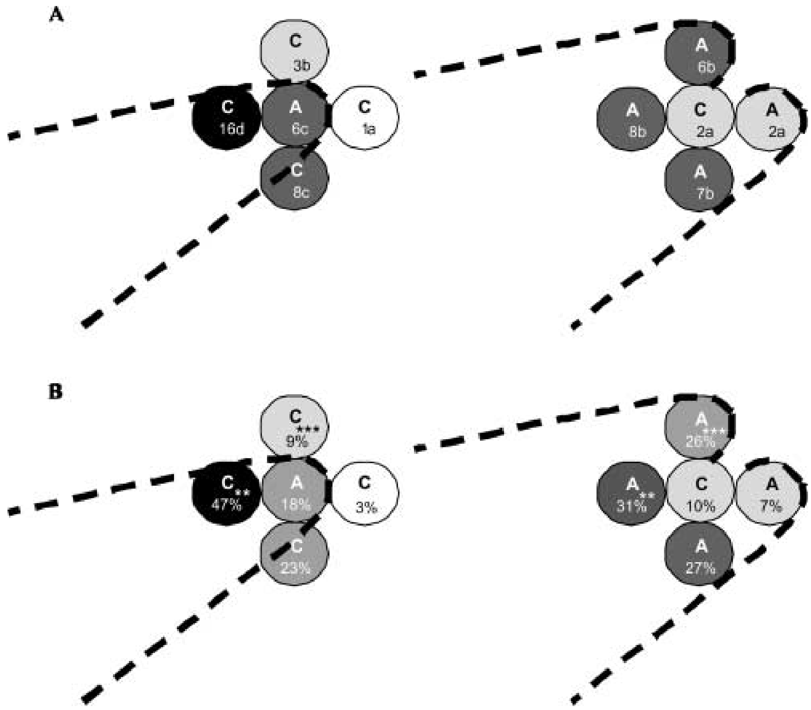

Figure 2 (A) Absolute number and (B) proportion of female *Thrips tabaci* caught per sticky white-coloured plate placed horizontally in a pasture field at the four cardinal directions (N, S, E, W) surrounding a central sticky plate within each water–attractant combination (n = 4). A = plate sprayed with 1 ml of the onion thrips attractant ethyl *iso*-nicotinate; C = plate sprayed with 1 ml of water. Dotted lines refer to likely odour plume of the attractant. Different letters (a, b, c, d) present significantly different numbers of onion thrips between the plates within each water–attractant combination at P = 0.05. Asterisks present a significantly different distribution of onion thrips on plates of the same compass direction of the two control treatments (Figure B, left vs. right) (**P<0.01 and ***P<0.001). Different shades of grey are used to visualize the different numbers (A) or proportion (B) on the plates.

Table 1 and used for analysis of the results. There was no correlation found between the treatments and these other thrips species found.

Discussion

In this field study, we compared the efficacy of several plant essential oils to repel the onion thrips, *T. tabaci*, in the presence of an attractive odour. Essential oil of *O. majorana* (sweet marjoram) and *O. gratissimum* (clove basil) effectively reduced the numbers of thrips on white sticky plates placed horizontally in a pasture field in the presence of plates sprayed with the onion thrips attractant ethyl *iso*-nicotinate. Essential oil of *O. majorana* was the most effective repellent oil; it reduced the number of thrips on the four repellent-sprayed plates surrounding

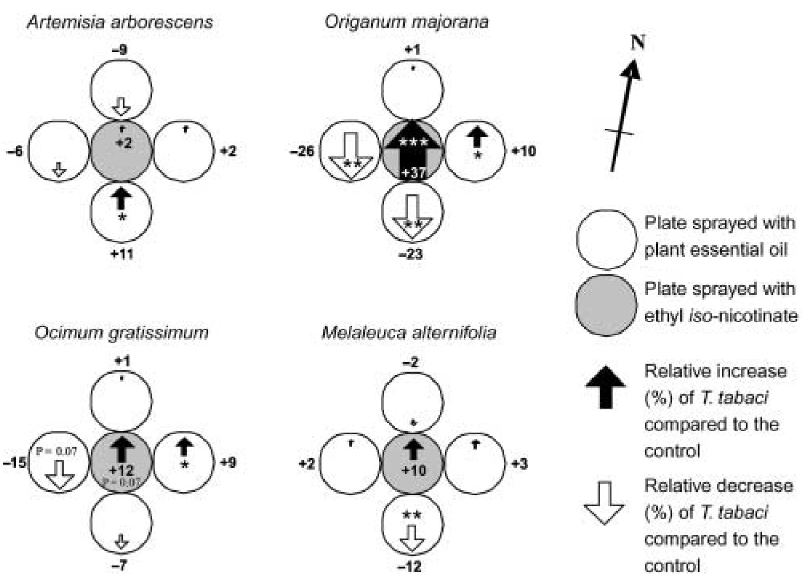

Figure 3 Change in distribution (expressed in percentage of total thrips on the five plates of each essential oil–attractant combination) of female *Thrips tabaci* on sticky white-coloured plates placed horizontally in a pasture field at the four cardinal directions (N, S, E, W) (n = 4) relative to the control–treatment plates of the same compass direction (Figure 2). Values marked with asterisks are significantly different from the control (*P<0.05, **P<0.01, and ***P<0.001).

one attractant-sprayed plate by 87%, and when tested with the four attractant-sprayed plates surrounding one repellent-sprayed plate, *O. majorana* reduced the number of thrips by 62%. Essential oil of *O. gratissimum* only reduced thrips numbers where the attractant-sprayed plate was surrounded by four repellent-sprayed plates (71% reduction on repellent-sprayed plates). The two other tested plant essential oils, *A. arborescens* and *M. alternifolia*, were not effective in reducing thrips numbers in any of the tested combinations with ethyl *iso*-nicotinate. Test combinations without an attractant as control treatments were not performed because pretesting showed that any combination of plates without the attractant caught near to zero numbers of thrips.

We also compared the distribution of onion thrips on the plates. In general an effect of prevailing wind direction and thrips numbers on the different plates (N, S, E, or W) was found. More thrips were found on the downwind south and west plates than on the north and east plates. The odour plume of the attractant and the higher number of thrips found downwind indicate a specific upwind movement of thrips to the treatments. Relative thrips numbers on each plate were also compared with similar (N, S, E, W, and central) plates in the control treatment. There was a major shift of thrips from the downwind placed west (26% reduction) and south plate (23% reduction) treated with essential oil of *O. majorana* to the central plate treated with ethyl *iso*-nicotinate (37% increase). For *O. gratissimum* a shift of thrips from the west plate (15% reduction) sprayed with the essential oil to the central plate with ethyl *iso*-nicotinate (12% increase) was nearly significant ($P = 0.07$). For *M. alternifolia* there was a significant shift from the south plate (12% reduction) to the central plate with ethyl *iso*-nicotinate (10% increase). For *A. arborescens*, no change in distribution of *T. tabaci* on the plates was found. The shift of thrips from the surrounding repellent plates to the central plate treated with ethyl *iso*-nicotinate can be considered as a short distance push–pull effect.

The percentage of *T. tabaci* relative to other thrips species found on the plates in the different treatments varied depending on the treatment. This variation was, however, caused by variation in response by *T. tabaci* to the attractant in combination with the essential oils and not by variation in response of the other thrips species, which showed no attraction to the onion thrips attractant ethyl *iso*-nicotinate. Numbers per plate for these other species were more or less constant and independent of the treatments.

Repellence of *T. tabaci* has been shown only in olfactometer tests with walking thrips (Koschier & Sedy, 2003) for rosemary oil but not for marjoram oil and several other tested plant essential oils. One reason for the varying results may be found in the different composition of the marjoram oil used by Koschier & Sedy (2003) and published in Koschier et al. (2002). The main compounds were terpinen-4-ol (23%), (*Z*)-sabinene hydrate (19%), and *p*-cymene (11%) while our marjoram oil consisted mainly of 1,8-cineole (62%) and linalool (21%) which was either not found (1,8-cineole) or found only in trace amounts (3% linalool) in the marjoram oil of Koschier et al. (2002). Although terpinen-4-ol was a main compound (41%) of the essential oil of *M. alternifolia* it had little or no effect on the repellence of onion thrips in our field trial. The component 1,8-cineole (eucalyptol) was a major constituent in the rosemary oil (51%) used in the olfactometer test by Koschier & Sedy (2003), which appeared to be repellent for onion thrips (77% repellence) in the olfactometer, but only at a high concentration (10%) and not at 1% or lower. Results in a Y-tube olfactometer (MM Davidson & WJ de Kogel, unpubl.) with our marjoram oil revealed clear repellence (78%) for western flower thrips (*Frankliniella occidentalis*) at 0.01% dilution in paraffin oil. Koschier et al. (2000) found no attraction of western flower thrips to 1,8-cineole but a positive attraction (76% attraction) to linalool at high concentration (10%) offered in a Y-tube olfactometer, whereas Katerinopoulos et al. (2005) found positive attraction to both components at much lower concentrations (1–2%). Eugenol, a main component in the essential oil of *O. gratissimum* elicited positive chemotaxis of western flower thrips in the Y-tube olfactometer at a concentration of 1% (Koschier et al., 2000), but as part of the essential oil (75% eugenol) it was repellent in our field trial with onion thrips. These results suggest that western flower thrips and onion thrips differ in their behaviour to different odours. Kogel & Koschier (2002) showed this difference for salicaldehyde, which appeared to be attractive for onion thrips but repellent for western flower thrips at 1% concentration. The influence of the concentration of some compounds, however, cannot be excluded as a possible explanation for differences found between olfactometer and field results.

An important consideration of true repellence or attractiveness (RWHM van Tol, DEJ James, ARG McLachlan, WJ de Kogel and DAJ Teulon, unpubl.) is that onion thrips use odour and colour preferentially during downwind flight, upwind orientation, and walking. These results suggest that odour is the main stimulus for upwind flight to the cue and after landing on the visual cue thrips continue searching for the odour source by walking. Although still needing experimental proof, 'odour-dominated visual arrestment' was suggested to play a role in the behaviour of onion thrips. Our field results with repellent–attractant combinations for *O. majorana* oil (eucalyptol type) and

O. gratissimum oil (eugenol type) show that the larger part of repellence is related to avoidance of the repellent–attractant combination. Only the shift of the thrips from the surrounding repellent plates to the central attractant plate could be attributed to the short distance repellence. It is likely that once thrips has landed on a visually attractive cue, behaviour related to attractive and repellent odours will change compared to behaviour during the flying orientation. Results of repellence and attractiveness based only on walking behaviour in bioassays (without a visual cue) may thus miscalculate the behaviour of thrips in a field or greenhouse situation.

Linalool and eugenol, main compounds of, respectively, *O. majorana* and *O. gratissimum*, were found to inhibit the feeding activity of onion thrips according to Koschier et al. (2002). The combination of repellence to essential oils and attractiveness of ethyl *iso*-nicotinate with the inhibition of feeding in a push–pull strategy may be a promising tool in thrips control.

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