Decision-making tools for *Frankliniella occidentalis* management in strawberry: consideration of target markets

Moshe Coll¹, Sulochana Shaya¹*†, Inbar Shouster¹‡, Yaakov Nenner¹§ & Shimon Steinberg²

¹Department of Entomology, The Hebrew University of Jerusalem, Rehovot 76100, Israel, ²Bio-Bee Biological Systems, Kibbutz Sde Eliyahu, Beit Shean Valley 10810, Israel

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**Abstract**

The western flower thrips (WFT), *Frankliniella occidentalis* Pergande (Thysanoptera: Thripidae), a cosmopolitan pest of many crops, is considered a major pest of low tunnel and greenhouse strawberries. The extent of damage to strawberry is unclear because different studies have produced contradictory results. Also, economic thresholds published for WFT in strawberry vary greatly, and most fail to incorporate economic factors. This study was aimed at developing a decision-making tool for WFT management in strawberries in Israel. Toward this end, economic injury levels (EIL) and economic thresholds were calculated, based on target markets (export vs. domestic). Results indicate that serious infestation of ripe berries may cause a dull, rough appearance, and the fruit may be soft and have a reduced shelf life, rendering it unsuitable for export. Most fruit damage occurred at green and turning-red stages of development. Two decision-making tools were developed, one for winter, when WFT populations increase slowly but crop value is high (export market); and the second for spring, when the pest increases rapidly but crop value is low (local markets). Economic thresholds of 10 and 24 WFT/flower were calculated for winter and spring strawberries, respectively, based on direct thrips damage to fruit. This calculation does not take into account the recorded WFT damage to flowers, or its role in facilitating *Botrytis cinerea* fruit infection. Western flower thrips has proved only an occasional economic pest in Israeli strawberries, and no routine control measures are warranted. Furthermore, augmentative releases of *Orius laevigatus* or *Neoseilus cucumeris* against WFT are not justified in this system, because *Orius* colonizes strawberry fields spontaneously in high numbers when no broad spectrum insecticides are used.

**Introduction**

Strawberry (*Fragaria* spp.) (Rosaceae) is an intensively managed crop cultivated for its fresh, aromatic red berries. It is an important fruit crop in temperate regions and is popular throughout the world. Nonetheless, attacks by various pests remain a limiting factor for strawberry production and marketing. Until recently, strawberry pests have been controlled conventionally by intensive application of insecticides and acaricides. As is the case in many other agricultural systems, the intensive use of broad-spectrum insecticides has reduced natural enemy populations and has had a negative impact on human health and the environment. More recently, the demands of export and domestic markets have led growers to adopt a biological control-based integrated pest management program in low-tunnel strawberry fields in Israel (Coll et al., 2005). Insect pests are being monitored routinely now and natural enemies are employed in place of chemical control in about 90% of Israeli strawberry fields. When necessary, natural enemy-compatible, low-residual insecticides are...
used (Coll et al., 2005). The program includes mass releases of the predatory mite *Phytoseiulus persimilis* Athias-Henriot (Acarina: Phytoseiidae) against red spider mites and of the parasitic wasp *Aphidius colemani* Viereck (Hymenoptera: Aphidiidae) against the cotton aphid. However, the status of the western flower thrips (*WFT*), *Frankliniella occidentalis* Pergande (Thysanoptera: Thripidae) in the Israeli strawberry crop was unclear until recently, and insecticide applications for its control threatened to jeopardize the entire program.

The WFT is a serious pest of a wide range of crops throughout the world (Lewis, 1997) and is thought to be a major pest of low-tunnel and greenhouse strawberries. Western flower thrips, which first appeared in Israel in 1987 (Argaman et al., 1989), was recently reported to be the dominant thrips species in strawberries in Israel (Shouster, 2003). Chemical control of WFT has proven difficult because of its small size, rapid population growth, and cryptic habits. Some observations suggest that WFT causes flower abortion, fruit bronzing, and fruit deformation in strawberries. Studies have shown that flowers may provide the thrips with essential resources, either by serving as a mating site (Rosenheim et al., 1990) or as a source of high-quality food in the form of pollen (Lublinkhof & Foster, 1977; Trichilo & Leigh, 1988). It was therefore suggested that WFT infestation affects strawberry flowers and fruit, while damage to foliage is negligible.

The extent of *F. occidentalis* damage to strawberry is unknown, as various studies have produced contradictory results. Feeding by thrips on strawberry blossoms may cause stigmas and anthers to turn brown and wither prematurely, but not before fertilization has occurred (Zalom et al., 2005). Because damage to styles and stigmas may lead to irregular fertilization and consequent failure of some achenes to develop, it was suggested that this damage may result in malformation of fruit, sometimes called cat facing or monkey facing (Allen & Gaede, 1963; Buxton & Easterbrook, 1988). The WFT may therefore be responsible for uneven ripening and yield loss (Parker, 2000), both of which reduce grower profits (Houlding & Woods, 1995). It was also proposed that thrips, while feeding on flowers, inject toxic saliva into developing fruit, which can result in deformed fruit (Buxton & Easterbrook, 1988). However, Allen & Gaede (1963), Easterbrook (2000), and Schaefers (1966) also suggested that WFT feeding may sometimes cause fruit discoloration. Finally, Medhurst & Steiner (2001) suggested that WFT feeding may sometimes cause fruit discoloration. The nature of WFT damage to strawberries thus remains ambiguous, and it may be confused with that caused by other pests and diseases (Steiner & Goodwin, 2005).

Materials and methods

**Plants and insect cultures**

*Strawberry plants.* For laboratory and greenhouse experiments, strawberry plants (cultivar 328, Tamar) were grown in a mixture of vermiculite and potting soil (2-L pots transplanted in 2002), and provided with slow release fertilizer (Osmocote®, Marysville, OH, USA) and drip irrigation in a greenhouse on the Hebrew University campus in Rehovot, Israel. The plants were grown under natural light at 20 ± 3°C. The flowers were hand pollinated using a hair paint brush. Spontaneous infestations of aphids and spider mites were controlled with detergent (ZoharNat, Zohar Dalia, Israel), parasitic wasps (*A. colemani*) and predatory mites (*P. persimilis*) (BioBee, Sde Eliyahu, Israel). Mature leaves were occasionally removed.

*Western flower thrips culture.* A WFT culture was established in November 2003 with ca. 150 field-collected adults. The

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WFT were held in glass jars (0.72 l) and provided with pods and seedlings of *Phaseolus vulgaris* (cultivar 4095, Ben Shahar Co., Tel Aviv, Israel). Organically grown pods and seedlings at the two leaf stage were rinsed in water and dried. A 4% sugar solution was then applied to the leaves and pods, and seedlings were placed in small tubes of water sealed with parafilm. The rearing jars were covered with fine mesh gauze for ventilation. At the bottom of each jar, a piece of foam was provided for WFT 'pupation', and filter paper was placed below it to absorb excess moisture accumulating in the jar. The jars were kept in a growth chamber at 25 ± 1°C and L16:D8. Pods and seedlings were replaced every 4–5 days. Upon removal, old pods and seedlings were transferred to new rearing jars containing a fresh bean pod and seedling until all eggs had hatched in about 2 days.

**Timing of WFT-inflicted damage**

Forty strawberry flowers, one per plant, were hand pollinated and caged individually until fruit harvest some 20 days later. The thrips-proof cages consisted of a ventilated plastic container (4 cm high × 10 cm in diameter) fitted over each flower. Three groups of 10 flowers each were infested with 20 adult WFT on each of three consecutive days, each group at a different stage: the flowering stage, the green fruit stage (14 days after flowering), and the turning-red stage (22 days after flowering). The remaining 10 flowers were caged without WFT and served as controls. At harvest, fresh weight, colour, and deformation of fruit were recorded. The experiment was replicated 10 times in a complete randomized block design.

**Western flower thrips facilitation of Botrytis cinerea infection**

The possible role of WFT in facilitating *Botrytis cinerea* infection of strawberry fruit was explored in a greenhouse experiment. Hand-pollinated flowers were caged as described above, and then subjected to one of four treatments: 20 adult and 10 second-instar WFT; 20 adult WFT; without thrips, but with *B. cinerea*-infected bean pods; and control flowers with no thrips or *B. cinerea*-infected bean pods. We did not include *B. cinerea*-infected pods with WFT because the thrips are often exposed to infected pods in culture. The experimental setup therefore simulates a field situation in which WFT move between infected and uninfected plants. Three weeks later, at the early turning-red stage, all fruit were examined for signs of *Botrytis* infection, and their size and fresh weight were recorded. The experiment was replicated five times in a complete randomized block design for a total of 20 fruit.

**Density-dependent WFT-inflicted damage**

Two greenhouse experiments were conducted from March to June 2004 to determine the density-dependent WFT damage to strawberry flowers and fruit. Each experiment consisted of five WFT-density treatments: 0, 5, 10, 15, and 25 adult WFT per flower or fruit, replicated six times. The experiment was replicated over time to ensure uniform, fully opened 1-day-old flowers and pink fruit of uniform size and shape. Insects were caged on an intact mature flower or pink fruit (the most vulnerable stages – see Results) as described above, for four consecutive days under natural light at 20 ± 3°C. The cages were then transferred to the laboratory to determine the number of live and dead WFT, the height and width (at the base) of each flower receptacle (measured under a stereomicroscope), and the presence of symptoms of WFT-inflicted damage on the calyx, achene, and anthers of the flowers, and on the fruit calyx and surface.

The size of the receptacle was established by calculating the surface area of the cone using the following formula: 

\[ \text{surface area of cone} = \pi r^2 + \pi r h \]

where \( \pi = 3.14; r = \text{radius of the receptacle} \); \( p = \text{slant height of receptacle} = \sqrt{h^2 + r^2} \) (derived from Pythagoras theorem), where \( h = \text{height of receptacle} \). Fruit were classified into six damage categories: 

- 0 = no damage
- 1 = light spotting and slight browning of calyx
- 2 = 6–35% surface damage (bronzing and punctures)
- 3 = 36–65% surface damage (bronzing, punctures, and surface russetting)
- 4 = 66–95% surface damage (bronzing, punctures, surface russetting, and sucking parts around the achene)
- 5 = severe damage (category 4 damage over > 96% of the fruit surface)

**Field assessment of WFT-inflicted damage**

Six plots (6 × 7 m) were established in 2002 in commercial strawberry fields near Qadima, Israel. Thrips populations were allowed to build up in half of the plots by applying imidacloprid (0.15%) and chlorfluazuron (0.3%) on 18 March and on 10 and 30 April. These treatments selectively exclude natural enemies, primarily predatory *Orius* species. In the other plots, thrips were selectively excluded by applying spinosad (0.06%) when mean thrips density reached three per flower (i.e., every 2–3 weeks between 5 March and 30 April). Between 12 March and 28 May 2002, thrips and predator populations in the plots were monitored weekly. On each sampling date, the number of insects was recorded in 15 randomly selected flowers per plot. To establish the effect of treatments on flowering, the number of flowers in 10 groups of 10 plants each was recorded in each plot on each sampling date. Aborted flowers (undeveloped with brown receptacle) in the central 5-m row of each plot were also counted. All mature fruit in the central 5-m row of each plot were harvested on each sampling date. They were counted, weighed, and categorizing as: a, export quality (round shape, uniform color, and ≥25 mm in size); b, small (<25 mm – unmarketable); c,
slightly deformed (irregular shape – local market); d, severely deformed (unmarketable); e, unevenly colored (marketable locally if bronzing or rusting does not exceed 15–20 mm² or 30% of the fruit cheek); f, other (unmarketable due to mechanical damage, over-ripening, disease, or other causes). Fruit damage was monitored from 9 April, 5 weeks after thrips were excluded from half of the plots. In this way, we could be certain that all WFT-related damage had been inflicted after manipulation of the thrips population size.

Calculation of economic injury levels and economic thresholds

The EIL was calculated based on the relationship between the level of fruit damage and WFT density, and according to the following formula (Pedigo et al., 1986): 

\[ \text{EIL} = \frac{C}{VID} \]

where \( C \) = cost of WFT control, \( V \) = strawberry market value, \( I*D \) = yield loss per insect (derived from our experimental results). Strawberry production targets export markets during the winter months (December–February) and the local market in the spring (March–June). Because crop value differs greatly between these two markets, we calculated separate EILs for winter (export) and spring (local market). These EILs, however, are calculated for WFT per fruit. Because it is most cost effective to monitor WFT populations in flowers (Steiner & Goodwin, 2005; Shouster, unpubl.), we tested the relationship between WFT density on strawberry fruit and flowers in the field. Fifteen randomly selected strawberry plants were examined in the field, and the density of WFT on three flowers and three pinkish fruit was recorded per plant. The obtained ratio (WFT in flower/fruit) was then multiplied by the calculated EIL for the fruit, to obtain the value per flower.

These EILs were used to calculate the ETs. Field data (Shouster, 2003) show that population rates of increase (\( r \)) for WFT in winter (early January to late February) and spring (March to early April) are 0.027 and 0.046, respectively. To allow for an 1-day response time between scouting and treatment, the ET\(_{\text{export}}\) (winter time) was conservatively set at 67% of EIL\(_{\text{export}}\). For the spring, when temperatures and thrips population rate of increase are higher, ET\(_{\text{local}}\) was conservatively set at 50% of EIL\(_{\text{local}}\).

Statistical analysis

Data of each laboratory and greenhouse experiment were analyzed separately using JMP IN software (SAS Institute, 2001). When necessary, data were transformed to correct homogeneity of variances (Levene’s test). The means were compared using Student’s t-test at a 5% level of significance and are reported with associated standard errors. Correlation analyses were performed to test the relationship between WFT density and flower-damage parameters. Time-serial data from field experiments were subjected to repeated measures analysis of variances (SAS Institute, 2001). Regression and correlation analyses were used to detect the effect of thrips on flower abortion and the relationship between thrips density and fruit damage, respectively. In these analyses, we used the average density of thrips on the week preceding the focal sampling date (e.g., when fruit damage was determined).

Results

Timing of WFT-inflicted damage

The fresh weight of fruit in the control (no WFT) treatments was higher than in the treatments with WFT (Figure 1). This difference was statistically significant only when thrips infestation occurred at the green and turning-red fruit stages. Bronzing (up to 15 mm²) and non-uniform coloration were detected only when thrips were introduced at the turning-red stage. Small rotting spots (2–3 mm in diameter) were detected on two of the 10 fruits that were infested at the turning-red stage. Fruit in all other treatments had a healthy and uniform red colour. No fruit deformation was recorded in any of the treatments and no damage was visible when WFT were introduced onto the flowers.

Western flower thrips facilitation of Botrytis cinerea infection

Fruit size and fresh weight did not differ significantly among treatments. Fruit infection rate, however, differed markedly among treatments: fruit were infected with \textit{B. cinerea} only in the presence of thrips (Figure 2). In these treatments, signs of infection were visible almost
Density-dependent WFT-inflicted damage

Flower damage. Western flower thrips feeding damage to strawberry blossoms was characterized by brown and withered stigmas and anthers. Necrotic spots were detected on the calyx at high thrips densities. Strawberry flower receptacles were significantly smaller at thrips densities >10 per flower than in the control (\(F_{4,20} = 5.41, P = 0.004\)) (Figure 3). Flower receptacle width and height were significantly and positively correlated (\(y = 0.528x + 0.4119; r^2 = 0.6529, P<0.0001\)), and both were significantly smaller at thrips densities >10 per flower than in the control (\(F_{4,20} = 4.8, P = 0.007\) and \(F_{4,20} = 6.87, P = 0.001\), respectively).

Fruit damage. Feeding by thrips on young berries resulted in punctures around the achenes and the appearance of silvery spots. At low WFT densities, light spotting and slight browning of the calyx were visible (Figure 4). At the lowest density (five WFT per fruit), damage to fruit was barely visible and not significantly different from the control (Figure 4). Fruit damage increased significantly with increasing thrips densities (\(F_{4,20} = 46.96, P = 0.0001\)). At higher densities, fruit damage was characterized by bronzing, surface russetting, and feeding punctures on the fruit surface, especially beneath the calyx.

Field assessment of WFT-inflicted damage

Significantly more thrips inhabited flowers in thrips-infested than in thrips-excluded plots (\(F_{1,16} = 75.6, P<0.01; 4.31 \pm 0.49\) and 1.63 \(\pm 0.29\) thrips per flower, respectively), indicating that attempts at manipulating the thrips population were successful. Yet the possible effect of imidacloprid application in increasing probing by WFT (Joost & Riley, 2005) could not be ruled out. Nonetheless, results indicate that bronzing was the only type of damage that differed statistically between thrips-infested and thrips-excluded plots (Table 1); the percentage of fruit that showed bronzing damage was 17.1 \(\pm 2.9\) and 5.4 \(\pm 5.4\) in the thrips-infested and thrips-excluded plots, respectively.
A significant positive regression was detected between thrips infestation level and the degree of bronzing damage to the fruit (y = 4.1x – 0.37; r² = 0.53, P<0.01). Fewer and slightly smaller fruit were harvested in the thrips-infested vs. the thrips-excluded plots (254 ± 24 vs. 300 ± 17 fruit per meter of row, and 9.9 ± 0.2 vs. 10.3 ± 0.3 g per fruit, respectively). These differences were marginally significant (number of fruit: F₁,44 = 3.43, P = 0.076; fruit weight: F₁,44 = 3.71, P = 0.066). Overall, fruit quality was significantly higher in the thrips-excluded than the thrips-infested plots (0.84 ± 0.04 and 0.53 ± 0.02 kg export quality fruit per meter of row, respectively; F₁,44 = 7.26, P<0.01).

The decrease in fruit number in thrips-infested vs. thrips-excluded plots may be attributed in part to increased flower abortion in these plots (15.1 ± 2.9 and 12.2 ± 1.2 aborted flowers per meter of row, respectively). These differences, however, were not statistically significant (F₁,44 = 2.87, P = 0.097). Furthermore, most flower abortion is probably due to factors other than thrips infestation: the number of aborted flowers was found to be negatively correlated with WFT density (y = −3.1539x + 156.04; r² = 0.42, P<0.01). In addition, more flowers are aborted when plants bear many fruit (i.e., flower abortion positively correlated with fruit weight; y = 37.6x + 1.63; r² = 0.52, P<0.01).

**Table 1** Repeated measures analyses of variance for the percentage of strawberry fruit in five damage categories. Fruit damage was monitored over time in *Frankliniella occidentalis*-infested and *Frankliniella occidentalis*-excluded plots

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Light deformation</th>
<th>Severe deformation</th>
<th>Bronzing</th>
<th>Undersized fruit</th>
<th>Other damage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>d.f.</td>
<td>F</td>
<td>P</td>
<td>F</td>
<td>P</td>
</tr>
<tr>
<td>WFT</td>
<td>1,24</td>
<td>2.55</td>
<td>0.12</td>
<td>1.23</td>
<td>0.28</td>
</tr>
<tr>
<td>Date</td>
<td>7,24</td>
<td>4.56</td>
<td>&lt;0.01</td>
<td>4.93</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Date(WFT)</td>
<td>4,24</td>
<td>1.96</td>
<td>0.14</td>
<td>1.37</td>
<td>0.27</td>
</tr>
<tr>
<td>Date*WFT</td>
<td>7,24</td>
<td>0.67</td>
<td>0.69</td>
<td>0.55</td>
<td>0.79</td>
</tr>
</tbody>
</table>

To calculate an EIL for WFT in strawberry, we used the statistics on annual strawberry production and marketing for 2002/03 compiled by the Extension Service, Ministry of Agriculture, Israel. Production costs (C) were fixed at 435 US$ per ha (⇒ 1.47 × 10⁻¹ US$ per fruit), and market value (V) at 4.44 US$ per kilogram and 1.31 US$ per kilogram for export and local market quality berries, respectively. Because our results indicated that turning-red fruit are most susceptible to WFT damage, our analyses refer to the relationship between WFT and fruit at this stage. Experimental results indicate that one WFT per fruit per day leads to a 2.4% reduction in strawberry yield by weight (13 WFT per fruit reduced its weight by 4 g). We therefore set I × D at 0.0003 kg per WFT per fruit. Substituting these values in the equation, the estimated EIL was 5.5 thrips per fruit for export quality fruit and 16.3 thrips per fruit for locally marketed fruit. Our field survey indicated that the density of WFT adults and larvae was about 3–4 times higher on strawberry flowers than on fruit (means of 11.22 ± 1.40 and 2.71 ± 0.41 WFT per flower and fruit, respectively). These results are similar to those reported by Steiner & Goodwin (2005) [4.12 vs. 4.63 (WFT per flower)/(WFT per fruit), respectively]. Because WFT density is 3–4 times higher in flowers than fruit, the estimated EIL was set at 16.5 and 48.9 thrips per flower for export and local market produce, respectively.

These EILs were then used to calculate ETs. To allow for a 1-day response time between scouting and treatment, and in view of WFT rate of population increase in the winter, ETexport was set at 67% of EILexport = 10 WFT per flower. During the spring, when thrips populations multiply more rapidly, the ETFlocal is set at 50% of EILlocal = 24 WFT per flower. It is difficult to differentiate in the field between adults and second-instar WFT, the most damaging life stages of the thrips. The above EIL and ET values are therefore applied jointly to these two life stages.

**Discussion**

The central goal of this study was to determine the relationship between WFT density and damage to strawberry flowers and fruit. The data obtained are central for the development of decision-making tools in integrated pest management (IPM) programmes and are used in conjunction with pest monitoring to guide farmers in pest-control decision-making.

Western flower thrips causes damage to both strawberry flowers and fruit. A significant reduction in flower receptacle size was observed at high thrips density of >25 WFT per flower. Western flower thrips also caused brown and withered stigmas and anthers, and slight necrotic spots on the calyx of the flowers. These findings are in agreement with earlier reports. Gonzalez Zamora & Garcia Mari (2003) reported that feeding by thrips turns strawberry
flowers brown and causes premature withering. Steiner (2002), however, showed that high populations of WFT often cause only slight noticeable damage, with the exception of petal bronzing. Yet, she stated that extremely high adult populations may damage anther bases and prevent pollen maturation.

Only slight damage is in evidence on fruit infested with WFT at lower densities (five thrips per fruit). Higher WFT densities (>25 thrips per fruit), however, caused characteristic bronzing, surface russetting, silvery spots, and punctures around the achenes. Serious infestation of ripe berries may cause a dull, rough appearance, and the fruit may be soft and have a reduced shelf life, rendering it unsuitable for export. Our results indicate that most fruit damage is inflicted at the green and turning-red stages of development. Similar results were reported by Steiner (2002), who suggested that bronzing damage by thrips larva or adults was significant on green and red strawberry fruit when thrips density was ≥10 per fruit and relative humidity and temperature were high.

In Israel, the winter strawberry harvest (December–February) is targeted mostly for export, while the spring crop (March–June) is sold on the local market. Western flower thrips first appears in strawberry fields in the winter (December–January), but becomes well established only in the spring (March–June). The dichotomy of pest phenology and crop-target markets requires separate treatments. Two sets of decision-making tools were therefore developed, one for the winter months, when WFT populations are slow to increase but crop value is high (export market); and the second for spring, when the pest increases rapidly but crop value is low (local markets). Our analyses indicate that the ETs for WFT in strawberry in the winter and spring strawberry crops are 10 and 24 WFT per flower, respectively. These values are conservative estimates of the ET, because they are derived from experiments conducted at somewhat higher temperatures than those experienced in the field, and greater thrips damage occurs at higher temperatures (Steiner & Medhurst, 2003). The threshold values are set for adult and second-instar thrips because these two life stages are easily confused in the field. When flowers are not available, WFT populations can be monitored on red fruit. In that case, three and eight WFT per fruit (i.e., one-third of ET in flowers) should be used as the ET for export and local markets, respectively.

Our calculated ET for the export market is in general agreement with those of Grassely (1995) and Gremo et al. (1997), Laudonia et al. (2000), and Steiner & Goodwin (2005), who suggest that 8–10, 7–15, and 7.5–15 thrips per flower, respectively, represent realistic ETs for thrips in strawberry. Laudonia & Viggiani (1999), however, recommended that control measures be employed at 15–20 thrips per flower. Linder et al. (2000) have suggested lower treatment levels of three to six thrips per flower. It is important to note, however, that all of these studies, with the exception of Laudonia & Viggiani (1999) and Laudonia et al. (2000), involved other thrips species in addition to WFT. Furthermore, most studies failed to incorporate economic criteria in the calculation of the threshold levels (but see Laudonia & Viggiani, 1999). In our study, economic considerations resulted in a much greater tolerance (higher ET) for WFT populations when the product is destined for the local market. It is important to note that we were unable to validate the calculated ET levels because WFT populations generally do not reach the EIL and ET levels we propose based on our experimental results.

Many factors other than pest–crop interactions may influence the calculated thresholds (Higley & Pedigo, 1996). Any change in market price or cost of control measures, for example, will affect the EIL and the resulting dynamic EIL requires recalculation as conditions change. Furthermore, augmentative biological control should be initiated at a lower ET than that set for chemical control. Changes in the rate of pest population growth due to changes in weather also affect the degree of injury by the pest, and this in turn alters the value of the ET in relation to the EIL (Pedigo, 1986).

Activity of WFT enemies, particularly Orius spp. and Neoseiulus cucumeris, is another important factor influencing thrips population size and thus should be incorporated into a decision-making process. Orius species spontaneously colonize Israeli strawberry fields in high numbers (Shouster, 2003), whereas mass releases of predatory mites, such as N. cucumeris, are being made in strawberry fields. The two predators are known to engage in intraguild predation; Orius spp. are intraguild predators of N. cucumeris in pepper (Gillespie & Quiring, 1992), bean (Ramakers, 1993; Wittmann & Leather, 1997), and strawberry (Shakya, 2005). In fact, the contribution of N. cucumeris to thrips suppression is negligible when Orius laevigatus is present (Shakya, 2005). Moreover, both predators also feed on pollen and thus predate significantly fewer WFT in the presence of pollen than in its absence (Shakya, 2005). On the other hand, the presence of pollen also decreases the degree to which Orius bugs feed on N. cucumeris or interfere with the mite’s predatory activity (Shakya, 2005). Both predators should therefore be monitored in strawberry flowers, together with the WFT, and the ET could be adjusted according to O. laevigatus and N. cucumeris densities, and the abundance of pollen. The ET level could be relaxed to a greater degree when pollen is absent from the system, between flowering cycles.

Our calculations of the ET are based on direct thrips damage to fruit, disregarding the damage WFT inflicts on
strawberry flowers, or its indirect role in facilitating B. cinerea infection. Thrips may also be useful in strawberry by pollinating the flowers (Steiner & Medhurst, 2003). Finally, WFT feeds and develops on pollen (Hulshof & Vanninen, 2003), and the presence of pollen affects thrips distribution on strawberry plants and the degree of damage to fruit (Shakya, 2005). Similar results were reported by Higgins (1992) on peppers, by Atakan et al. (1996) on cotton, and by Gerin et al. (1999) on wax flower plants. That WFT may be involved in both pollination and infection of strawberries by pathogens, and that the strawberry flowering cycle (i.e., pollen availability) may affect the dynamics of WFT damage, add new dimensions to assessment of the economic importance of WFT in strawberry. More extensive work is needed to quantify the full economic importance of these complex interactions. Nevertheless, it is important to note that WFT densities never reached the calculated ET values during 3 years of monitoring insecticide-free fields in Israel (Shouster, 2003). In fact, maximum densities of WFT were only 25–30% of the calculated ET during the winter months and approximately 14% of the ET in the spring. It can therefore be concluded that WFT is only an occasional economic pest in strawberry in Israel and no routine control measures are warranted as long as insecticides do not interfere with natural control. Indeed, Orius predators colonize insecticide-free Israeli strawberry fields spontaneously and in high numbers (Shouster, 2003). Results of the present study and the derived recommendations are now being adopted by the vast majority of strawberry growers in Israel; for three growing seasons now, insecticide applications are rare, other pests are being controlled with augmentative releases of natural enemies, and thrips-inflicted damage rarely appears on the fruit. Thus, augmentative releases of either O. laevigatus or N. cucumeris are not warranted against WFT in strawberry fields in Israel (Coll et al., 2005).

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