Biocontrol Science and Technology (1994) 4, 177–186

The Potential of Flower Odours for Use in Population Monitoring of Western Flower Thrips *Frankliniella occidentalis* Perg. (Thysanoptera: Thripidae)

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(Received for publication 20 August 1993; revised manuscript accepted 23 February 1994)

Sticky blue traps are a suitable and important tool for Western Flower Thrips population monitoring in greenhouses. They can be used in vegetables and in ornamentals, and provide important information on the current status of the pest population. However, such traps cannot be used in some susceptible plant species when they are flowering because at that stage the plants are more attractive to Western Flower Thrips than the traps. We therefore tried to increase trap attractiveness by combining the colour cue with an attractive odour cue. In laboratory experiments, we found a significant additive effect on attractiveness for two odours in traps provided with both the visual and the olfactory cues as compared to traps with either cue alone. However, these results could not easily be reproduced in greenhouses. The main factors responsible for this failure seem to be (1) the only moderate, additive increase of trap attractiveness when using combined visual and olfactory cues, and (2) the problems associated with odour diffusion. Unless a more attractive odour is found and a suitable odour dispenser is available, the use of odours to enhance sticky blue trap attractiveness for Western Flower Thrips cannot be recommended and, given the added cost for the trap, may not be affordable for growers.

Keywords: *Western Flower Thrips,* Frankliniella occidentalis, *monitoring, blue sticky traps, host plant odour compounds*

INTRODUCTION

Monitoring of pest and antagonist population densities is one of the most important factors determining the long-term success of plant protection in greenhouses. It is therefore essential to develop and optimize monitoring tools suited for plant producers.

Western Flower Thrips *Frankliniella occidentalis* [Pergande] is one of the major insect pest species in greenhouses and is particularly damaging to ornamental plants (Brødsgaard, 1989a). Due to its cryptic behaviour, this pest species is difficult to detect in the initial stages of an

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infestation, thus making it difficult to find the optimum time for control measures. Because antagonists usually need longer than pesticides to achieve pest control, this is a major problem when using beneficials against *F. occidentalis*. The usually high degree of pesticide resistance of *F. occidentalis* populations further increases the problems associated with *F. occidentalis* control. Therefore, early detection and reliable estimates of population densities are critical to be able to take countermeasures in the early stages of population build-up.

Blue sticky traps were shown to be attractive to *F. occidentalis* (Brødsgaard, 1989b) and, because their attractiveness in greenhouses is rather specific to thrips species, they are well suited for long-term monitoring of this pest species. Trap catches depend on population density, and on temperature which determines activity and reproductive potential (Lublinkhof & Foster, 1977). Furthermore, the attractiveness of colour traps is relative to the attractiveness of other environmental cues, i.e. the more attractive the environment the less pests are caught on the traps (Prokopy & Owens, 1983; Smith, 1976; Berlinger *et al.*, 1993). In consequence, trap catches in ornamental greenhouses are dependent on the growing stage of the culture, i.e. the number of trapped *F. occidentalis* in relation to the total greenhouse population is lower when the plants are flowering compared to a vegetative crop (M. E. Schmidt & J. E. Frey, unpublished data). We therefore tried to increase trap attractiveness by using attractive flower odours in combination with the blue sticky trap.

Several odours have been reported to be behaviourally attractive to thrips species. Aldehydes were first described as thrips attractants (Howlett, 1914; Morgan & Crumb, 1928; Attaway *et al.*, 1966; Loper, 1972). Some compounds not occurring in flowers were also shown to be attractive to flower thrips species, e.g. ethyl nicothianate increased trap catches of *Thrips obscuratus* Crawford over 100 times (Penman *et al.*, 1982) and benzaldehyde, an odour often found in fruits, was also attractive to the same species (Teulon, 1988; Teulon & Ramakers, 1990). Of the many odours occurring in flower scents, only anisaldehyde, eugenol and geraniol have so far been tested for their attractiveness to flower thrips species (Kirk, 1985; Teulon, 1988). Among these, only anisaldehyde has been tested with *F. occidentalis*, increasing trap catches in tomato and sweet peppers up to 10 times (Teulon *et al.*, 1993; Brødsgaard, 1990). In general, the results of these studies show a large variation in attractiveness of different odours between and within flower thrips species.

The main objective of this study was to test whether some typical flower odours are behaviourally as attractive to *F. occidentalis* as some of the aldehydes reported as thrips attractants, and whether these odours show a synergistic effect on trap catch when combined with the blue sticky trap. Furthermore, we tested the applicability of the combined use of odours and blue sticky traps to the greenhouse situation.

MATERIALS AND METHODS

Laboratory Experiments

For the experiments, we used *F. occidentalis* females of a strain reared on beans (*Phaseolus vulgaris* L. var. Nerina) and kept in culture for 3 years (*c.* 50 generations). The behavioural experiments were performed in meshed cages (40 × 50 × 50 cm, $W \times D \times H$; mesh size 30 μm) at 23 ± 1°C, 16:8 h light:dark (L:D) and 55% relative humidity (RH). On one side of each cage, a plastic funnel, 50 cm deep, was attached, covering the entire side. A fan was mounted at the centre of the funnel, providing a slow and constant air flow out of the cage at a rate of approximately 1 cm/s^{-1}.

Potted bean plants (*P. vulgaris* var. Nerina) were used as negative control and as the 'substrate' for offering the odour and colour cues (all odorous compounds were purchased from Fluka Chemie AG, Buchs, Switzerland). Fifty microlitres of each odour at a dilution of 10^{-3} vol/vol in light paraffin oil (Fluka) were administered on 1 × 2 cm pieces of filter paper (Schleicher & Schuell AG, Feldbach, Switzerland; No. 595) which were then attached to the wooden sticks used to support the bean plants and oriented towards the centre of the cage. The control plants were similarly equipped except that the filter papers contained only the solvent, i.e.

50 μl of light paraffin oil (Fluka); preliminary assays showed that light paraffin oil is not behaviourally attractive to *F. occidentalis*. The colour cues were 2 × 5 cm pieces of Biopax blue (Plüss-Staufer AG, Oftringen, Switzerland; paper sticky trap of dark blue colour) attached to the plant supports mentioned above. The trap pieces were covered with clear saran wrap to prevent attracted thrips individuals from sticking to the traps and to allow them to move to the leaves underneath the colour cue. Between 20 and 40 adult thrips individuals of mixed age and sex were always released in the centre of the cage in a Petri dish. After each replication the cages were turned 180 degrees to avoid any position effects. Preliminary assays to determine the appropriate exposure time suggested a 3-day period as optimal. Three days after releasing the thrips the plants were carefully covered with a plastic bag, removed from the cage and searched for thrips using CO_2 for immobilization. The results were analyzed by the Wilcoxon Signed Rank Test.

Establishing the behavioural attractiveness of selected flower odours. In the two-choice experiments (six to seven replicates, 20–25 thrips individuals each), one potted plant was positioned close to each side of the cage perpendicular to the air stream to avoid mixing the odour plume with the control or with other odours in those experiments testing the rank order of attractiveness between different odours.

Testing the behavioural effect of the combination of olfactory and visual cues. In the four-choice experiments testing the effect of the combination of odour and colour cue, three baited plants and one unbaited control plant were placed close to each side of the cage. The two treatments using odours (odour and odour–colour combination) were positioned close to the funnel side of the cage, the two other treatments with no odours (negative control, i.e. a plant with neither colour nor odour cue, and the plant with only a colour cue) were positioned at the opposite side of the cage. The experiments were conducted with seven replications, the first with 30, all others with 40 adult thrips of mixed ages and sex.

Greenhouse Experiments

The greenhouse experiments were conducted between August and November 1991. Five pairs of blue sticky traps Biopax blue, representing five replicates, were placed on tables with flowering plants (*Chrysanthemum [Dendranthema] indicum* var. 'Fatima', *Cyclamen persicum* var. 'F1 Sierra' and 'Kleine Dresdnerin', *Sinningia vulgaris* var. 'Gensetter DK red' and 'Michelssen Nordland', and *Eustoma grandiflorum* var. 'Blue Bell') in each of two greenhouses. They were positioned in pairs of baited and unbaited traps, generally at a distance of 2 m apart (minimum distance 1 m) and at 10 cm above the top plant level. The position of the odour-baited traps was alternated between replicates. The odour sources (filter papers or glass vials) were attached at the top of the traps. The number of *F. occidentalis* caught on the traps was assessed after 3–7 days of exposure (see Table 4). Geraniol was presented on filter papers prepared as described above, and in glass vials with evaporation rates between 4.1 and 28.8 mg day^{-1} (see Table 4).

Evaporation Experiments

The release rate of geraniol from the filter paper dispensers could not be quantitatively determined because it was diluted in paraffin oil. The release rate of geraniol from surfaces was determined using self-made aluminium containers with diameters of 9.5, 12, 15, 21 and 29 mm (all 15 mm high), on a Mettler Toledo MT5 microbalance. We measured the weight of the containers one day after filling and, to evaluate the stability of the release rate, repeated the measurement 4 days later. To establish the release rate of geraniol from the filter papers described above, we tested glass containers with geraniol release rates of 0.01, 4.1, 12.6 and 28.8 mg day^{-1} for their attractiveness to *F. occidentalis* in the laboratory cages described above.

RESULTS

Establishing the Behavioural Attractiveness of Selected Flower Odours

Three compounds known to contribute to the odours of many flowers, anisaldehyde, eugenol and geraniol (Williams, 1983; Kirk, 1985), were tested in the choice tests; ethylnicothianate, already reported to be behaviourally attractive to *F. occidentalis* (Teulon & Ramakers, 1990), was included as a positive control assay to test the experimental set-up. The average recovery of thrips from the plants was 70.9% (assay 1–4) and 71.8% (assay 5–8), with 25 thrips released per replication (20 thrips per replication in assay 4). We found that all compounds were behaviourally attractive to *F. occidentalis* (for all compounds: $P < 0.028$, $n = 6$; Table 1(a)). In further tests, we established the rank order of behavioural attractiveness among the flower odours (Table 1(b)). Geraniol was the most attractive compound. It was significantly more attractive than eugenol ($P = 0.028$, $n = 6$) and anisaldehyde ($P = 0.431$, $n = 6$) and eugenol was more attractive than anisaldehyde ($P = 0.028$, $n = 6$). Geraniol was also more attractive than ethylnicothianate ($P = 0.018$, $n = 6$).

Testing the Behavioural Effect of the Combination of Olfactory and Visual Cues

The effect of the combination of colour and olfactory cues was tested in a four-choice experiment (Table 2). Thirty (replication 1) or forty thrips were released per replication, and an average of 71.7% were recovered from the plants. For both tested odours, i.e. geraniol and ethylnicothianate, each at a concentration of 10^{-3} v/v in paraffin oil, the results show that the odour cue presented alone is at least as attractive as the colour cue (geraniol $P = 0.273$, $n = 7$; ethylnicothianate $P = 0.028$, $n = 7$; Table 2), both being more attractive than the negative control (i.e. the plant with neither a colour nor an odour cue) ($P = 0.028$, $n = 7$ for both odours; Figure 1(a) and (b)). Furthermore, there is an additive effect of the combined cues which are significantly more attractive for *F. occidentalis* than each single cue presented alone ($P < 0.018$, $n = 7$ for all tested combinations: geraniol/blue versus blue; geraniol/blue versus geraniol; ethylnicothianate/blue versus blue; ethylnicothianate/blue versus ethylnicothianate).

Assessing Odour Release Rates in Laboratory Experiments

The release rate of pure geraniol from aluminium containers increased linearly with the surface of the container up to 350 mm^2 (= 36.5 mg day^{-1}; $f(x) = 4.023^{-3} \times x + 0.126$, $R^2 = 0.996$), above which it leveled off (44.0 mg day^{-1} from 660 mm^2 surface). Four days after the first assessment, the release rate of two containers had increased (15 mm: + 36.7%; 29 mm: + 27.0%), one had decreased (21 mm: − 29.1%) and one had remained essentially the same (12 mm: − 2.0%). We then used glass containers with geraniol release rates of 0.01, 4.1, 12.6, 25.9 and 28.8 mg day^{-1} in the same experimental set-up as described above for the cage experiments. However, none of these containers elicited the same attractant behaviour as the filter paper assays (Table 3). The assay with a release rate of 28.8 mg day^{-1} was discontinued because of the negative results of the first two replications and because preliminary greenhouse results using this release rate were also negative.

Assessing the Suitability of Olfactory Cues for Greenhouse Use

We tried to reproduce the results observed for geraniol on beans in the laboratory under greenhouse conditions with flowering plants. The same dispenser as in the cage experiments, i.e. a 1 × 2 cm filter paper, was inadequate for the greenhouse. In two different greenhouses on three plant species (Chrysanthemum, Sinningia, Eustoma), we found no difference between colour traps provided with the odour compared to those without the odour (Table 4).

Similar results were obtained with the geraniol containers in the greenhouses. Only the container with a geraniol release rate of 25.9 mg day^{-1} increased the attractiveness of the blue trap significantly ($P = 0.023$, $n = 20$); however this was only on Chrysanthemum and by only 25.6% (Table 4). None of the other tested containers with higher or lower release rates

TABLE 1. (a) **Number of thrips recovered from odour-baited and unbaited (control) plants** (25 **thrips** released per replication **(20 in** assay 4))

Replication	Assay 1		Assay 2		Assay 3		Assay 4	
	AN	CO	EU	CO	GE	CO	ET	CO
1	6	4	11	5	7	5	10	5
2	12	8	11	8	10	3	12	4
3	10	8	11	9	11	4	10	6
4	12	6	10	9	10	6	15	8
5	14	8	11	5	12	7	13	6
6	14	8	12	7	12	10	13	7
AVG	11.33	7.00	11.00	7.17	10.33	5.83	12.17	6.00
SE	1.23	0.68	0.26	0.75	0.76	1.01	0.79	0.58
P	0.026		0.027		0.027		0.027	

EU = eugenol; AN = anisaldehyde; GE = geraniol; ET = ethyl nicothianate; CO = control; AVG = average; SE = standard error of mean; *P* = probability value (Wilcoxon signed rank test).

(b) **Number of thrips recovered from each of two odour-baited plants (25 thrips released per** replication)

Replication	Assay 5		Assay 6		Assay 7		Assay 8	
	EU	AN	GE	AN	GE	EU	GE	ET
1	5	6	8	4	11	5	9	5
2	7	11	10	6	13	7	10	8
3	6	10	12	7	10	9	7	6
4	7	17	9	8	14	10	7	6
5	5	12	7	7	12	7	10	7
6	7	14	13	8	14	9	6	4
7	—	—	—	—	—	—	7	5
AVG	6.17	11.67	9.83	6.67	12.33	7.83	8.00	5.86
SE	0.40	1.52	0.95	0.61	0.67	0.75	0.62	0.51
P	0.027		0.041		0.027		0.018	

EU = eugenol; AN = anisaldehyde; GE = geraniol; ET = ethyl nicothianate; AVG = average; SE = standard error of mean; *P* = probability value (Wilcoxon signed rank test).

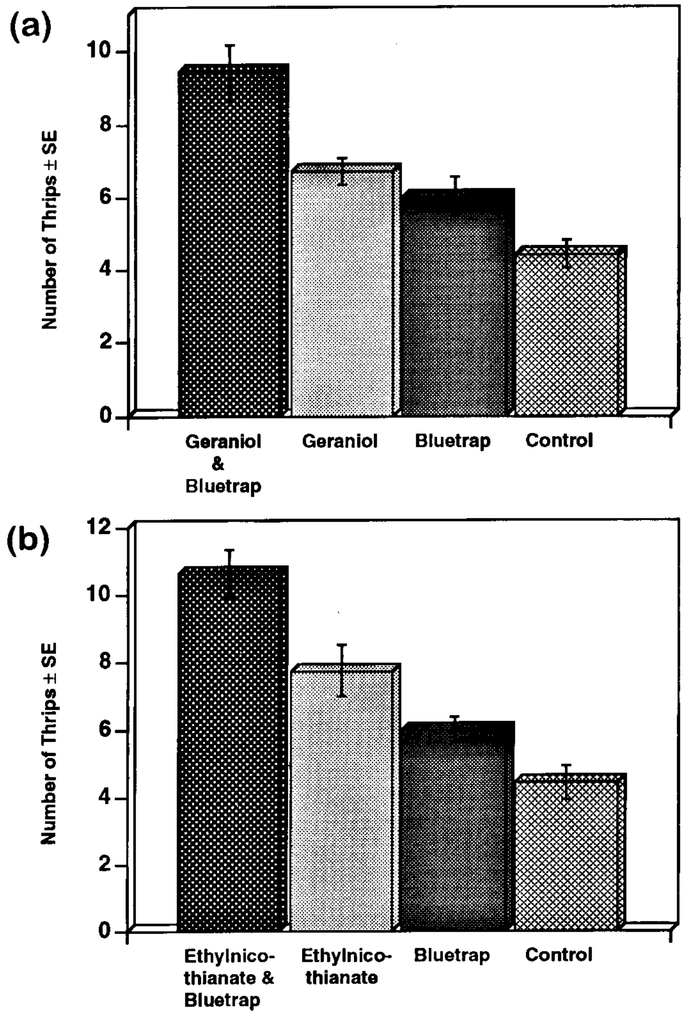

FIGURE 1. Behavioural attractiveness of olfactory and visual cues offered in a four-choice experiment using potted French beans as a substrate for the cues and (unbaited) as control plants. The colour cue used was a 2 × 5-cm piece of Biopax blue sticky trap covered with transparent saran wrap. The odour cue was in (a) geraniol and (b) ethylnicothianate, both at a concentration of 10^{-3} v/v in paraffin oil.

significantly increased the attractiveness of the blue traps to *F. occidentalis* in the greenhouses (Table 4).

DISCUSSION

Population monitoring is one of the most important tools for successful pest control. This is especially true for pests that have developed resistance to most of the currently used pesticides. *F. occidentalis* is a serious greenhouse pest with a world-wide distribution and a high degree of pesticide resistance (Brødsgaard, 1989a; Helyer & Brobyn, 1992). It is therefore important to develop optimal monitoring tools for this pest. Blue sticky traps have been shown to be useful in *F. occidentalis* monitoring in ornamental plants before they enter the flowering stage. For many plant species, they can also be reliably used during the flowering period (Frey, 1993).

TABLE 2. Number of thrips recovered from the assay plants in a four-choice experimental design (30 thrips released in the first, 40 in the other replications)

Replication	Assay 9				Assay 10			
	GE	OV	BL	CO	ET	OV	BL	CO
1	7	11	6	4	8	10	7	4
2	8	10	7	4	7	11	6	5
3	7	10	7	5	11	13	6	5
4	7	9	3	3	5	7	4	2
5	7	12	7	6	8	11	6	5
6	6	7	6	4	6	12	6	6
7	5	7	6	5	9	10	7	4
AVG	6.71	9.43	6.00	4.43	7.71	10.57	6.00	4.43
SE	0.36	0.72	0.53	0.37	0.75	0.72	0.38	0.48
SIG	b	a	b	c	b	a	c	d

GE = geraniol; ET = ethyl nicothianate; BL = blue visual cue; OV = odour and visual cue combined; CO = control; AVG = average; SE = standard error of mean; SIG = columns with different letters are significantly different from each other at the 0.05 level (Wilcoxon signed rank test).

However, increasing the trap attractiveness by using a second attractive cue may help to expand the range of plants where this trap could be used.

Our laboratory results show that the degree of attractiveness elicited by the odours alone is comparable to that elicited by the colour and that the combination of both cues results in an additive effect on trap catches, i.e. the combined cues increased the attractiveness at least 1.87-fold over that elicited by either cue alone (Table 2, Figure 1(a) and (b)). The average recovery of released thrips from the plants was 70.3%. This fairly low recovery rate can be explained by the high activity levels of *F. occidentalis* that we observed in our assay cages, and that probably reflects a searching behaviour for more suitable, i.e. pollen and/or nectar providing host plants.

Increasing the attractiveness of the blue sticky trap by 71% by adding odour was not enough to increase significantly trap catches in the greenhouse. We were not able to reliably reproduce our laboratory results under typical greenhouse conditions using the same odour release systems. Using glass dispensers, a moderate trap catch increase of 26% was achieved with only one release rate and on only one of the two tested host plants. Several factors may be responsible for

TABLE 3. Attractiveness of different geraniol release rates in laboratory experiments on French bean at 23 ± 1°C

Release rate (mg day^{-1})[a]	Rep	Geraniol		Control		P
		AVG	SE	AVG	SE	
0.01	5	3.2	0.5	3.2	1.0	> 0.999
4.1	7	5.0	0.6	5.3	1.2	0.865
12.6	15	9.7	1.0	10.5	1.2	0.727
28.8	2[b]	7.0	1.0	10.0	1.0	—

[a] Estimated from surface evaporation data of geraniol.
[b] Assay discontinued.
Rep = number of replications; AVG = average; SE = standard error of the mean; P = probability value (Wilcoxon signed rank test).

TABLE 4. Average number of thrips caught in greenhouses on sticky blue traps baited with geraniol and on unbaited control traps

Release rate (mg day^{-1})	Host plant	Exp	Temp	Rep	Geraniol AVG	Geraniol SE	Control AVG	Control SE	P
Filter paper[a]	Eustoma	5	22.4	10	100.4	6.6	112.4	6.8	0.241
Filter paper[a]	Chrysanthemum	4	20.8	20	24.6	2.6	24.1	2.7	0.845
Filter paper[a]	Sinningia	7	24.3	20	20.7	3.9	21.0	4.3	0.808
4.1[b]	Cyclamen	7	17.7	5	68.2	2.5	64.4	13.7	0.686
4.1[b]	Chrysanthemum	4	19.5	10	9.6	2.2	10.6	2.3	0.234
12.6[b]	Chrysanthemum	3	18.0	5	2.6	0.7	2.6	0.8	> 0.999
25.9[b]	Chrysanthemum	4	15.8	20	10.8	1.8	8.6	1.9	0.023
25.9[b]	Cyclamen	7	14.6	10	8.8	2.3	6.9	1.8	0.386
28.8[b]	Chrysanthemum	4	15.5	25	3.4	0.7	3.2	0.4	0.974
28.8[b]	Cyclamen	7	15.5	15	21.8	3.3	21.6	3.1	0.798

[a] Geraniol concentration 10^{-3} vol/vol in light paraffin oil.
[b] Release rate estimated from surface evaporation data of geraniol.
Exp = days of trap exposure; Temp = temperature; Rep = number of replications; AVG = average; SE = standard error of the mean; P = probability value (Wilcoxon Signed Rank Test).

the low odour-induced increase in attractiveness that we observed in the greenhouses. Our laboratory assays on the stability of geraniol release rates from surfaces suggest that significant changes in release rates may be caused by changes in temperatures and/or humidity, both being frequent and relatively unpredictable in greenhouses. Air movement may at times have been too low or too high to allow the build-up of a clear odour gradient between baited and unbaited traps, and the distance between the traps may have been too small (Teulon *et al.*, 1993). Our odour concentrations may have been too low to elicit attraction. Alternatively, the higher concentrations used may have been repellent to *F. occidentalis*. Odour attractiveness usually shows a concentration-dependent optimum above which compounds that usually attract insects exert repellency (Soni & Finch, 1979; Wallbank & Wheatley, 1979). This may explain why only one of the concentrations used on Chrysanthemum was attractive and not the lower nor the higher ones. However, the same concentration was not attractive on Sinningia, suggesting that the plant species may influence the response of *F. occidentalis* to geraniol, e.g. by interfering with the insects' receptors for geraniol (see Visser, 1986).

Our results suggest that the increase of trap attractiveness observed in the laboratory may only be reproducible under very specific conditions not necessarily typical for greenhouses. One of the major problems was to provide the appropriate odour release rate to maintain attractiveness over prolonged periods. This problem is also well known from pheromone research, where it is one of the prime factors affecting the success of pheromone traps (H. Arn & E. Mani, Swiss Federal Research Station, Wädenswil, personal communication). Because handling of odours in greenhouses proved to be very difficult, a suitable odour dispenser would have to be developed prior to commercial introduction of this method. The costs of such a dispenser would add to the already considerable costs of the blue sticky traps, resulting in a price per trap that producers may not be willing to pay.

Under the conditions of this study, the use of odours to increase trap catches of *F. occidentalis* in greenhouses is not justified. The moderate trap catch increase found in our study is corroborated by results of Brødsgaard (1990), who found a catch increase of a factor of 1.7 when using anisaldehyde with blue sticky traps, and with results from other thrips species (e.g. Kirk, 1987). However, unscented blue sticky traps are already successfully used in non-flowering plants that are susceptible to *F. occidentalis* attack and in many less susceptible plants can also be used in the flowering stage (Frey, 1993). Preliminary tolerance thresholds for *F. occidentalis* population levels have been suggested for the sticky blue trap Rebell blu (Frey, 1993) and so far seem to provide a robust basis for *F. occidentalis* population monitoring. They also serve as a decision-making tool to assess the optimal time for plant protection measures and are a necessary prerequisite for using beneficials against *F. occidentalis*. We therefore believe that unscented sticky blue traps are already a valuable and necessary tool for *F. occidentalis* population monitoring and that their use should be recommended on all cultures susceptible to *F. occidentalis* attack.

To conclude, our results show that our approach was not successful in increasing the attractiveness of sticky blue traps for *F. occidentalis* in greenhouses. This does not exclude the possibility that further research may reveal an optimal odour cue that synergizes the attractiveness of a specific colour trap. Teulon *et al.* (1993) recently reported a 10-fold increase in attractiveness of yellow water traps baited with *p*-anisaldehyde. With such an increase in attractiveness, increased trap costs may be compensated for by lower numbers of traps necessary for *F. occidentalis* population monitoring; such traps may even be used as effective control measures at least in initial phases of population build-up.

ACKNOWLEDGEMENTS

This project was supported in part by the Verband Schweizerischer Gärtnermeister VSG, the Migros Genossenschaftsbund and Credit Suisse CS. We are grateful to Mettler Toledo AG for providing a MT5 microbalance for the evaporation assay.

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