Associations between *Frankliniella* spp. and *Orius niger* Populations in Cotton

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The distribution of the *Frankliniella* species *F. occidentalis* (Pergande) and *F. intonsa* (Trybom) (Thysanoptera: Thripidae), and of the predatory bug *Orius niger* (Wolff) (Hemiptera: Anthocoridae), in various organs of the cotton plant, as well as prey – predator interactions between thrips and *O. niger*, were investigated over 6 years in cotton fields in the eastern Mediterranean region of Turkey. The highest number of larvae of *Frankliniella* spp. were found inhabiting bolls, whereas the adults colonized mainly flowers. The majority of predatory bug nymphs were present on leaves, followed by bolls, whereas *O. niger* adults visited mostly flowers. The thrips larvae were most likely preyed upon on flowers and squares, and bolls were safe plant parts for thrips, with a low predation rate. An intermediate but relatively high predation rate occurred on cotton leaves. In further field experiments, the effects of insecticide treatment on the relationships between *O. niger* and *Frankliniella* spp. were investigated. These trials revealed that a higher correlation existed between the numbers of adult *O. niger* in flowers and *Frankliniella* spp. in non-treated cotton fields than in insecticide-treated fields. The proportions of prey/predator in flowers ranged from 1.53 to 19.28 and were below four thrips per predator at most sampling dates in some of the non-treated cotton fields. It is concluded that *O. niger* is an effective predator that can play an important role in suppressing population increase of *Frankliniella* spp. in cotton.
KEY WORDS: Plant distribution; biological control; *Frankliniella* spp.; *Orius niger;* cotton.

INTRODUCTION

The flower-dwelling thrips *Frankliniella intonsa* (Trybom) and *F. occidentalis* (Pergande) (Thysanoptera: Thripidae) occur as a species complex in cotton fields of the eastern Mediterranean region of Turkey (2). *F. intonsa* was of minor interest in the cotton fields until the 1990s. In the following years, prior to the occurrence of *F. occidentalis* on cotton, it became the predominant thrips species in this crop, causing high crop losses by attacking young bolls, particularly in late-planted cotton in the region (3). *F. occidentalis* was first recorded from some vegetables in the Mediterranean region of Turkey in 1993. One year later, it colonized cotton plants in the eastern part of the Mediterranean region, within 3 years becoming the predominant thrips species (6). *F. occidentalis* was first detected in the monoculture-cotton area of that region in 1996, and its population levels were very low in 1996 and 1997 (2,5). The recent pest status of *F. occidentalis* in the monoculture-cotton areas is not known. The patched distribution pattern of *F. occidentalis* which existed on vegetation in the region at the beginning, might have changed. The aim of the present study was to determine the changes in the abundance of both thrips species in cotton fields,

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planted at different times, in the monoculture-cotton area. *F. occidentalis* is a known vector of *Tomato spotted wilt virus* that infects many cultivated plants worldwide.

High populations of *Frankliniella* spp. occur in cotton fields of the eastern Mediterranean region during mid-season (2). In an attempt to control the thrips, cotton growers used to spray cotton fields with mixtures of insecticides very often at doses above the recommended ones, with doubtful results presumably due to development of insecticide resistance. It is known that *F. occidentalis* developed resistance to insecticides (7,19). The overuse of insecticides affects negatively beneficial fauna, resulting in outbreaks of secondary pest populations and resurgence of target pests in most cases (12,13,18). Outbreaks of thrips populations were proven experimentally after natural enemies were destroyed by using insecticides (21,26,35). Therefore, an integrated pest management (IPM) approach should be considered first, to solve pest problems. Biological control is a major tool in all outstanding IPM programs.

Numerous predators, parasitoids, parasitic nematodes and fungal pathogens of thrips are recognized (8,25,31). Among the natural enemies, generalist hemipteran predators play an important role in the regulation of thrips populations. The associations between populations of *Orius* spp. and *F. occidentalis* on greenhouse-grown vegetables have been well documented (20,36,41). Although *F. occidentalis* in the USA (28,30,38) and Israel (1,23), and *F. occidentalis* and *F. intonsa* in Greece (10), and *F. intonsa* in China (24), were reported as cotton pests, there is limited knowledge about associations between thrips and their predators in cotton. Management of crop pests through biological and integrated control methods requires a working knowledge of the complex interactions between populations of pests and beneficial insects. Deligeorgidis *et al.* (10) assessed the populations of thrips including *Frankliniella* spp. and the predatory thrips *Aeolothrips intermedius* Bagnall (Thysanoptera: Aeolothripidae) on cotton leaves to estimate the density with an acceptable level of precision. The seasonal abundance of three generalist predators, including *Orius niger* (Wolff) (Hemiptera: Anthocoridae), in relation to populations of adult *Frankliniella* spp. on cotton plants, was studied in the Cukurova region of Turkey (5). In the present paper, the degree of spatial associations between immature thrips and *Orius* on various plant structures has also been investigated, for a more reliable assessment of the predator's potential or actual field efficacy.

Quantifying the within-plant distribution of pests and natural enemies is important for development of cost-effective sampling protocols, which are the basis for all decision-making in IPM programs. Within-plant distributions of predators (42) and western flower thrips on cotton (27) have been examined. In a previous study (1), the effect of cotton variety and development stage on within-plant distribution of two thrips species: *F. occidentalis* and *Thrips tabaci* Lindeman (Thysanoptera: Thripidae), and their predators: *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae), *Deraeocoris pallens* Reut. (Hemiptera: Miridae) and *Orius* spp., were assessed while considering the total numbers of adult thrips and predator species. In the paper, the distributions of immatures and adult *Frankliniella* thrips and *Orius* on plant parts have been quantified separately in a 2-year study.

The present study was undertaken to describe the plant distributions of *Frankliniella* spp. and *O. niger*, and to assess the relationships between populations of thrips and predators on various plant parts, or fruiting development of plants in the cotton fields.

MATERIALS AND METHODS

Experimental fields Field experiments were conducted on cotton cv. 'Çukurova 1518' at Haciali and Balcali in Adana province located in the eastern Mediterranean region of Turkey during the years 1994-1996 and 2000-2003. The experimental fields were planted on 19 April 1994, 19 May 1996, 17 April 2000, 14 April 2001, 5 May 2002, and 12 June 2003 (Field I) and 20 June 2003 (Field II). The cotton fields are considered as normal-planted (15 April – 15 May) and late-planted (after 15 May) in this region. In 2002 the experimental field was close to other experimental cotton fields that were sprayed conventionally against some cotton pests including *Frankliniella* thrips. The other experimental fields were ~2 km distant from the fields grown commercially within the same area in Haciali. The distance between the experimental fields in Haciali and Balcali was ~45 km. The size of fields varied between 100 and 150 ha; cotton rows were spaced 0.75 m apart.

Mineral nitrogen was applied to the soil at a rate of 160 kg ha^{-1}, split into doses of 80 kg ha^{-1} as 20-20-0 (N-P-K) at planting and 80 kg ha^{-1} as 46% urea when the first squares appeared. Fields were furrow-irrigated every 3 weeks after the complete dose of nitrogen had been applied. No pesticides were used in 1994, 1996, 2000 or 2001, whereas they were applied at the recommended doses of the active ingredients acetamiprid 20% (100 g ha^{-1}), lufenuron 50 g l^{-1} (300 ml ha^{-1}) and fenpropatrin + pyriproxyfen 150 + 50 g l^{-1} (1000 ml ha^{-1}) for control of leafhoppers in mid-season in Haciali in 2002, and for control of cotton whitefly *Bemisia tabaci* Gen. (Homoptera: Aleyrodidae) and cotton leafworm *Spodoptera littoralis* (Boisd.) (Lepidoptera: Noctuidae) in mid- or late season in Balcali in 2003.

Distribution and seasonal fluctuations of *Frankliniella* spp. and *O. niger* on cotton structures The experiments were conducted in a field at Haciali from June to September in 1994 and 1996. To determine the distribution of thrips species and the anthocorid predator *O. niger* on various plant structures (*i.e.*, leaves, squares, bolls and flowers), the experimental plots were divided into five sections for sampling. There were four plants within each sub-plot; a total of 20 plants were selected at random per field and inspected visually at weekly intervals for the presence of thrips and predators, using a hand lens with ×20 magnification. To reduce the diurnal variations in insect distribution, all samplings were conducted between 08:00 and 10:00 hours. In the field, thrips species were determined using color and size characteristics, individuals of *F. intonsa* being darker (dense brown) and smaller than those of *F. occidentalis* (light yellow).

Monitoring *Frankliniella* spp. adults and *O. niger* on cotton flowers The field studies of seasonal fluctuations of *Frankliniella* spp. and *O. niger* were conducted in one normal-planted cotton field at Haciali in the years 2000 – 2002 and one late-planted field each at Haciali and Balcali in 2003.

Experimental fields were divided into five equal sections for sampling. Five flowers (one upper flower from each plant) within each sub-plot, for a total of 25 flowers, were picked at random at weekly intervals at 10:00 – 11:00 hours (4), put separately into plastic cups (250 ml), and placed in insulated cool containers and transferred to the laboratory. Flowers were kept for 1 or 2 h in a deep-freezer and then tapped onto a white plastic sheet. The extracted thrips and predators were collected with a fine brush and placed in plastic tubes (2 ml) containing 60% ethyl alcohol for the identification process. Flowers were dissected to remove any remaining thrips on flower parts and rinsed in a

2% detergent solution for 25 sec. The solutions were poured through the sieves. Thrips extracted from the solution were transferred to plastic tubes. Thrips were slide-mounted and identified to species. Thrips and predators were counted under a steromicroscope with ×45 magnification; thrips larvae were pooled into one category. Because another anthocorid species, *O. laevigatus* (Fieber), had very low population densities on the plants during the samplings, its population density was not included.

Plant phenology To determine associations between the generative phase of cotton growth (forming of squares, flowers and bolls) and thrips populations, five plants were selected at random from each sub-plot. The number of fruiting structures were recorded for each plant during the monitoring procedure.

Data analysis Distribution data of thrips and *O. niger* were pooled over each plant part at each sampling date. The relations between larvae of thrips and nymphs of *Orius* on various parts of plants in 1994 and 1996 were assessed because seasonal fluctuations of the adult *Frankliniella* spp. and *O. niger* in the cotton flowers had been studied by Atakan and Ozgur (5). Thrips and predators collected at each sampling date were divided by the numbers of plant parts sampled to obtain an average number of thrips per structure. The numbers of thrips larvae and *Orius* nymphs in flowers in 2000 – 2003 were excluded from data analysis due to their very low numbers. Measurement of the predation on various plant parts was done by dividing overall numbers of thrips larvae per plant structure by overall numbers of *Orius* nymphs. Associations between thrips larvae and predator nymphs were investigated using a total of 14 and 16 data points in 1994 and 1996, respectively. To determine the degree of associations between the mean numbers of thrips and predators or flowers throughout the sampling periods, a total of ten data points were qualified per year. All relations were examined by a simple correlation test (Pearson correlation) at $P \leq 0.05$. Ratios of thrips larvae to *Orius* nymphs on all plant structures were subjected to analysis of variance (ANOVA) and significant differences were identified by Duncan's multiple range test ($P \leq 0.05$). Data were log-transformed (x+1) prior to analysis of variance in order to correct for heterogeneity of variance. All analyses were performed using the SYSTAT version 9.0.1 statistical package (33).

RESULTS

Distribution of *Frankliniella* spp. and *O. niger* on cotton structures According to the data presented in Table 1, most thrips larvae were found on bolls (55.2–66.3%), followed by leaves (22.4–33.8%), whereas few thrips larvae were recorded in flowers. *Frankliniella* spp. and *O. niger* adults were found mostly on flowers. Most nymphs of *O. niger* colonized leaves (65.1–73.8%), followed by bolls (15.8–17.7%). Squares were less favorable plant structures for predatory nymphs. Adults of *O. niger* occupied mainly flowers (66.0–74.8%). There were only few adults of *Orius* on the bolls and squares during the samplings.

Prey-to-predator ratios on squares, flowers and bolls were similar and significantly lower than those of leaves in 1994 (F=4.885; P=0.032; df=3,11) (Table 2). In 1996, prey:predator ratios on leaves and bolls were similar but significantly higher than those on squares and flowers (F=3.876; P=0.024; df=3,24).

Seasonal fluctuations of thrips larvae and *Orius* nymphs on plant parts The mean number of thrips larvae on all plant structures was generally much higher in the late-planted field in 1996 than in 1994 (Figs. 1 and 2). The mean number of thrips larvae

TABLE 1. Distribution of immatures and adults of *Frankliniella* spp. and *Orius niger* on various cotton structures in Adana province, Turkey, in 1994 and 1996

Year/insect[z]	Distribution of *Frankliniella* thrips or *Orius niger*[y] (%)							
	Immature				Adult			
	Leaves	Squares	Flowers	Bolls	Leaves	Squares	Flowers	Bolls
1994/Thrips	33.8	4.9	6.0	55.2	0.3	<0.1	99.5	<0.1
1994/*O. niger*	65.1	13.8	3.4	17.7	12.2	4.6	74.8	8.4
1996/ Thrips	22.4	2.2	9.1	66.3	<0.1	<0.1	99.7	<0.1
1996/*O. niger*	73.8	7.0	3.4	15.8	17.0	11.3	66.0	5.7

[z]Thrips = *Frankliniella occidentalis* plus *F. intonsa*.
[y]Averaged over all samples in each year.

TABLE 2. Prey:predator ratios on various cotton structures in Adana province, Turkey, in 1994 and 1996

Year	Prey:predator ratios on various plant structures[z]			
	Leaves	Squares	Flowers	Bolls
1994	1.04±0.19a[y]	0.18±0.05b	0.13±0.11b	0.59±0.52b
1996	1.05±0.67bc	0.98±0.36c	0.18±0.13c	2.37±0.56ab

[z]Values were calculated from raw data; analysis of variance was performed on log (+) values.
[y]Within rows, means (± SEM) of prey:predator ratios followed by a common letter do not differ according to Duncan's multiple range test ($P \leq 0.05$).

was low on the squares and flowers but high on the leaves and bolls in both years. Two peaks of thrips larvae were noticed on leaves in mid- and late-season in 1994. Seasonal fluctuations of *Orius* nymphs on plant structures varied in 1994 and 1996. Nymphs of *Orius* were associated with the population of thrips larvae on leaves and bolls. The relation between the numbers of thrips larvae and *Orius* nymphs on leaves was significant in both

TABLE 3. Correlation analysis between numbers of thrips larvae and *Orius* nymphs on various plant structures in cotton fields in Adana province, Turkey, in 1994 and 1996

Year	Plant structures	*P*	*r*
1994	Leaves	0.0001	0.925**
	Squares	–[z]	–
	Flowers	0.049	0.459
	Bolls	0.0001	0.858**
1996	Leaves	0.0001	0.934**
	Squares	0.210	0.216
	Flowers	0.281	0.157
	Bolls	0.0001	0.939**

*Asterisks denote correlations significant at $P \leq 0.01$.
[z]Correlation was not calculated because of low values of both thrips larvae and *Orius* nymphs on squares in 1994.

TABLE 4. Correlation analysis between numbers of flowers and total thrips in cotton fields in Adana province, Turkey, in 2000–2003

Year	Planting date	*P*	*r*
2000	Normal	0.166	-0.433
2001	Normal	0.144	-0.446
2002	Normal	0.480	-0.018
2003	Late / Field I	0.026	0.664*
	Late / Field II	0.001	0.877**

*,** Asterisks denote correlations significant at $*P \leq 0.05$, $**P \leq 0.01$.

TABLE 5. Correlation analysis between numbers of *Orius niger* and *Franklinella intonsa* or *F. occidentalis* on cotton flowers in Adana province, Turkey, in 2000–2003

Year	Plantings/ field	Insecticide application	Correlations	*P*	*r*
2000	Normal	No	*O. niger* and *F. intonsa*	0.264	0.417
			O. niger and *F. occidentalis*	0.001	0.887**
2001	Normal	No	*O. niger* and *F. intonsa*	0.364	0.304
			O. niger and *F. occidentalis*	0.016	0.702*
2002	Normal	Yes	*O. niger* and *F. intonsa*	0.232	0.393
			O. niger and *F. occidentalis*	0.535	0.210
2003	Late/ Field I	No	*O. niger* and *F. intonsa*	0.035	0.703*
			O. niger and *F. occidentalis*	0.004	0.845**
	Late/ Field II	Yes	*O. niger* and *F. intonsa*	0.657	0.173
			O. niger and *F. occidentalis*	0.640	0.182

*,** Asterisks denote correlations significant at $^*P\leq0.05$, $^{**}P\leq0.01$.

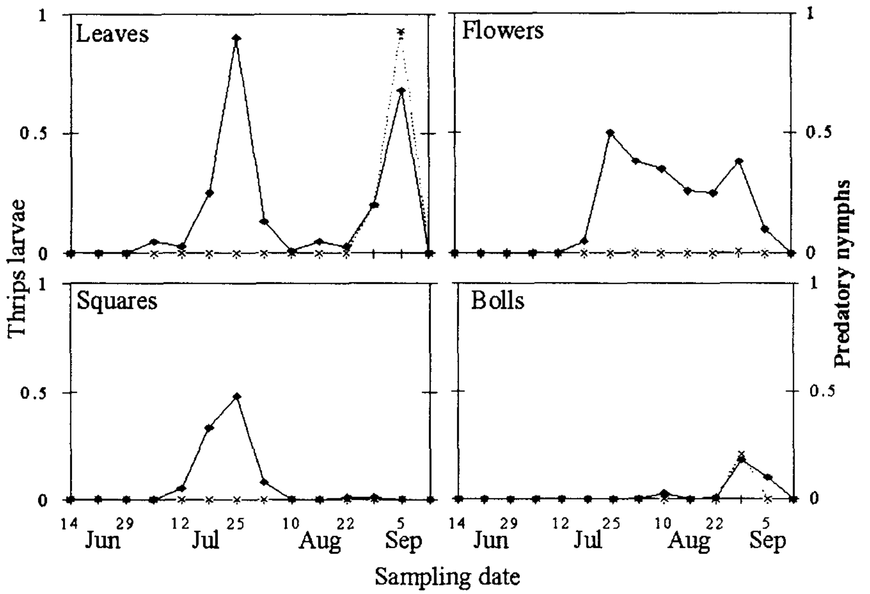

Fig. 1. Mean numbers of thrips larvae and predatory nymphs of *Orius niger* on various plant structures of cotton in Haciali, Turkey, in 1994. Broken line, thrips larvae; solid line, predatory nymphs.

years ($P\leq0.05$) (Table 3). There were also significant correlations between the number of nymphs on bolls and the number of larvae in both years ($P\leq0.05$). However, the relationships between *O. niger* and thrips larvae on flowers and squares remained steady at very low or negligible levels.

Seasonal fluctuations of *Frankliniella* spp. adults and *O. niger* on cotton flowers The seasonal fluctuations of adult *Frankliniella* spp. thrips and *O. niger* parallel the fruiting development of plants in the normal-planted cotton fields (Figs. 3a, b). The highest population densities of *Frankliniella* spp. coincided with the late-blooming period of plants in all years. *Frankliniella* spp. peaked in the flowers at boll formation or maturation

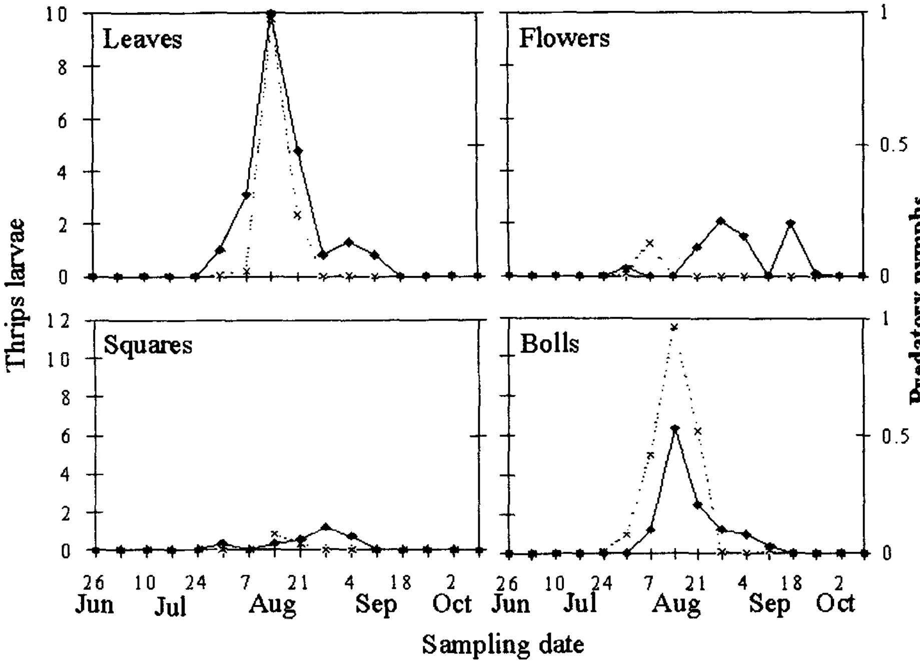

Fig. 2. Mean numbers of thrips larvae and predatory nymphs of *Orius niger* on various plant structures of cotton in Haciali, Turkey, in 1996. Broken line, thrips larvae; solid line, predatory nymphs.

stage, and mean numbers of squares and flowers were relatively low in the normal-planted cotton fields during 2000–2002. Correlations between mean numbers of *Frankliniella* spp. and flowers were not significant (P>0.05) (Table 4). Trends in the seasonal fluctuations and abundance of thrips species were similar in both fields in 2000 and 2001. Thrips populations usually peaked in mid-August and then gradually decreased to low levels. The mean numbers of *F. occidentalis* and *F. intonsa* were higher in 2002 than in 2000 and 2001. *F. occidentalis* rapidly colonized flowers and increased to its highest population level in mid-July in 2002. After the second application of insecticide (acetamiprid 20%), *F. intonsa* increased rapidly to a peak level in the flowers in late August, when population densities of *F. occidentalis* and *O. niger* were low (Fig. 3b).

Population fluctuations of thrips species and *O. niger* according to fruiting development of plants in late-planted cotton fields in 2003 are displayed in Figures 4a and b. In the two late-planted fields, the population curves of *F. intonsa* and *F. occidentalis* were usually similar, but their densities were different. In treated field II, population densities of *F. occidentalis* were higher than in other fields except in 2002. The highest levels of total thrips populations coincided with a peak bloom of cotton, and correlations between numbers of *Frankliniella* spp. and flowers were significant in both field I and field II ($P\leq$0.05) (Table 4).

The population density of *O. niger* was significantly correlated with that of *F. occidentalis* in normal-planted cotton fields in 2000 and 2001 ($P\leq$0.05) but not with *F. intonsa* populations (P>0.05) (Table 5). In these fields, *Orius*-to-*Frankliniella* spp. ratios

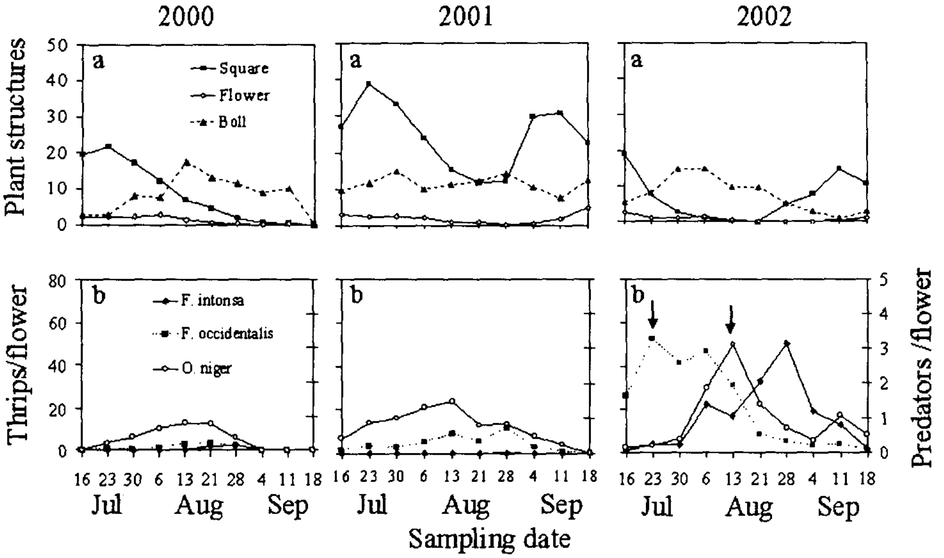

Fig. 3. Mean numbers of *(a)* plant structures per cotton plant, and of *(b)* adults of *Frankliniella* spp. and *Orius niger* on cotton flowers in Haciali, Turkey, during the years 2000, 2001 and 2002. Arrows indicate sprays against leafhoppers.

ranged from 1:2 to 1:15 in the course of the season. Significant correlations were also detected between *Orius* and *F. occidentalis* and between *Orius* and *F. intonsa* in the late-planted field I in 2003. The ratios of predator-to-prey in this field varied between 1:8 and 1:19 from the second to sixth sampling. The mean numbers of *Orius* in flowers in the insecticide-treated fields in 2002 and 2003 were lower than those in other fields (Figs. 3b and 4b). There was no correlation between thrips and predator populations in either insecticide-treated field ($P>0.05$) (Table 5). The ratios of predator-to-total thrips ranged between 1:12 and 1:29 in 2002, and 1:36 and 1:16 in 2003.

DISCUSSION

The majority of thrips larvae infested cotton bolls (~60%), whereas adults of *Frankliniella* thrips species visited mostly flowers. These results are in agreement with the findings of Pickett *et al.* (27), who determined that the proportions of thrips larvae on leaves and bolls were higher than on other plant parts and that adult thrips were attracted most by cotton flowers. The low abundance of adult thrips on bolls and leaves may reflect rapid escape rather than low occurrence. Therefore, the flower sampling method is much more precise for estimating the abundance of flower-inhabiting thrips on cotton. Most nymphs of *O. niger* colonized leaves and to a lesser extent bolls. The high density of *Orius* nymphs on leaves was related to high densities of another prey, the cotton aphid *Aphis gossypii* Glov. (Homoptera: Aphididae), which fed on leaves during mid-season in both years, prior to the occurrence of the main colonization of flowers by *Frankliniella.* Thereafter, *Orius* nymphs inhabited the bolls, infested by most thrips larvae for several weeks late in the season. In contrast, data were obtained by Wilson and Gutierrez (42) for nymphs of *Orius tristicolor* (white) during the peak period of square retention (mid July), and the highest proportion of the population occurred on cotton fruit, in San Joaquin Valley. Gonzales *et*

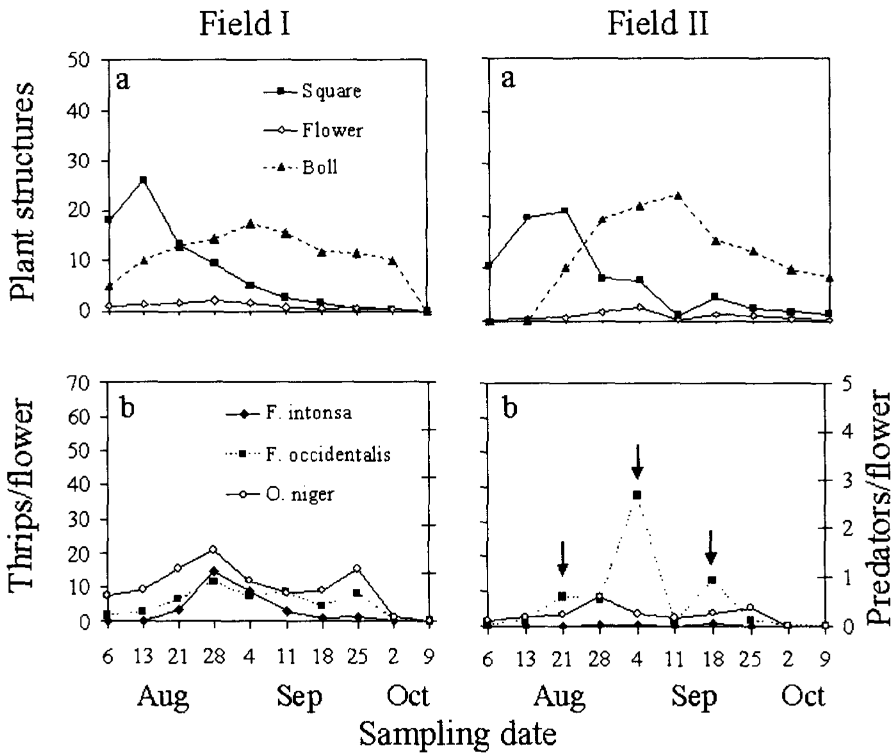

Fig. 4. Mean numbers of *(a)* plant structures per cotton plant, and of *(b)* adults of *Frankliniella* spp. and *Orius niger* on cotton flowers in Haciali (Field I) and Balcali (Field II), Turkey, in 2003. Arrows indicate sprays against whitefly and cotton leafworm.

al. (16) reported that immatures of generalist predators, *viz. Orius, Nabis, Geocoris* and *Chrysopa,* were less accessible because of their tendency to hide inside fruiting parts of the cotton plant. This was particularly true for *Orius* nymphs, and to a lesser extent for adults. The occurrence of a high proportion of nymphs on fruits in previous work may be due to their protecting themselves from predacious attacks of other generalist feeders – which were highly abundant on the plants – nearly all of which are cannibalistic and feed on other predator species (42). In contrast, in the present study, the numbers of other generalist predators were fewer on plants and a vast number of their prey were present. Thus, the results may suggest that distribution of *Orius* nymphs on cotton plants changes according to availability of the different preys, when other generalist predators are scarce. Adults of *O. niger* were attracted mostly to flowers. Some reports indicate that *O. tristicolor* adults readily visit cotton flowers (42) and also feed on plant pollen when other prey is scarce (11,22,32).

Frankliniella intonsa was the dominant thrips species in cotton flowers in the monoculture-cotton areas of the eastern part of Turkey's Mediterranean region in the years 1994-1997 (5). Recently, *F. occidentalis* spread quickly to all cotton areas, becoming the dominant thrips species, and displaced *F. intonsa* within 4 years after its first introduction into the monoculture-cotton area in the eastern Mediterranean in 1996. Among the 33,041 adult thrips extracted from flowers during the 4-year study, *F. occidentalis* represented

~70% of the total number of adult thrips collected. *F. occidentalis* is a better competitor because the females are highly fecund [up to 230 eggs per female: K.L. Robb (1989) Ph.D. thesis, Univ. of California, Riverside, CA, USA] and may colonize the same host plant for several generations. The ability of adults to detect shifts in host quality and to disperse, greatly contributes to their reproductive success (37).

Adults of *F. intonsa* were not detected on plants until flowering, but a few adults of *F. occidentalis* were recorded on seedlings also populated by red spider mites in the early season. In contrast, in cotton fields in Greece, *F. intonsa* was found to be the most numerous species early in the sampling period (May – June) and also during the last samplings (September) (10). This may be due to the effect of various ecological factors occurring in each geographical area. The numbers of *Frankliniella* spp. peaked in the flowers at similar sampling periods, mid-or-late August, in the normal- or late-planted fields. The occurrence of high numbers of thrips species in a few flowers at boll formation or during the maturation period in the normal-planted fields might have been due to migration of thrips from other host plants, including weeds near by or late-season crops, to cotton fields. Seasonal fluctuations in the abundance of flower thrips on cotton did not show the seasonal patterns in the number of cotton flowers in the normal-planted fields. Significant correlations between the numbers of thrips and flowers in the late-planted fields suggest that cotton serves as a preferred host for these thrips species in the eastern part of Turkey's Mediterranean region.

The mean numbers of thrips larvae were greatly reduced to low or even extinction levels after peaks of predatory nymph numbers in both years. Although adult *F. intonsa* on flowers slightly exceeded the threshold level of 50–75 adults per flower (3) for 4 weeks in 1996 (2), no damage caused by larvae was noticed. This presumably was due to high predatory activity of *Orius* nymphs, since other generalist predators were very rare on the plants during the sampling periods in both years. Overall, thrips larvae were most likely preyed upon on flowers and squares (0.92 and 0.47 prey per predator, respectively), and bolls were safe plant parts – with a low larval predation rate (11.57 larvae per predator). An intermediate but relatively high predation rate occurred on leaves (4.72 larvae per predator). These results agree with findings of a previous study in Israeli cotton fields where thrips were most likely preyed upon on squares due to overall numbers of polyphagous predators: *D. pallens, C. carnea* and *Orius* spp., and an intermediate but relatively high predation risk occurred on the leaves of both Pima and Acala cotton plants (1).

Strong correlations between prey and predator populations may not be used as an indication of strong predatory ability. For instance, strong correlations in flowers may be the result of thrips and *Orius* aggregation in response to pollen availability (flower-inhabiting thrips species and *Orius* readily feed on pollen). Although in this study a specific experiment had not been planned to investigate the efficiency of *O. niger* on cotton thrips, there were significant and positive correlations between thrips and predator populations in the flowers in non-treated fields but not in the treated fields. The occurrence of *Frankliniella* spp. populations at lower densities in the flowers throughout the season in untreated fields may have been due to the high predation by *Orius*. The abundance of thrips in flowers in insecticide-treated fields was much higher than in untreated fields. The use of insecticides in the fields might have resulted in an increase of both thrips populations, while suppressing the populations of *Orius*. Ripper (29) suggested that negative or no correlations between predator and prey could indicate prey resurgence or outbreaks of a target pest after the elimination of predators. Stoltz and Stern (34) found that numbers of *F. occidentalis* and *Orius* were clearly reduced in plots treated by dimethoate and naled + toxaphene in cotton fields, whereas thereafter the population of *F. occidentalis* peaked due to the elimination of generalist predators. The predator *O. insidiosus* (Say) effectively suppressed population increases of *Frankliniella* spp. on pepper flowers in non-treated plots, and elimination of the predator by use of synthetic pyrethroids resulted in permanent thrips infestations (14).

The low levels or absence of thrips larvae in the flowers in 2001–2003 may show the predacious effects of *Orius*. Immature thrips are easily preyed upon by predators because they are less mobile and smaller than adult thrips. A similar case was reported by Deligeorgidis (9), who found that in laboratory experiments *O. niger* was an effective predator of thrips species including *Thrips tabaci* Lindeman and *F. occidentalis*, and had promising potential for use in greenhouses. Under laboratory conditions, adult *O. niger* mostly preferred immature thrips to adult thrips.

The insecticide applications never reduced predator populations to extinction levels and allowed the survival of predators to a low extent. This may be a reason for thrips never exceeding the economic threshold level on flowers in the treated fields. It was noted that no typical damage caused by thrips appeared on plants, particularly in late-planted and sprayed fields. In a previous study, the serious damage caused by large populations of *Frankliniella* spp. was observed on young plants in late-planted commercial cotton fields, where predatory species such as *O. niger* were rarely found (3).

Increased efficiency of a predator on prey populations most likely depends upon associations between predators, the predator:prey ratio, and the time needed to suppress pest populations, which are important factors for a better understanding of prey – predator dynamics. Delayed suppression of thrips populations was assumed for anthocorid:thrips ratios above 1:217, and immediate suppression of populations within 6.5 days at predator:prey ratios above 1:50 (40). In the present study, the ratio of prey to predator ranged from 1.53 to 19.28 and was below four adult thrips per *Orius* on most sampling dates in 2000 and 2001. Funderburk *et al.* (14) found that numbers of *F. occidentalis* and larvae colonizing field peppers were close to extinction level within days after predator:prey ratios had reached 1:40. The results obtained from the non-treated fields may indicate that thrips on cotton flowers might have suffered most from predation induced by *O. niger*, because prey:predator ratios were often lower than the ratios previously published.

Although usually phytophagous, *F. occidentalis* is known to feed on small insects including tetranychid mites (17,39). The importance of *F. occidentalis* as the major natural enemy of spider mites in the early growing season in San Joaquin Valley cotton has been demonstrated (15,17,39). Without thrips, serious damage occurs (17,43). Gonzales and Wilson (17) stated that thrips inhabited flowers late in the growing season of cotton and were less effective predators of spider mites. Pollen may be a better food source for thrips than leaves. Availability of alternative food, and food quality, may affect late-season control of spider mites in this system. Additionally, although there is no observation on the interaction between *F. occidentalis* and spider mites in this study, spider mites may have been less affected by preying of this thrips in mid- or late-season cotton, because of the high predation of *F. occidentalis* by *Orius* during that period in the non-treated fields. *F. occidentalis* offers an alternative prey for some generalist predators such as *Geocoris pallens* (Stal), *G. punctipes* (Say) and *O. tristicolor* in cotton fields (17).

Clearly, the identified distributions of larval thrips and *Orius* nymphs to plant parts suggest that cost-effective monitoring of populations of these insects could be achieved by sampling leaves and bolls rather than other plant parts. Likewise, the population densities of adult thrips and *O. niger* could be estimated by examining the flowers. The absence of a significant positive relationship between mean numbers of total thrips and of fruiting structures, mainly flowers, may indicate that normal-planted cotton in the region serves as a temporary host for thrips species, rather than as a favorable host for their development. Furthermore, late-planted cotton fields are presumably more damaged by flower-inhabiting thrips species, since significant correlations are often found between mean numbers of thrips and of flowers. Therefore, it is suggested that avoiding late-planting of cotton fields will be an important cultural practice in flower-inhabiting thrips management. The findings of this study suggest that using insecticides to control the flower-inhabiting thrips species in normal-planted cotton fields is needless because (i) plants have enough bolls to recover and produce sufficient yield, when main infestations of *Frankliniella* spp. occurred, and (ii) the number of flower exposed to thrips infestations is low and most bolls will mature. With regard to thrips – predator interactions, the results suggest that *Orius* spp. may play a more important role in regulating populations of thrips on cotton because (i) positive and significant correlations were recorded between thrips and predator populations, and (ii) prey:predator ratios in non-sprayed fields were lower than the ratios previously predicted and published.

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