ABSTRACT

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. The program consists of the mass release 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. A study was launched to assess the potential use of Orius laevigatus (Fieber) (Heteroptera: Anthocoridae) to control the western flower thrips (WFT), Frankliniella occidentalis (Pergande) (Thysanoptera: Thripidae), in strawberry. After first developing economic thresholds for WFT in strawberry, we investigated (i) the ability of O. laevigatus to reproduce on vegetative and reproductive plant parts, (ii) the potential damage to fruits caused by O. laevigatus feeding and oviposition, and (iii) the species composition of the naturally-occurring WFT predator complex in strawberry fields.

ORIUS REPRODUCTION

Laboratory experiments show that O. laevigatus females prefer to deposit most of their eggs in reproductive parts of strawberry plants, including flowers, green, white and ripened fruits, and their petioles. Inspection of strawberry plants collected from commercial fields revealed a similar distribution pattern of O rius eggs. A similar egg deposition pattern was found on field-collected strawberry plants. The egg deposition pattern corresponded with egg hatch: hatching rate was significantly higher for eggs deposited in flowers than in those deposited in leaf tissues.

ORIUS-INFLICTED DAMAGE

To test whether O rius feeding and oviposition cause damage to strawberry fruits, we confined 10 female O. laevigatus on intact flowers, green fruits and white fruits for 72 hrs. After
removing females, we allowed the fruits to develop and recorded their quality at harvest. Inspection of the flowers and fruits revealed an extremely high density of Orius eggs imbedded in plant tissues. Nonetheless, no Orius-inflicted damage was visible on the harvested fruits as compared to controls. Orius feeding and oviposition thus do not inflict appreciable damage to strawberry fruits even at extremely high and un-realistic densities.

PREDATOR POPULATIONS IN STRAWBERRY FIELDS

The predominant WFT predators found in strawberry flowers were Orius albidipennis, Orius niger and predaceous thrips of the genus Aeolothrips.

CONCLUSIONS

In light of the established thresholds, the natural abundance of Orius predators in strawberry fields in Israel, their spatial and temporal co-occurrence with WFT, and their ability to reproduce successfully in this crop, Orius laevigatus could be excluded from the commercial biological control package. This step made the package much more economically attractive to growers and accelerated its implementation, so that more than 80% of the strawberry acreage in Israel is now under a biologically-based integrated management program.

INTRODUCTION

The IPM/biocontrol program in Israeli strawberries was initiated as a direct result of the Western European export market’s demand for significantly lower chemical input in plant protection. During the season of 1998/99, 15 ha. of commercial strawberries were designated as a pilot/demonstration field. Since then, the area encompassed by the program has increased steadily, reaching 300 ha. in the 2004/05 season (Fig. 1), which is ca. 80% of the total strawberry acreage grown in Israel. The majority of the crop is produced under low tunnels on Israel’s coastal plain between the months of September and May. About 120 growers currently participate in the program.

![Figure 1. Area of the Israeli strawberry crop under IPM/biocontrol program.](image-url)
From the onset, the IPM/biocontrol program for Israeli strawberries has been financially supported by the export marketing companies, growers’ association and the Ministry of Agriculture. The technical implementation of the program is conducted by Bio-Bee Sde Eliyahu Ltd, the sole commercial producer of natural enemies for biological pest control in Israel. Professional scouts, supervised by Bio-Bee’s technical advisory service, monitor the IPM/biocontrol plots on a weekly basis. They provide the grower with detailed reports on the status of pests and natural enemies, as well as recommendations for biological or chemical control action.

We report herein on the major biological components of the biologically-based IPM program for Israeli strawberries. Special emphasis is placed on the predatory bug Orius laevigatus (Fieber) (Heteroptera: Anthocoridae) and the rationale behind its exclusion from the commercial biocontrol package.

DEVELOPMENT OF THE BIOLOGICAL CONTROL COMPONENT OF THE PROGRAM

USE OF THE PREDATORY MITE PHYTOSEIULUS PERSIMILIS ATHIAS-HENRIOT (ACARINA: PHYTOSEIIDAE) AGAINST THE RED SPIDER MITE

In most plots, P. persimilis is introduced in early November, when plastic mulch is in place. The red spider mite is present in the majority of the fields at that time. During the last two seasons, the release rate of P. persimilis has stabilized at 20-24 predatory mites per m², a dramatic decrease from the 1999/2000 season when an average of 86 predatory mites were released per m² (Fig. 2). The continuous reduction in predatory mite release rate can be attributed to experience gained by the growers and scouts during the course of the project regarding both timing and mode of introduction of the predatory mites, and to economic considerations: during the last two seasons, growers have paid for P. persimilis on the basis of product used, rather than a lump sum paid in the past for a “biocontrol package” including an almost unlimited supply of natural enemies. In addition, since the 2003/04 season, the new acaricide ‘bifenazate’ has been applied with P. persimilis. ‘Bifenazate’ is harmless to the predatory mites or to any other natural enemies in the system. Hence, it is an ideal chemical for use against the red spider mite in this system, where needed. ‘bifenazate’ is mainly effective against the adult spider mites, allowing P. persimilis to sustain itself on the immature stages (eggs, larvae and nymphs). In this case the biological and the chemical agents act synergistically. During the 2003/04 season, 35% of the 67 participating IPM/biocontrol plots did not correct with ‘bifenazate’ at all, 23% used one application, and 42% corrected selectively in hot spots.

USE OF THE PARASITOID APHIDIUS COLEMANI VIEREC (HYMENOPTERA: APHIDIIDAE) AGAINST THE COTTON APHID

A. colemani is released following a single application of ‘imidacloprid’ or ‘thiamethoxam’ at the beginning of fruit-set. During the last two seasons, the average release rate of A. colemani has ranged from 0.7-1.0 parasitoids per m². As with P. persimilis, this rate also reflects a sharp decrease in the number of parasitoids released per m², from 13 per m² in the 1999/2000 season (Fig. 3). The reasons for this trend are the same as discussed regarding P. persimilis, i.e., experience, economics and availability of compatible aphicides.
USE OF THE PREDATORY BUG *ORIUS LAEVIGATUS* (FIEBER) (HETEROPTERA: ANTHOCORIDAE) AGAINST WESTERN FLOWER THRIPS

During the 1999/2000 winter growing season, an average of 3.5 predatory *O. laevigatus* bugs were introduced per m² of strawberry. There was no significant recovery of this species from the release fields. During the spring of the 2000/01 growing season, an average of 0.8 predatory bugs was released per m². Again, no recovery was recorded of the released bugs. As a result of an intensive research effort (see below), no commercial applications of *O. laevigatus* bugs were made on the subsequent growing seasons in strawberry fields.
ASSESSMENT OF THE PEST STATUS OF THE WESTERN FLOWER THRIPS
AND JUSTIFICATION FOR ORIUS LAEVIGATUS RELEASES

BACKGROUND

The first report of western flower thrips, Frankliniella occidentalis (Pergande) (Thysanoptera: Thripidae) (WFT), in Israel dates back to 1987 (Argaman et al. 1989). This species is reported to be the dominant thrips species on strawberries in Israel (Shouster 2003) and is thought to be a key pest of this crop elsewhere (Allen and Gaede 1963; Tommasini and Maini, 1995). It has been credited for causing serious damage, mainly through flower drop and fruit distortion. Yet the pest status of WFT in strawberries and the nature of the damage it inflicts are the subject for much debate in many parts of the world.

The few published studies provide contradictory reports regarding WFT damage to strawberry. Damage to the flowers is typically caused by feeding punctures (Tommasini and Maini 1995) that lead to browning and premature withering of the stigmas and anthers, occurring after fertilization (Ribes 1990; Zalom et al. 2001). This damage can result in malformation of fruits, sometimes called cat-facing or monkey-facing (Allen and Gaede 1963; Buxton and Easterbrook 1988), which is unacceptable to consumers (Houlding et al. 1995). It has been suggested that thrips inject toxic saliva into the plant tissues, which also results in fruit deformation (Buxton and Easterbrook 1988). However, Allen and Gaede (1963), Easterbrook (2000) and Schaefers (1966) reported that various thrips species did not cause fruit malformation through their feeding but instead sometimes caused fruit discoloration. Damage to styles and stigmas may also lead to irregular fertilization and consequent failure of some achenes to develop. WFT may therefore be responsible for uneven ripening and yield loss (Parker 2004). Feeding by thrips on fruit surface and underlying cells often results in discoloration, sometimes accompanied by a silvery sheen caused by air filling the emptied cells (Lyth 1985). Hancock (1999) suggested that thrips feeding on developing seeds and the tissues between seeds results in damaged, small fruit with a seedy, dull or bronze-colored surface, and unevenly developed berries. Views on WFT-inflicted damage in strawberry thus remain ambiguous. Determining the extent and nature of the damage inflicted by WFT to strawberry flowers and fruits was therefore our first step toward the development of a thrips management program in this crop. Specifically, we (i) characterized damage symptoms, (ii) established WFT thresholds, and (iii) monitored pest population densities and compared them to the established threshold levels.

The second stage of this research involved assessing the possible use of Orius predators (Heteroptera: Anthocoridae) for the biological control of WFT in strawberry. Predatory bugs of this genus, such as Orius laevigatus (Fieber), are known to be effective natural enemies of WFT and are currently used for its control in a number of agricultural systems (Riudavets 1995). Towards this end, we (iv) investigated the ability of O. laevigatus to establish itself and reproduce on strawberries, and (v) determined the natural occurrence of Orius predators and other natural enemies of WFT in strawberry fields.
WESTERN FLOWER THRIPS AS A STRAWBERRY PEST IN ISRAEL

To characterize WFT damage and determine the vulnerable stage of fruit development, we confined 20 WFT adults for three days on flowers and on white, green and pink fruits. The fruits were then allowed to develop to maturity. At harvest, we compared the weight, size, shape, and coloration of fruits from the different treatments (i.e., time of exposure to WFT) to those of uninfested control fruits. In an additional experiment, we varied the number of adult WFT confined for four days on pink fruits (0 to 25 adults per fruit) and assessed the WFT density-fruit damage relationship.

A significant reduction in fruit fresh weight was recorded only when WFT infestation occurred at the green and pink fruit stages. Fruits in these treatments weighed approximately 40% less than controls. Bronzing was the only type of fruit damage attributable to WFT infestation, and this symptom appeared only when thrips fed on pink fruits. Thrips feeding 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. At higher densities, fruit damage was characterized by bronzing, surface russetting and feeding punctures on the fruit surface. WFT-inflicted damage was clearly visible on the fruit surface beneath the calyx; these brown spots due to WFT feeding were particularly apparent at high densities (25 thrips per fruit). No fruit deformation was recorded in any of the treatments and no fruit damage was visible when WFT infestation occurred at the flowering stage. Field experiments, in which thrips populations were kept low in half of the plots but allowed to attain high densities in the others, showed similar results. The field experiments also suggest that WFT may play an important role in flower drop: a tendency toward higher flower drop was recorded in the high-WFT plots in the field. WFT feeding on strawberry blossoms was characterized by brown and withered stigmas and anthers. Necrotic spots were detected on the calyx of the flowers at high thrips densities and flower receptacles were significantly smaller at thrips densities greater than 10 per flower, compared to uninfested control.

These results were used for the establishment of economic thresholds for WFT in strawberry. Two thresholds were established, one for fruits grown for winter export between December and February, and the other for fruits for the local market (March-May). Thresholds for WFT sampling in strawberry flowers were set according to density-damage relations on the fruits, and the recorded ratio of 1:3 of WFT found on fruits and in flowers, respectively. Our calculations indicate that the economic threshold for WFT for exported fruits is 10 adults and second instars per flower. The threshold for the local market was set at 25 adults and second instars per flower.

Weekly sampling of strawberry flowers showed that WFT appears in strawberry fields during the winter, but populations become well established only in early spring. WFT numbers per flower rarely exceed the above thresholds. Typically, an average of 2-7 adult and second instar thrips were found per flower at peak population densities, with high variability among fields and years. WFT density on strawberry flowers began to decrease in April, and the population level remained low until the end of the season (an average of < 2 individuals per flower). Based on our field monitoring, it therefore appears that WFT populations rarely exceed the economic thresholds and, usually, no control measures are warranted against thrips in strawberry.
POSSIBLE USE OF *ORIUS LAEVIGATUS* TO CONTROL WFT IN STRAWBERRY

Laboratory experiments demonstrated that the predatory bug *Orius laevigatus* is able to reproduce on strawberries. Most oviposition takes place on plants that are in the reproductive stages of growth, and oviposition was higher on flowers than on leaves. Flowers and both unripe and ripe fruits were the preferred oviposition sites, and significantly fewer eggs were deposited between flowering cycles, when flowers and fruits were not available. Orius oviposition did not cause any visible damage to strawberry fruits even under excessive deposition of eggs in fruits and flowers (approx. 70 eggs per plant part). These results indicate that while inoculative releases of *O. laevigatus* could be considered for the control of thrips in strawberry, the bugs should not be released before flowers and fruits appear in the field, or between flowering cycles. The establishment of the bug in the field could be confirmed by examining egg deposition in flowers and fruits.

Our field monitoring indicated that the dominant natural enemies of thrips in strawberry flowers were *O. niger* (Wolff) and *O. albidipennis* (Reuter). Contrary to expectations, *O. laevigatus* was rare in our fields. Orius spp. became established in the crop in April and appeared to reduce WFT populations at that time. Other thrips natural enemies that spontaneously occurred in strawberry fields included predatory thrips of the genus *Aeolothrips* and the hymenopteran parasitoid *Ceranisus menes* (Walker).

RECOMMENDATIONS

Taken together, our results indicate that the western flower thrips is not a key pest of strawberries in Israel, and that under most circumstances no steps are needed for its control. WFT is present on the crop mainly during the second half of the growing season (spring), when the market value of the yield is relatively low and the fruit is destined for the local market, which tolerates a moderate level of cosmetic damage. Also, thrips density in flowers is generally kept in check by naturally occurring natural enemies that are abundant in un-sprayed, biological control-IPM fields. The predatory bug *Orius laevigatus* has the potential to serve as an effective biological control agent of WFT in strawberries; it reproduces on the crop, its presence is compatible with standard agrotechnical practices, and it causes no damage to flowers or fruits. In the Israeli strawberry system, however, the release of *O. laevigatus* is not economically justified; other Orius species appear spontaneously in high numbers in insecticide-free fields and the cost of Orius production is prohibitive.

CONCLUDING REMARKS

Several important lessons could be derived from the biological control-IPM program in Israeli strawberry. First, it is important to address all major pests in the system so that all used control measures are compatible with the employed biological control agents. Second, it is crucial to secure, early on, the financial and strategic support of private and government sectors, to allow the development of a viable and sustainable program. Third, to maximize profits, biological control producers and suppliers must not seek to maximize sales of a particular biological control agent. Rather, they should aim at developing a system-wide program, even at the cost of excluding a particular biological control agent from the package. Finally, stake-
holders often include growers, extension people, natural enemy producers, marketing companies, and retailers that spread across several countries. An international coordinated effort is therefore warranted to match the interest of all parties.

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