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Seasonal abundance of parasitoids (Hymenoptera: Braconidae, Aphidiinae) and predators (Coleoptera: Coccinellidae) of aphids infesting citrus in Greece

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Field experiments were carried out in a citrus orchard in Greece for two years in order to examine the role of aphidophagous insects in the population reduction of aphids infesting citrus. The aphid species found were: *Toxoptera aurantii*, *Aphis (Aphis) gossypii* and *Myzus (Nectarosiphon) persicae* (Hemiptera: Aphidoidea). Among these species *T. aurantii* was by far the most abundant. The aphidiine parasitoids recorded from *T. aurantii* were in decreasing order: *Aphidius colemani*, *A. matricariae*, *Diaeretiella rapae*, *Praon volucre* and *Ephedrus persicae* (Hymenoptera: Braconidae, Aphidiinae). In the case of *A. gossypii*, the aphidiine parasitoids emerged were in decreasing order: *Binodoxys angelicae*, *A. colemani* and *D. rapae* (Hymenoptera: Braconidae, Aphidiinae). In contrast, *M. persicae* was not found to be parasitized. The parasitization of *T. aurantii* was significantly higher than that of *A. gossypii*. Coccinellid species found were: *Scymnus (Pullus) subvillosus*, *S. apetzi*, *S. rubromaculatus*, *Coccinella septempunctata*, *Adalia bipunctata*, *A. decempunctata, Hippodamia (Semiadalia) undecimnotata*, and *Propylaea quatuordecimpunctata* (Coleoptera: Coccinellidae). The species of the genera *Scymnus, Coccinella* and *Adalia* were the most abundant.

Key words: Aphidiinae, Coccinellidae, aphids, citrus, parasitoids, predators.

Introduction

Aphids are very important citrus pests in several citrus growing areas of the world causing great damage both directly and indirectly (Barbagallo & Patti, 1983, 1986; Kavallieratos & Lykouressis, 1999, 2000; Kavallieratos et. al., 2002b). However, aphids have several natural enemies such as aphidiines and coccinellids that can affect their numbers (Starý, 1970; Hodek & Honěk, 1996). In Greece, nine aphid species have been reported to infest citrus trees (Kavallieratos & Lykouressis, 1999, 2000; Kavallieratos et al., 2002a, b). Furthermore, 11 aphidiine species have been reported to parasitize and ten coccinellid species to prey on aphids infesting citrus in Greece (KATSOYANNOS, 1996; KATSOYANNOS et al., 1997; KAVALLIERATOS & LYKOURESSIS, 1999, 2000; KAVALLIERATOS et al., 2001, 2002a, b).

Recent work has focused on the study of the abundance and the patterns of host utilization of aphid parasitoids on citrus and the interactions among parasitoid species and host density responses (KAVALLIERATOS et al., 2002b). There are also many reports on the parasitoids and predators of aphids infesting citrus. In the current study, it was considered necessary for the simultaneous study of coccinellid and aphidiine abundance on aphids infesting citrus as very little data is available (MICHELENA & SANCHIS, 1997).

Material and methods

In 2000 and 2001, samples were taken every week, from an untreated citrus orchard in Central Greece (Marathon) (38°09′ N, 23°57′ E) covering an area of 8,500 m^2, planted with approximately ten years old, orange trees. Twenty young shoots (two shoots per tree), 20 cm long, were randomly collected on each sampling date (KAVALLIERATOS et al., 2002b).

Each sample was placed separately in a plastic bag. These bags were taken to the laboratory where aphids were identified to species. Live aphids were preserved in a 2:1 ratio of 90% ethyl alcohol and 75% lactic acid (EASTOP & VAN EMDEN, 1972). Mummies, attached on a small leaf piece each, were placed separately in small plastic boxes inside a growth cabinet. On the lid of each box was a circular opening covered with muslin for ventilation in order to maintain similar conditions inside the boxes to those existing in the growth cabinet (22.5 ℃, 65% R.H., 16:8 h light:dark regime). The percentage of parasitization was estimated by calculating the number of mummified aphids to the total number of aphids (TOMANOVIĆ et al., 1996; KAVALLIERATOS et al., 2002b, c).

Coccinellids were sampled by beating six randomly chosen branches of trees with a rubber-covered stick over a 1-m^2 cloth screen. The number of adults and larvae of the predators that were dislodged was recorded. Predators were returned to the leaves on the trees with the aid of a small brush (STATHAS, 2001). Regarding the genus *Scymnus* the total number of individuals of all species was recorded. The species of this genus were identified at the adult stage.

Finally, the number of the destroyed mummies (preyed upon) found in each sample was also recorded. They were recognized by the edges of the irregular holes made by coccinellids (darkly stained) (FRAZER & GILBERT, 1976).

Data were analyzed by one-way ANOVA using the statistical package JMP (SALL et al., 2001). Means were compared with the Tukey – Kramer (HSD) test (at $P = 0.05$).

Results

The numbers of aphids recorded in each sampling year of the study were high mainly from the end of April until the beginning of June (Fig. 1). Orange trees were infested by the aphids *Toxoptera aurantii* (Boyer de Fonscolombe, 1841), *Aphis (Aphis) gossypii* Glover, 1877 and *Myzus (Nectarosiphon) persicae* (Sulzer, 1776) (Fig. 1). ANOVA showed significant differences between the species of aphids that infested orange trees ($F = 26.61$, df = 2, 36, $P < 0.0001$ in 2000, $F = 10$,

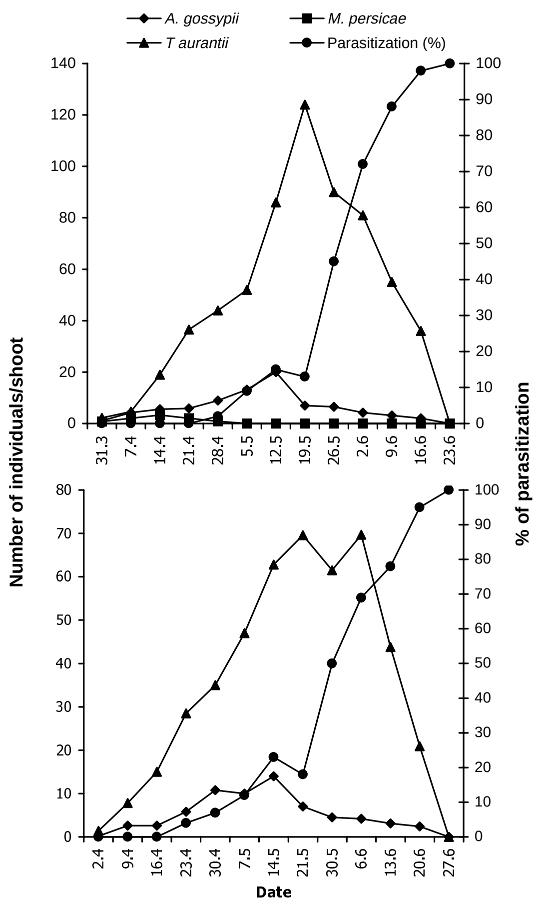

Fig. 1. Percentage of parasitization and number of aphids per shoot (live and mummified) found on orange trees in C Greece in 2000 (top) and 2001 (bottom).

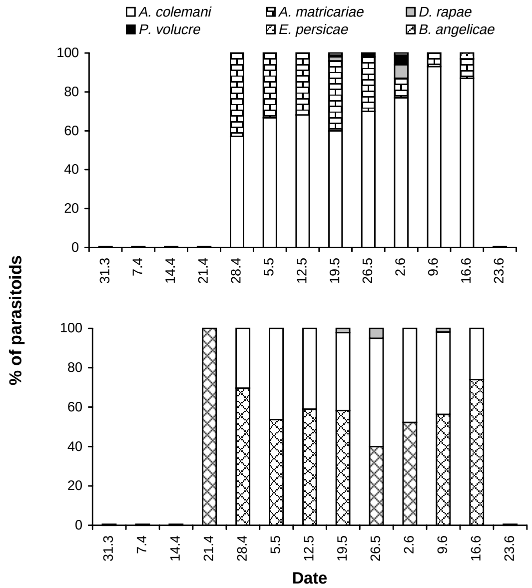

Fig. 2. Percentage of parasitoids of *Toxoptera aurantii* (top) and *Aphis gossypii* (bottom) found on orange trees in C Greece in 2000.

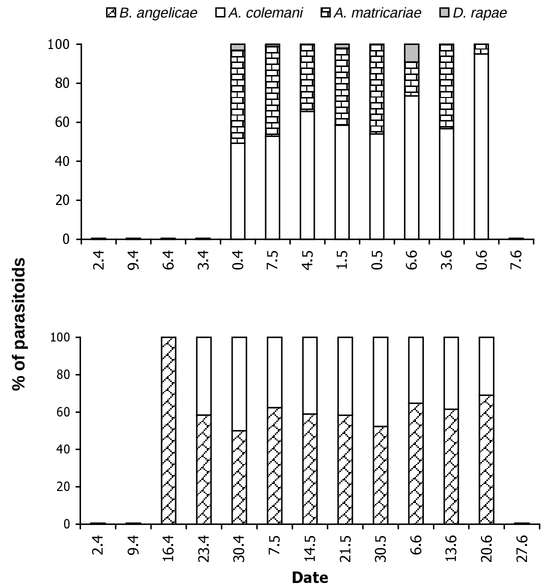

Fig. 3. Percentage of parasitoids of *Toxoptera aurantii* (top) and *Aphis gossypii* (bottom) found on orange trees in C Greece in 2001.

df = 1, 24, $P = 0.0035$ in 2001). There were significantly more *T. aurantii* ($\bar{x} = 969.69$ in 2000, $\bar{x} = 712.31$, in 2001) than *A. gossypii* ($\bar{x} = 125.54$ in 2000, $\bar{x} = 103.39$ in 2001) or *M. persicae* ($\bar{x} = 13.85$ in 2000).

The highest percentage of parasitization each year was recorded at the end of the period (Fig. 1). *T. aurantii* was parasitized by *Aphidius colemani* Viereck, 1912, *A. matricariae* Haliday, 1834, *Diaretiella rapae* (M' Intosh, 1855), *Ephedrus persicae* Froggat, 1904 and *Praon volucre* (Haliday, 1833). *A. gossypii* was parasitized by *Binodoxys angelicae* (Haliday, 1833), *D. rapae* and *A. colemani*. In contrast, *M. persicae* was not found to be parasitized. The relative abundance of parasitoids of *T. aurantii* and *A. gossypii* on orange trees per sampling date during 2000 and 2001 is shown in Figs 2–3. Significant differences were recorded between the species of aphidiines that parasitized *T. aurantii* and *A. gossypii* on orange trees ($F = 13.87$, df = 4, 60, $P < 0.0001$ for *T. aurantii* in 2000, $F = 11.29$, df = 2, 36, $P = 0.0002$ for *A. gossypii* in 2000 and $F = 7.58$, df = 2, 36, $P = 0.0018$ for *T. aurantii* in 2001). In contrast, no significant differences were found between the aphidiines that parasitized *A. gossypii* in 2001 ($F = 1.56$, df = 1, 24, $P = 0.22$). In the case of *T. aurantii*, there were significantly more *A. colemani* ($\bar{x} = 44.54$ in 2000, $\bar{x} = 38.88$ in 2001) than *A. matricariae* ($\bar{x} = 15.31$ in 2000), *D. rapae* ($\bar{x} = 0.69$ in 2000, $\bar{x} = 1.18$ in 2001), *E. persicae* ($\bar{x} = 0.38$ in 2000) or *P. volucre* ($\bar{x} = 0.62$ in 2000). In contrast, the mean number of *A. colemani* was not significantly different from that of *A. matricariae* in 2001, although lower numbers were recorded ($\bar{x} = 1.38$). In the case of *A. gossypii*, there were significantly more *B. angelicae* ($\bar{x} = 33.16$ in 2000, $\bar{x} = 48.88$ in 2001) than *D. rapae* ($\bar{x} = 0.69$ in 2000). In contrast, the mean number of *A. colemani* was not significantly different from that of *B. angelicae* in both years, although lower numbers of the former were recorded ($\bar{x} = 25.21$ in 2000, $\bar{x} = 28.04$ in 2001).

The numbers of predators increased during the period from March to May and reduced during June (Fig. 4). *Scymnus* was the dominant coccinellid genus during both years of the study (Fig. 4). Three species of this genus were recorded during the entire experimental period: *Scymnus (Pullus) subvillosus* (Goeze, 1777), *S. apetzi* Mulsant, 1846 and *S. rubromaculatus* (Goeze, 1777) (Tab. 1). Apart from the species presented in Fig. 4, a small number of *Hippodamia (Semiadalia) undecimnotata* (Schneider, 1792) individuals were recorded in 2000 and 2001 (three and two individuals were recorded on 5.V. and 12.V., respectively in 2000 whereas two, four and one individuals were recorded on 30.IV., 5.V. and 14.V.,

Table 1. Composition of the *Scymnus* spp. adult populations sampled on aphids infesting citrus in C Greece in 2000 and 2001.

Dates 2000–2001	*Scymnus* spp. numbers		
	Scymnus apetzi	*Scymnus (Pullus) subvillosus*	*Scymnus rubromaculatus*
31.III.2000	0	0	0
7.IV.2000	6	0	0
14.IV.2000	14	2	1
21.IV.2000	21	6	1
28.IV.2000	15	5	5
5.V.2000	30	7	5
12.V.2000	28	4	3
19.V.2000	33	7	4
26.V.2000	19	4	6
2.VI.2000	21	7	0
9.VI.2000	3	3	3
16.VI.2000	1	0	1
23.VI.2000	0	0	0
2.IV.2001	0	0	0
9.IV.2001	2	0	0
16.IV.2001	7	3	2
23.IV.2001	9	3	3
30.IV.2001	10	3	1
7.V.2001	21	5	2
14.V.2001	24	3	3
21.V.2001	18	4	2
30.V.2001	10	0	0
6.VI.2001	1	4	0
13.VI.2001	5	0	1
20.VI.2001	50	0	0
27.VI.2001	0	0	0

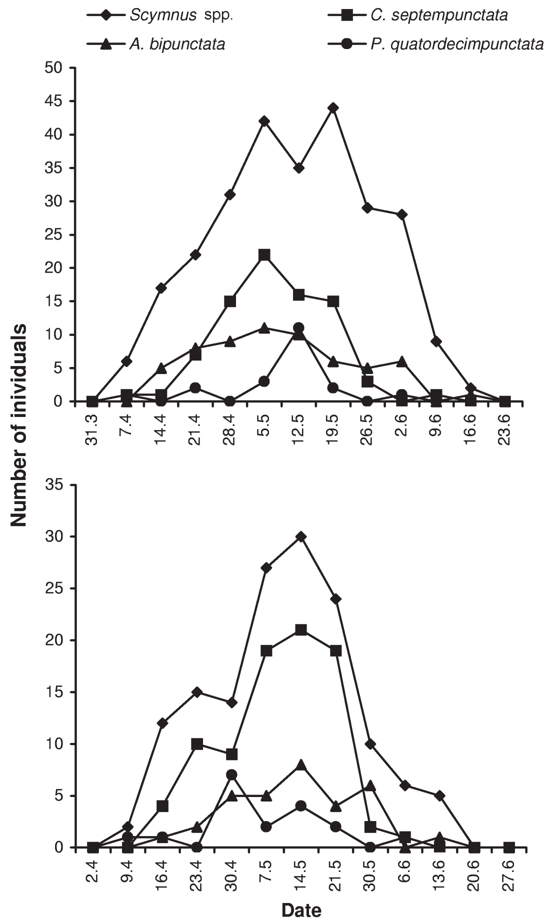

Fig. 4. Number of individuals of coccinellid species found on aphids infesting citrus in C Greece in 2000 (top) and 2001 (bottom).

respectively in 2001). Similarly, few individuals of *A. decempunctata* (L., 1758) were recorded in 2000 and 2001 (one and two individuals were recorded on 5.V. and 12.V., respectively in 2000 whereas two individuals were recorded on 7.V. in 2001).

Significant differences were recorded amongst the genera of coccinellids recorded during both years ($F = 12.20$, df = 4, 60, $P < 0.0001$ in 2000, $F = 6.55$, df = 4, 60, $P = 0.0002$ in 2000). There were significantly more *Scymnus* spp. ($\bar{x} = 20.38$ in 2000, $\bar{x} = 11.15$ in 2001) than *Coccinella septempunctata* L., 1758 ($\bar{x} = 6.23$ in 2000), *Adalia* spp. ($\bar{x} = 4.92$ in 2000, $\bar{x} = 2.62$ in 2001), *Propylaea quatuordecimpunctata* (L., 1758) ($\bar{x} = 1.55$ in 2000, $\bar{x} = 1.38$ in 2001) or *H. (S.) undecimnotata* ($\bar{x} = 0.38$ in 2000, $\bar{x} = 0.54$ in 2001). However, the mean number of *C. septempunctata* was not significantly different from that of *Adalia* spp., *P. quatuordecimpunctata* or *H. (S.) undecimnotata* in both years, although lower numbers of the former were recorded. Finally, during the examination of the samples a small number of destroyed mummies were observed during June (a total of 22 individuals in 2000 and 17 in 2001)

Discussion

The predominance of *T. aurantii* during both years of the study over *A. gossypii* could be attributed to the factor area since in reports from other citrus growing areas, there were significantly more *A. gossypii* than *T. aurantii* (Kavallieratos et al., 2002b). The low numbers of *M. persicae* could be attributed to the fact that this aphid species is considered a minor species for citrus (Barbagallo & Patti, 1983, 1986; Kavallieratos et. al., 2002b).

The present study, in agreement with previous ones (Kavallieratos & Lykouressis, 1999; Kavallieratos et al., 2002a, b), showed that *A. colemani* and *B. angelicae* were the most abundant parasitoids of *A. gossypii* whereas *A. colemani* was also the most abundant parasitoid of *T. aurantii*. In Greece *L. testaceipes* is the dominant parasitoid species of aphids infesting citrus (*T. aurantii*, *A. gossypii*, *A. craccivora*) only in those areas where it has been established (Kavallieratos & Lykouressis, 1999) whereas in others it is a minor parasitoid species (Kavallieratos et al., 2002b) or as in the present case it does not even exist. *A. matricariae* appeared also to be an abundant parasitoid species on *T. aurantii* following *A. colemani*. However, from previous studies in Greece and elsewhere (Tremblay et al., 1980; Tremblay, 1984; Kavallieratos & Lykouressis, 1999; Kavallieratos et al., 2002b) it is reported that *A. matricariae* appears generally in low percentages in comparison with other aphidiines from *T. aurantii*. The other aphidiines found in the present study: *D. rapae*, *P. volucre*, *E. persicae* which were recorded in low numbers on *A. gossypii* and *T. aurantii* are considered to be minor parasitoids of aphids infesting citrus (Tremblay, 1984; Kavallieratos & Lykouressis, 1999; Kavallieratos et al., 2002b). The fact that *M. persicae* was not found to be parasitized could be attributed to its limited numbers (Starý, 1970; Kavallieratos et al., 2002b).

The initial increase and the subsequent decrease in the number of coccinellids could be attributed to changes in the availability of food, given that these species react numerically to changes of prey densities (Hodek, 1973; Hodek & Honěk, 1996). Particularly for *C. septempunctata* the rapid decline of its population towards the end of June may be explained by the summer diapause of a part of its population that has been observed in Greece and the migration of a large part of the population to hibernation sites (Katsoyannos et al., 1997).

The species of predators found on *A. gosypii*, *T. aurantii* and *M. persicae* during the present study have also been observed in other studies. *S. (P.) subvillosus*, *S. apetzi*, *S. rubromaculatus*, *C. septempunctata*, *A. bipunctata*, *H. undecimnotata*, *A. decempunctata* and *P. quatuordecimpunctata* have been found previously on aphids infesting citrus in Greece (Katsoyannos, 1996; Katsoyannos et al., 1997; Kavallieratos et al. 2002a). With respect to the population composition of coccinellid on aphids infesting citrus, Barbagallo & Patti (1983) reported that in Italy *C. septempunctata* and *Scymnus* spp. appeared to be important predators. Similarly, Michelena & Sanchis (1997) reported that in Spain *C. septempunctata* and *S. subvillosus* dominated the other coccinellid species on aphids infesting citrus. In Greece (Western Peloponnese) control of aphids on citrus was achieved with augmentative releases of *C. septempunctata* adults imported from Italy (Stathas, unpubl. data). These facts are in accordance with the high numbers mainly of *Scymnus* spp. and also of *C. septempunctata* (Fig. 4) observed during the present study.

The small number of mummies destroyed by coccinellids found towards the end of the period could be attributed to the absence of live aphids and to the presence mostly of mummified aphids. The lack of new growth during summer in citrus trees makes them unsuitable for infestation causing the migration of aphids to alternative host plants and the subsequent population decline which is unrelated to intensive parasitization (Barbagallo & Patti, 1986; Kavallieratos et al., 2002b). Takizawa et al. (2000) showed that in the absence of live aphids, predatory labyrids eat parasitized aphids and mummies.

Predators appeared on aphids earlier than parasitoids during both years of the study. The earlier activity of coccinellids on aphids, the activity of aphidiines, which in agreement with other studies appear generally after the development of aphid population to high levels (Starý, 1970; Kavallieratos et al., 2002b), as well as the summer migration of aphids, resulted in the final proportion 80–100% of parasitized aphids/living aphids during the end of the study in June.

Given that aphidiines and coccinellids are abundant insect groups in citrus (Kavallieratos & Lykouressis, 1999, 2000; Kavallieratos et al., 2001, 2002b; Magro et al., 1999) further experimentation is required in order to assess their interactions in the field for understanding better ways of biological control strategies in citrus.

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