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Parasitoids and hyperparasitoids (Hymenoptera) on aphids (Hemiptera) infesting citrus in east Mediterranean region of Turkey

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ABSTRACT. The aphids, aphid parasitoids, and hyperparasitoids found in citrus orchards, the parasitoids' and hyperparasitoids' seasonal abundance, and the plant–aphid–parasitoid relationships in Hatay, Osmaniye, Adana, and Mersin provinces of the east Mediterranean region of Turkey are presented in the present 2-yr study. *Aphidius colemani* Viereck, *Binodoxys angelicae* (Haliday), and *Lysiphlebus confusus* Tremblay and Eady (Hymenoptera: Braconidae: Aphidiinae) were encountered as the most common parasitoids among 10 identified aphidiine and aphelinid taxa on different citrus species. Hyperparasitoids belonging to the genera *Alloxysta*, *Phaenoglyphis*, *Asaphes*, *Pachyneuron*, *Syrphophagus*, and *Dendrocercus* are reported for the first time emerging from aphids feeding on citrus in Turkey. Among them, *Asaphes* spp., *Pachyneuron* spp., and *Syrphophagus* spp. were recorded as the most common ones. *Citrus reticulata* Blanco and *Citrus limon* (L.) Burm. fil. were recorded as main hosts for the aphid parasitoids and their hyperparasitoids.

Key Words: citrus, aphid, Aphidiinae, Aphelinidae, hyperparasitoid

Aphids are considered as important pests of citrus causing serious damages directly and indirectly, i.e., loss of saps, deformities, change of color, not normal development, reduction in photosynthesis due to sooty mold growth, and transmission of plant viruses (Blackman and Eastop 2000; Hermoso de Mendoza et al. 2001, 2006; Satar et al. 2007). Despite that more than 25 aphid species have been reported to infest citrus worldwide, only few of them can cause economic injury (Uygun et al. 2012). In the Mediterranean area, *Aphis gossypii* Glover, *Aphis spiraeicola* Patch, and *Toxoptera aurantii* (Boyer de Fonscolombe) (Hemiptera: Aphididae) are the major species occurring on citrus and form effective vectors of citrus tristeza virus, a harmful disease of citrus (Hermoso de Mendoza et al. 2001, 2006; Kavallieratos et al. 2002; Marroquín et al. 2004; Satar et al. 2007; Tena and Garcia Mari 2011). Furthermore, the recently detected citrus yellow vein clearing virus in lemon trees in Turkey is also transmitted by aphids (Loconsole et al. 2012). According to Hermoso de Mendoza et al. (2001, 2006), the increase in *A. gossypii* and *A. spiraeicola* numbers resulted in the yield loss of *Citrus clementina* Hort. ex Tan in Spain.

Aphidiinae parasitoids contribute significantly in the regulation of aphid populations. They are all solitary endophagous parasitoids of aphids and strictly specific to aphids (Starý 1970). Until now, only Yumruktepe and Uygun (1994) and Yoldaş et al. (2011) provided lists of parasitoids attacking aphids infesting citrus in Turkey, i.e., *Aphidius colemani* Viereck, *Aphidius matricariae* Haliday, *Binodoxys aculephae* (Marshall), *B. angelicae* (Haliday), *Ephedrus persicae* Froggatt, *Lysiphlebus confusus* Tremblay and Eady, *Lysiphlebus fabarum* (Marshall), *Lysiphlebus testaceipes* (Cresson), and *Praon volucre* (Haliday) (Hymenoptera: Braconidae: Aphidiinae). Furthermore, Yoldaş et al. (2011) reported that the combined activity of natural enemies (parasitoids and predators) caused the suppression of aphid

densities on *Citrus deliciosa* Ten. plantations in the Izmir province, in the west part of Turkey.

Citrus has important commercial value for the agricultural market of Turkey. Half of the exporting fresh agricultural material for Turkey is citrus and annually it provides more than 40% of the total agricultural export income of Turkey. Within Mediterranean, Turkey is the second citrus exporter country, while it is the fourth in the world (Food and Agriculture Organization of the United Nations (FAO) 2012). Given that aphids infesting citrus are economic important pests in Turkey (Uygun et al. 2001), environmental friendly solution of this problem could be based on biological control and the key to this approach is the research on the native aphid parasitoids. The objective of this study was the determination of parasitoids attacking aphids feeding on certain citrus species and the investigation of their seasonal abundance in the east Mediterranean region of Turkey, given that the overall knowledge on the aphid parasitoid composition in citrus in Turkey is poorly investigated.

Materials and Methods

Samples were collected from citrus trees between January 2007 and December 2008 from 15 areas in Hatay (Dörtyol, Erzin, İskendurun), Adana (Ceyhan, Karataş, Kozan, Seyhan, Toprakkale, Yüreğir), and Mersin (Erdemli, Kuyuluk, Merkez, Silifke, Tarsus, Yenice), all located in the east Mediterranean region of Turkey. Ten orchards were visited in each location and 100 shoots of 20 cm long from 25 trees (four shoots per tree) were visually inspected for the presence of aphid colonies with mummies (Bora and Karaca 1970). The shoots were collected once per month from all locations throughout the experimental period. Out of 360,000 inspected shoots 316, upon which one or more aphid mummies were observed, were collected from the citrus trees. The shoots bearing aphid colonies and mummies were gently cut with scissors, placed in

plastic bags, and were brought to the laboratory where aphids were identified to species. Living aphids were preserved in 90% ethyl alcohol plus 75% lactic acid (Eastop and van Emden 1972). Mummies were placed separately in plastic vials (50 ml) inside a growth room (22°C, 65% RH, 16:8 h [L:D]) for parasitoid and hyperparasitoid emergence (Kavallieratos et al. 2005b). The vials had a circular opening on their lid covered with muslin for ventilation in order to maintain conditions inside the vials similar to those existing in the growth room. Parasitoid adults were identified from ethanol-preserved samples, a part of them was point mounted or slide mounted for detailed examination. Specimens for slides were washed in distilled water, boiled in 10% KOH for about 2 min, rewashed, and then placed in a drop of Faure-Berlese medium (Krantz 1978) for dissection or whole mounting. External morphology was studied using an Olympus SZX9 (Olympus, Tokyo, Japan) or Carl Zeiss Microscopy GmbH SMXX (Carl Zeiss Microscopy GmbH, Jena, Germany) stereomicroscopes. Percentage of hyperparasitization was estimated by dividing the number of hyperparasitoid individuals to the total number of parasitoid and hyperparasitoid individuals. The voucher specimens are deposited in P. Starý's personal collection at České Budějovice.

The chi-square analysis was performed to determine statistical differences in the following: 1) abundance of the most commonly identified parasitoid species on *Citrus aurantium* L., *Citrus limon* (L.) Burm. fil., *Citrus reticulata* Blanco, and *Citrus sinensis* (L.) Osbeck and 2) preference of each parasitoid species to *C. aurantium*, *C. limon*, *C. reticulata* and *C. sinensis* for the two years, 2007 and 2008, experimental period at $P = 0.05$ (Sokal and Rohlf 1995). *Citrus paradisi* Macfad. was excluded from the analysis because only few parasitoid individuals were recorded on this plant species. All analyses were performed using the SPSS 17.0 software (Statistical Package for the Social Sciences (SPSS), Inc. 2008). Analysis was not conducted for hyperparasitoids because they were not identified in the species level and thus generalizations in higher taxonomic level (i.e., superfamilies) should be avoided.

Results

Aphids and Parasitoids. Seven aphid species were determined in the studied region, i.e., *A. gossypii*, *A. spiraecola*, *Aphis craccivora* Koch, *Myzus persicae* (Sulzer), *T. aurantii*, *Brachycaudus helichrysi* (Kaltenbach), and *Macrosiphum euphorbiae* (Thomas) (Hemiptera: Aphididae). Although there were seven aphid species on citrus, *A. gossypii* had the most diverse aphidiine spectrum, while no parasitoids were obtained from *A. spiraecola*, *Ma. euphorbiae*, and *T. aurantii* (Table 1). *M. persicae* was parasitized by *Ap. colemani* and *B. angelicae* on *C. aurantium* and *C. reticulata* while *A. craccivora* was parasitized only by *L. confusus* on *C. reticulata* and by *Ap. colemani* and *B. angelicae* on *C. limon* (Table 1).

Of the 316 samples, totally 2,752 parasitoid individuals were recorded belonging to the following taxa: *Aphelinus* sp. (Hymenoptera: Aphelinidae), *Ap. colemani*, *Ap. matricariae*, *B. angelicae*, *E. persicae*, *Lysiphlebus* sp., *L. fabarum*, *L. confusus*, *Diaeretiella rapae* (M'Intosh), and *P. volucre* (Hymenoptera: Braconidae: Aphidiinae) (Tables 1–3). The exotic parasitoid *L. testaceipes* (Hymenoptera: Braconidae: Aphidiinae) was only obtained from *Aphis ruborum* (Börner and Schilder) (Hemiptera: Aphididae) (1 ♀) which was creeping or rambling to citrus tree probably due to the close vicinity of *C. sinensis* trees to *Rubus fruticosus* L. growing at the margin of the citrus orchard in Yüreğir (Adana).

Ap. colemani, *B. angelicae*, and *L. confusus* were the most numerous and frequently recorded parasitoids (Tables 2 and 3). From these three species, only *B. angelicae* was recorded in all citrus species (Table 2). Within the citrus species, on *C. reticulata*, 9 parasitoid taxa were found parasitizing *A. craccivora*, *A. gossypii*, and *M. persicae* (Table 1). Also, 46.19% of parasitoids were identified on this citrus species followed by *C. limon* (27.10%) and *C. sinensis* (13.95%) (Table 2).

There is a statistical significant preference of parasitoid species to citrus species ($\chi^2 = 273.4$, $df = 12$, $P < 0.01$). The chi-square analysis

Table 1. Citrus–aphid–parasitoid associations in East Mediterranean region of Turkey from January 2007 to December 2008

Citrus plants	Aphids	Parasitoids	Number of parasitoid individuals
<i>Citrus aurantium</i>	<i>Aphis gossypii</i>	<i>Aphidius matricariae</i>	14
		<i>Binodoxys angelicae</i>	6
		<i>Ephedrus persicae</i>	1
		<i>Lysiphlebus fabarum</i>	11
		<i>Aphidius colemani</i>	6
<i>Citrus limon</i>	<i>Myzus persicae</i>	<i>B. angelicae</i>	28
		<i>Ap. colemani</i>	12
		<i>B. angelicae</i>	18
		<i>Lysiphlebus confusus</i>	38
		<i>Ap. colemani</i>	150
	<i>A. gossypii</i>	<i>Ap. matricariae</i>	18
		<i>B. angelicae</i>	252
		<i>L. confusus</i>	49
		<i>L. fabarum</i>	209
		<i>B. angelicae</i>	3
<i>Citrus paradisi</i>	<i>A. gossypii</i>	<i>Diaeretiella rapae</i>	1
		<i>E. persicae</i>	1
		<i>Ap. colemani</i>	128
<i>Citrus reticulata</i>	<i>A. gossypii</i>	<i>Aphelinus</i> sp.	3
		<i>Ap. matricariae</i>	14
		<i>B. angelicae</i>	408
		<i>D. rapae</i>	2
		<i>E. persicae</i>	7
		<i>L. confusus</i>	531
		<i>L. fabarum</i>	143
		<i>Praon volucre</i>	1
		<i>L. confusus</i>	21
		<i>Ap. colemani</i>	12
	<i>A. craccivora</i>	<i>B. angelicae</i>	1
		<i>Ap. colemani</i>	34
	<i>M. persicae</i>	<i>Ap. matricariae</i>	10
		<i>B. angelicae</i>	102
	<i>A. gossypii</i>	<i>E. persicae</i>	2
		<i>L. fabarum</i>	7
		<i>L. confusus</i>	57
		<i>Ap. colemani</i>	1
		<i>Ap. matricariae</i>	1
		<i>B. angelicae</i>	38
		<i>E. persicae</i>	1
		<i>L. confusus</i>	130
		<i>Lysiphlebus</i> sp.	1
		<i>Ap. colemani</i>	2
<i>Citrus spp.</i>	<i>A. craccivora</i>	<i>L. fabarum</i>	3
		<i>Aphelinus</i> sp.	1
		<i>Ap. colemani</i>	138
		<i>Ap. matricariae</i>	2
		<i>B. angelicae</i>	90
	<i>A. gossypii</i>	<i>E. persicae</i>	3
		<i>L. fabarum</i>	28
		<i>L. confusus</i>	13

showed that there are statistical differences in the abundances of *Ap. colemani*, *Ap. matricariae*, *B. angelicae*, *L. confusus*, and *L. fabarum* on *C. aurantium* ($\chi^2 = 27.9$, $df = 3$, $P < 0.01$), *C. limon* ($\chi^2 = 423.8$, $df = 4$, $P < 0.01$), *C. reticulata* ($\chi^2 = 777.9$, $df = 4$, $P < 0.01$), and *C. sinensis* ($\chi^2 = 356.4$, $df = 4$, $P < 0.01$). Furthermore, the chi-square analysis showed that there are statistical differences in the preferences of *Ap. colemani* ($\chi^2 = 206.3$, $df = 3$, $P < 0.01$), *B. angelicae* ($\chi^2 = 370.6$, $df = 3$, $P < 0.01$), *L. confusus* ($\chi^2 = 215.9$, $df = 2$, $P < 0.01$), and *L. fabarum* ($\chi^2 = 275.7$, $df = 3$, $P < 0.01$), but not for *Ap. matricariae* ($\chi^2 = 1.7$, $df = 3$, $P = 0.63$), to *C. aurantium*, *C. limon*, *C. reticulata*, and *C. sinensis*. The statistical differences in the abundances of *Ap. colemani*, *Ap. matricariae*, *B. angelicae*, *L. confusus*, and *L. fabarum* found on *C. aurantium*, *C. limon*, *C. reticulata*, and *C. sinensis* compared in pairs are shown in Table 4.

Hyperparasitoids. *Alloxysta* spp., *Phaenoglyphis* spp. (Hymenoptera: Cynipoidea), *Syrphophagus* spp., *Asaphes* spp., *Pachyneuron* spp. (Hymenoptera: Chalcidoidea), *Dendrocerus* spp. (Hymenoptera: Ceraphronoidea) were recorded as hyperparasitoids that attack primary parasitoids of aphids infesting citrus (Tables 2 and 3). The hyperparasitoid spectrum was composed mainly by Chalcidoidea (84.8%) followed by Cynipoidea (13.3%) and

Table 2. Abundance of parasitoids and hyperparasitoids found on citrus in east Mediterranean region of Turkey between January 2007 and December 2008

Parasitoids	Citrus spp.	<i>C. aurantium</i>	<i>C. limon</i>	<i>Citrus paradisi</i>	<i>C. reticulata</i>	<i>C. sinensis</i>	Total
<i>Aphelinus</i> sp.	1	—	—	—	3	—	4
<i>Ap. colemani</i>	140	6	162	—	140	35	483
<i>Ap. matricariae</i>	2	14	18	—	14	11	59
<i>B. angelicae</i>	90	34	270	3	409	140	946
<i>D. rapae</i>	—	—	—	1	2	—	3
<i>E. persicae</i>	3	1	—	1	7	3	15
<i>Lysiphlebus</i> sp.	—	—	—	—	—	1	1
<i>L. confusus</i>	13	—	273	—	552	187	1,025
<i>L. fabarum</i>	31	11	23	—	143	7	215
<i>Praon volucre</i>	—	—	—	—	1	—	1
Total	280	66	746	5	1,271	384	2,752
Total (%)	10.17	2.40	27.11	0.18	46.19	13.95	100
Hyperparasitoids							
Cynipoidea	7	—	29	—	50	31	117
Chalcidoidea	21	6	101	9	585	26	748
Ceraphronoidea	1	4	4	—	3	5	17
Total	29	10	134	9	638	62	882
Total (%)	3.29	1.13	15.19	1.02	72.34	7.03	100
Hyperparasitization (%)	9.39	13.16	15.22	64.29	33.42	13.90	

Cynipoidea includes the following genera: *Alloxysta* and *Phaenoglyphis*. Chalcidoidea includes the following genera: *Syrphophagus*, *Asaphes*, and *Pachyneuron*. Ceraphronoidea includes the genus *Dendrocerus*.

Table 3. Seasonal abundance of parasitoids and hyperparasitoids found on citrus in east Mediterranean region of Turkey, between January 2007 and December 2008

Parasitoids	Months												Total
	1	2	3	4	5	6	7	8	9	10	11	12	
<i>Aphelinus</i> sp.	—	—	—	—	3	1	—	—	—	—	—	—	4
<i>Ap. colemani</i>	—	—	—	186	278	16	—	—	—	—	2	1	483
<i>Ap. matricariae</i>	—	—	1	38	16	3	1	—	—	—	—	—	59
<i>B. angelicae</i>	12	—	5	589	153	3	1	—	—	2	76	105	946
<i>D. rapae</i>	—	—	—	2	1	—	—	—	—	—	—	—	3
<i>E. persicae</i>	—	—	—	8	5	—	—	—	—	—	1	1	15
<i>Lysiphlebus</i> sp.	—	—	—	—	1	—	—	—	—	—	—	—	1
<i>L. confusus</i>	—	—	—	60	380	575	7	—	—	—	3	—	1,025
<i>L. fabarum</i>	—	—	—	130	49	35	—	—	—	—	1	—	215
<i>P. volucre</i>	—	—	—	—	1	—	—	—	—	—	—	—	1
Total	12	—	6	1,013	887	633	9	—	—	2	83	107	2,752
Total (%)	0.44	—	0.22	36.81	32.23	23.00	0.33	—	—	0.07	3.02	3.88	100
Hyperparasitoids													
Cynipoidea	—	—	—	85	17	3	—	—	—	1	9	2	117
Chalcidoidea	—	—	—	121	73	537	—	—	5	—	5	7	748
Ceraphronoidea	—	—	—	13	1	—	—	—	—	—	—	3	17
Total	—	—	—	219	91	540	—	—	5	1	14	12	882
Total (%)	—	—	—	24.83	10.32	61.22	—	—	0.57	0.11	1.59	1.36	100
Hyperparasitization (%)	—	—	—	17.78	9.31	46.00	—	—	—	33.33	14.43	10.10	

Each month includes the total number of identified individuals for 2007 and 2008. Cynipoidea includes the following genera: *Alloxysta* and *Phaenoglyphis*. Chalcidoidea includes the following genera: *Syrphophagus*, *Asaphes*, and *Pachyneuron*. Ceraphronoidea includes the genus *Dendrocerus*. The numbers 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12 correspond to January, February, March, April, May, June, July, August, September, October, November, and December, respectively.

Ceraphronoidea (1.9%) (Tables 2 and 3). The main period for hyperparasitoids' activity was June (61.22%), although it was April (36.81) for parasitoids (Table 3). As in the case of parasitoids, *C. reticulata* also favored hyperparasitoids and assessed 33.42% composition of hyperparasitoids followed by *C. limon* (15.22%) (Table 2).

Discussion

Our study provides a rich parasitoid spectrum of *A. gossypii* feeding on citrus in the east Mediterranean region of Turkey which is composed of nine aphidiine taxa and *Aphelinus* sp. contrary to the rather narrow parasitoid complex provided by Yumruktepe and Uygün (1994). Given that previous studies have demonstrated that *A. gossypii* is a serious threat for citrus in southeastern Europe (Kavallieratos et al. 2002), in

eastern Mediterranean (Yumruktepe and Uygün 1994, Yoldaş et al. 2011), and western Mediterranean (Hermoso de Mendoza et al. 1998 2001, 2006) makes the research on its natural enemies necessary not only in the studied geographical area but also in other citrus production areas. As in this study, the abundance of the parasitoids should also be estimated in order to distinguish which species is the most effective bio-control agent in the target citrus area (Kavallieratos et al. 2002, 2004a). All identified parasitoids of *A. gossypii* and other aphids feeding on citrus in our study (i.e., *Ap. colemani*, *Ap. matricariae*, *B. angelicae*, *E. persicae*, *L. fabarum*, *L. confusus*, *D. rapae*, *P. volucre*) are commonly found in various cultivated and noncultivated plants in various habitats of Europe and are considered as important biological control agents (Powell 1982, Adisu et al. 2002, Stary and Havelka 2008,

Table 4. Differences in the abundances of parasitoids found on citrus in east Mediterranean region of Turkey between January 2007 and December 2008 (in all cases df = 1)

Parasitoids	Citrus	χ^2	P value	Citrus	Parasitoids	χ^2	P value
<i>Ap. colemani</i>	<i>C. aurantium</i> versus <i>C. limon</i>	144.9	<0.01	<i>C. aurantium</i>	<i>Ap. colemani</i> versus <i>Ap. matricariae</i>	3.2	0.07
	<i>C. aurantium</i> versus <i>C. reticulata</i>	123.0	<0.01		<i>Ap. colemani</i> versus <i>B. angelicae</i>	19.6	<0.01
	<i>C. aurantium</i> versus <i>C. sinensis</i>	20.5	<0.01		<i>Ap. colemani</i> versus <i>L. confusus</i>	—	—
	<i>C. limon</i> versus <i>C. reticulata</i>	1.6	0.21		<i>Ap. colemani</i> versus <i>L. fabarum</i>	1.5	0.23
	<i>C. limon</i> versus <i>C. sinensis</i>	81.9	<0.01		<i>Ap. matricariae</i> versus <i>B. angelicae</i>	8.3	<0.01
<i>Ap. matricariae</i>	<i>C. reticulata</i> versus <i>C. sinensis</i>	63.0	<0.01	<i>Ap. matricariae</i>	<i>Ap. matricariae</i> versus <i>L. confusus</i>	—	—
	<i>C. aurantium</i> versus <i>C. limon</i>	0.5	0.48		<i>Ap. matricariae</i> versus <i>L. fabarum</i>	0.4	0.55
	<i>C. aurantium</i> versus <i>C. reticulata</i>	0.0	1.00		<i>B. angelicae</i> versus <i>L. confusus</i>	—	—
	<i>C. aurantium</i> versus <i>C. sinensis</i>	0.4	0.55		<i>B. angelicae</i> versus <i>L. fabarum</i>	11.8	<0.01
	<i>C. limon</i> versus <i>C. reticulata</i>	0.5	0.48		<i>L. confusus</i> versus <i>L. fabarum</i>	—	—
<i>B. angelicae</i>	<i>C. limon</i> versus <i>C. sinensis</i>	1.7	0.19	<i>C. limon</i>	<i>Ap. colemani</i> versus <i>Ap. matricariae</i>	115.2	<0.01
	<i>C. reticulata</i> versus <i>C. sinensis</i>	0.4	0.55		<i>Ap. colemani</i> versus <i>B. angelicae</i>	27.0	<0.01
	<i>C. aurantium</i> versus <i>C. limon</i>	183.2	<0.01		<i>Ap. colemani</i> versus <i>L. confusus</i>	28.3	<0.01
	<i>C. aurantium</i> versus <i>C. reticulata</i>	317.4	<0.01		<i>Ap. colemani</i> versus <i>L. fabarum</i>	104.4	<0.01
	<i>C. aurantium</i> versus <i>C. sinensis</i>	64.6	<0.01		<i>Ap. matricariae</i> versus <i>B. angelicae</i>	220.5	<0.01
<i>L. confusus</i>	<i>C. limon</i> versus <i>C. reticulata</i>	28.5	<0.01	<i>Ap. matricariae</i>	<i>Ap. matricariae</i> versus <i>L. confusus</i>	223.5	<0.01
	<i>C. limon</i> versus <i>C. sinensis</i>	41.2	<0.01		<i>Ap. matricariae</i> versus <i>L. fabarum</i>	0.6	0.44
	<i>C. reticulata</i> versus <i>C. sinensis</i>	131.8	<0.01		<i>B. angelicae</i> versus <i>L. confusus</i>	0.0	0.90
	<i>C. aurantium</i> versus <i>C. limon</i>	—	—		<i>B. angelicae</i> versus <i>L. fabarum</i>	208.2	<0.01
	<i>C. aurantium</i> versus <i>C. reticulata</i>	—	—		<i>L. confusus</i> versus <i>L. fabarum</i>	211.1	<0.01
<i>L. fabarum</i>	<i>C. aurantium</i> versus <i>C. sinensis</i>	—	—	<i>C. reticulata</i>	<i>Ap. colemani</i> versus <i>Ap. matricariae</i>	103.1	<0.01
	<i>C. limon</i> versus <i>C. reticulata</i>	94.4	<0.01		<i>Ap. colemani</i> versus <i>B. angelicae</i>	131.8	<0.01
	<i>C. limon</i> versus <i>C. sinensis</i>	16.1	<0.01		<i>Ap. colemani</i> versus <i>L. confusus</i>	245.3	<0.01
	<i>C. reticulata</i> versus <i>C. sinensis</i>	180.3	<0.01		<i>Ap. colemani</i> versus <i>L. fabarum</i>	0.0	0.86
	<i>C. aurantium</i> versus <i>C. limon</i>	4.2	0.04		<i>Ap. matricariae</i> versus <i>B. angelicae</i>	368.9	<0.01
	<i>C. aurantium</i> versus <i>C. reticulata</i>	113.1	<0.01	<i>Ap. matricariae</i>	<i>Ap. matricariae</i> versus <i>L. confusus</i>	511.4	<0.01
	<i>C. aurantium</i> versus <i>C. sinensis</i>	0.9	0.35		<i>Ap. matricariae</i> versus <i>L. fabarum</i>	106.0	<0.01
	<i>C. limon</i> versus <i>C. reticulata</i>	86.8	<0.01		<i>B. angelicae</i> versus <i>L. confusus</i>	21.3	<0.01
	<i>C. limon</i> versus <i>C. sinensis</i>	8.5	<0.01		<i>B. angelicae</i> versus <i>L. fabarum</i>	128.2	<0.01
	<i>C. reticulata</i> versus <i>C. sinensis</i>	123.3	<0.01		<i>L. confusus</i> versus <i>L. fabarum</i>	240.7	<0.01
				<i>C. sinensis</i>	<i>Ap. colemani</i> versus <i>Ap. matricariae</i>	12.5	<0.01
					<i>Ap. colemani</i> versus <i>B. angelicae</i>	63.0	<0.01
					<i>Ap. colemani</i> versus <i>L. confusus</i>	104.1	<0.01
					<i>Ap. colemani</i> versus <i>L. fabarum</i>	18.7	<0.01
					<i>Ap. matricariae</i> versus <i>B. angelicae</i>	110.2	<0.01
					<i>Ap. matricariae</i> versus <i>L. confusus</i>	156.4	<0.01
					<i>Ap. matricariae</i> versus <i>L. fabarum</i>	0.9	0.35
					<i>B. angelicae</i> versus <i>L. confusus</i>	6.8	<0.01
					<i>B. angelicae</i> versus <i>L. fabarum</i>	120.3	<0.01
					<i>L. confusus</i> versus <i>L. fabarum</i>	167.0	<0.01

Dashes represent that no analysis was performed.

Tomanović et al. 2009, Pons et al. 2011). Furthermore, a possible alternation of these broadly oligophagous parasitoids to aphids on plants other than citrus may enhance the ecological friendly management of aphid infestations in the studied region, but further research is needed for the clarification of this issue. However, this hypothesis of possible exchange of parasitoid populations has been previously supported for different tritrophic systems of plants, aphids, and parasitoids in various geographical areas of the world (Starý and Pike 1998, Starý and Havelka 2008, Tomanović et al. 2009, Havelka et al. 2012).

Despite it has been demonstrated that *Ma. euphorbiae*, *A. spiraeicola*, and *T. aurantii* are parasitized by a wide spectrum of parasitoids from the Mediterranean region (Starý 1976; Tremblay 1984; Kavallieratos et al. 2004b, 2005b), we did not record any parasitoids from these aphids during our study. This phenomenon has been previously documented in Greece for certain observational period (Kavallieratos et al. 2002). Different population density of aphids in citrus orchards or different climatic conditions depending on the area could be responsible for this issue (Starý 1970; Kavallieratos et al. 2002, 2004a).

Based on recent reports, the overall parasitoid fauna on citrus in the studied region is quite similar to the respective fauna in southeastern Europe and north Africa (Kavallieratos et al. 2005b, Boukhris Bouhachem 2011). Moreover, the main period for parasitoids' highest population density was between April and June for both years of our

study which stands in agreement with previous studies from Greece (Kavallieratos et al. 2002, 2004a). Generally, the period between March and June is the most suitable for aphids infesting citrus in east Mediterranean region of Turkey like in other Mediterranean countries, i.e., Greece, Italy, and Spain (Barbagallo and Patti 1983; Michelena and Sanchis 1997; Kavallieratos et al. 2002, 2004b). According to Tomanović et al. (2009), the Mediterranean climatic conditions favor the presence of host aphids on plants in that period and consequently the parasitoids' activity.

The strong presence of hyperparasitoids could be the reason for the limitation of the numbers of the parasitoids rather late in the season (June). Despite the fact that the aphid densities and parasitism were not estimated in this study, our observations stand in accordance with previous reports from other geographical areas (Evenhuis 1964; Latteur 1973; Starý 1988; Kavallieratos et al. 2002, 2005a). The high presence of hyperparasitoids is favored by the architecture of the citrus trees. The canopy of citrus plants offers a natural protection against the solar radiation and consequently the aphids suffered by high percentage of hyperparasitization (Brodeur and McNeil 1991, 1992; Kavallieratos et al. 2005a). Hyperparasitoids which attack primary parasitoids in citrus orchards are reported in Turkey for the first time. In our study, the individuals of the superfamily Chalcidoidea belonging to the genera *Aphidencyrthus*, *Asaphes*, and *Pachyneuron* constituted the 84.8% of the total number of the obtained hyperparasitoids and they stably

dominated upon the other groups of hyperparasitoids during the entire experimental period. Similar results for hyperparasitoids on citrus trees have been reported by [Kavallieratos et al. \(2002\)](#).

Our study suggests that different citrus species affect both the species composition and the parasitization preference of Aphidiinae species. Thus, *Ap. colemani* is the main parasitoid for *C. limon* and *C. reticulata*; *B. angelicae* and *L. confusus* for *C. limon*, *C. reticulata*, and *C. sinensis*; and *L. fabarum* for *C. reticulata*. [Kavallieratos et al. \(2002\)](#) demonstrated the existence of significant differences in the percentages of *Ap. colemani*, *Ap. matricariae*, *B. acalephae*, *B. angelicae*, *D. rapae*, *E. persicae*, or *L. testaceipes*, all emerged from *A. gossypii* infesting *C. aurantium*, *C. deliciosa*, and *C. sinensis*, and concluded that the factor plant species affects the parasitization preference of these aphidiines. New evidences in the east Mediterranean region of Turkey showed that populations of *A. gossypii* are distinguished to one existing on cucumber, sweet pepper, citrus, eggplant, and okra and another one on cotton ([Satar et al. 2013](#)). It would be interesting to examine if different host races do exist for aphids feeding on different citrus species in the region and could influence the tritrophic (parasitoid–aphid–plant) associations.

Recent efforts for the introduction of *L. testaceipes* through augmentative releases in the east Mediterranean region of Turkey led to the recovery of this species on aphids feeding on cultivated and noncultivated plants, i.e., *Capsella bursa-pastoris* (L.) and citrus ([Satar et al. 2011](#)). The fact that we recorded *L. testaceipes* as a single specimen from *A. ruborum* is attributed to the timing of conducting this study which coincided with the commencement of the release of this species in 2008. Additional efforts are needed on aphids infesting citrus in the east Mediterranean area of Turkey and their parasitoids because the establishment of *L. testaceipes* causes changes in the native parasitoid–aphid associations ([Starý et al. 1988, 2004; Cecilio 1994; Tomanović et al. 2009](#)).

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References Cited

- Adisu, B., P. Starý, B. Freier, and C. Büttner. 2002.** *Aphidius colemani* Viereck (Hymenoptera: Braconidae: Aphidiinae) detected in cereal fields in Germany. *J. Pest Sci.* 75: 89–94.
- Barbagallo, S., and I. Patti. 1983.** Citrus aphids and their entomophagous in Italy, pp. 116–119. In **R. Cavalloro** (ed.), *Proceedings of a Meeting of the EC Experts' Group*, 23–24 November 1982, AA Balkema, Rotterdam, Portici.
- Blackman, R. L., and V. E. Eastop. 2000.** Aphids on the world's crops. An identification guide, 2nd ed. John Wiley and Sons Ltd, Chichester.
- Bora, T., and I. Karaca. 1970.** Kültür bitkilerinde hastalığın ve zararın ölçülmesi. Ege Üniversitesi Ziraat Fakültesi Yardımcı Ders Kitabı No 167, Ege Üniversitesi Matbaası, İzmir.
- Boukhris Bouhachem S. 2011.** Aphid enemies reported from Tunisian citrus orchards. *Tunisian J. Plant Prot.* 6: 21–27.
- Brodeur, J., and J. N. McNeil. 1991.** The effect of host plant architecture on the distribution and survival of *Aphidius nigripes* (Hymenoptera: Aphidiidae). *Redia* 74: 251–258.
- Brodeur, J., and J. N. McNeil. 1992.** Host behavior modification by the endoparasitoid *Aphidius nigripes*: a strategy to reduce hyperparasitism. *Ecol. Entomol.* 17: 97–104.
- Cecilio, A. 1994.** Faunistic evolution after the introduction of *Lysiphlebus testaceipes* (Cresson) (Hymenoptera: Aphidiidae) in Portugal, and its importance for the control of aphids. *Bol. Sanid. Veg. Plagas* 20: 471–476.
- Eastop, V. F., and V. F. van Emden. 1972.** The insect material, pp. 1–45. In **H. F. van Emden** (ed.), *Aphid technology*. Academic Press, London.
- Evenhuis, H. H. 1964.** The interrelations between apple aphids and their parasites and hyperparasites. *Entomophaga* 9: 227–231.
- Food and Agriculture Organization of the United Nations (FAO). 2012.** Citrus fruit. Fresh and processed, Annual statistics. FAO, Rome.
- Havelka, J., Ž. Tomanović, N. G. Kavallieratos, E. Rakhshani, X. Pons, K. S. Pike, P. Starý. 2012.** Review and key to the world parasitoids (Hymenoptera: Braconidae: Aphidiinae) of *Aphis ruborum* (Hemiptera: Aphididae) and its role as a host reservoir. *Ann. Entomol. Soc. Am.* 105: 386–394.
- Hermoso de Mendoza, A., E. Pérez, E. A. Carbonell, and V. Real. 1998.** Sampling methods to establish percentages of species and population patterns in citrus aphids, pp. 561–568. In **J. M. Nieto and A. G. Dixon** (eds.), *Aphids in natural and managed ecosystems*. Proceedings of the 5th International Symposium on Aphids, 15–19 September 1997, Universidad de León, León.
- Hermoso de Mendoza, A., B. Belliure, E. A. Carbonell, and V. Real. 2001.** Economic thresholds for *Aphis gossypii* (Hemiptera: Aphididae) on *Citrus clementina*. *J. Econ. Entomol.* 94: 439–444.
- Hermoso de Mendoza, A., R. Arouni, B. Belliure, E. A. Carbonell, and J. Pérez Panadés. 2006.** Intervention thresholds for *Aphis spiraeicola* (Hemiptera: Aphididae) on *Citrus clementina*. *J. Econ. Entomol.* 99: 1273–1279.
- Kavallieratos, N. G., C. G. Athanassiou, G. J. Stathas, and Ž. Tomanović. 2002.** Aphid parasitoids (Hymenoptera: Braconidae: Aphidiinae) on citrus: seasonal abundance, association with the species of host plant, and sampling indices. *Phytoparasitica* 30: 365–377.
- Kavallieratos, N. G., G. J. Stathas, and Ž. Tomanović. 2004a.** Seasonal abundance of parasitoids (Hymenoptera: Braconidae: Aphidiinae) and predators (Coleoptera: Coccinellidae) of aphids infesting citrus. *Biologia* 59: 191–196.
- Kavallieratos, N. G., Ž. Tomanović, P. Starý, C. G. Athanassiou, G. P. Sarlis, O. Petrović, M. Niketić, and M. Anagnou Veroniki. 2004b.** A survey of aphid parasitoids (Hymenoptera: Braconidae: Aphidiinae) of south-eastern Europe and their aphid-plant associations. *Appl. Entomol. Zool.* 39: 527–563.
- Kavallieratos, N. G., C. G. Athanassiou, Ž. Tomanović, A. Sciarretta, P. Trematerra, and V. Žikić. 2005a.** Seasonal occurrence, distribution and sampling indices for *Myzus persicae* (Hemiptera: Aphidoidea) and its parasitoids (Hymenoptera: Braconidae: Aphidiinae) on tobacco. *Eur. J. Entomol.* 102: 459–468.
- Kavallieratos, N. G., Ž. Tomanović, C. G. Athanassiou, P. Starý, V. Žikić, G. P. Sarlis, and C. Fasseas. 2005b.** Aphid parasitoids (Hymenoptera: Braconidae: Aphidiinae) infesting cotton, citrus, tobacco and cereal crops in southeastern Europe: aphid-plant associations and keys. *Can. Entomol.* 137: 516–531.
- Krantz, G. W. 1978.** A manual of acarology, 2nd ed. Oregon State University Book Stores, Inc, Corvallis.
- Latteur, G. 1973.** Étude de la dynamique des populations des pucerons des céréales. Premières données relatives aux organismes aphidiphages en trois localités différentes. *Parasitica* 29: 134–151.
- Loconsole, G., N. Önelge, O. Potere, A. Giampetruzzi, O. Bozan, S. Satar, A. De Stradis, V. Savino, R. K. Yokomi, and M. Saponari. 2012.** Identification and characterization of citrus yellow vein clearing virus, a putative new member of the genus *Mandarivirus*. *Phytopathology* 102: 1168–1175.
- Marroquín, C., A. Olmos, M. A. Gorris, E. Bertolini, C. M. Martínez, E. A. Carbonell, A. Hermoso de Mendoza, and M. Cambra. 2004.** Estimation of the number of aphids carrying citrus tristeza virus that visit adult citrus trees. *Virus Res.* 100: 101–108.
- Michelena, J., and A. Sanchis. 1997.** Evolución del parasitismo y fauna útil sobre pulgones en una parcela de cítricos. *Bol. Sanid. Veg. Plagas* 23: 241–255.
- Pons, X., B. Lumbierres, R. Antoni, and P. Starý. 2011.** Parasitoid complex of alfalfa aphids in an IPM intensive crop system in northern Catalonia. *J. Pest Sci.* 84: 437–445.
- Powell, W. 1982.** The identification of hymenopterous parasitoids attacking cereal aphids in Britain. *Syst. Entomol.* 7: 465–473.
- Satar, S., U. Kersting, and N. Uygün. 2007.** Transmission of Turkish citrus tristeza virus isolates by *Aphis gossypii* Glover (Homoptera: Aphididae) in the laboratory condition. *IOBC/WPRS Bull.* 38: 328–335.
- Satar, S., M. Karacaoğlu, G. Satar, and N. Uygün. 2011.** Studies on introduction of *Lysiphlebus testaceipes* (Cresson) (Hymenoptera: Braconidae), an important parasitoid of *Aphis gossypii* Glover (Hemiptera: Aphididae) in citrus orchards of east Mediterranean region of Turkey. *Türkiye Biyolojik Mücadele Derneği* 2: 55–62.
- Satar, S., U. Kersting, and R. Yokomi. 2013.** Presence of two host races of *Aphis gossypii* Glover (Hemiptera: Aphididae) collected in Turkey. *Ann. Appl. Biol.* 162: 41–49.
- Sokal, R. R., and F. J. Rohlf. 1995.** Biometry, 3rd ed. W.H. Freeman, New York.
- Statistical Package for the Social Sciences (SPSS), Inc. 2008.** SPSS version 17.0 for windows. SPSS, Inc, Chicago, IL.
- Starý, P. 1970.** Biology of aphid parasites (Hymenoptera: Aphidiidae) with respect to integrated control. Dr. W. Junk, The Hague.

- Starý, P. 1976.** Aphid parasites (Hymenoptera, Aphidiidae) of the Mediterranean area. Dr. W. Junk, The Hague.
- Starý, P. 1988.** Aphidiidae, pp. 171–184. In **A. K. Minks and P. Harrewijn** (eds.), *Aphids, their biology, natural enemies and control*. Elsevier, Amsterdam.
- Starý, P., and J. Havelka. 2008.** Fauna and associations of aphid parasitoids in an up-dated farmland area (Czech Republic). *Bull. Insectol.* 61: 251–276.
- Starý, P., and K. S. Pike. 1998.** Uses of beneficial insect diversity in agroecosystem management, pp. 49–67. In **W. W. Collins and C. O. Qualset** (eds.), *Biodiversity in agroecosystems. Series: advances in agroecology*. CRC Press, Boca Raton.
- Starý, P., J. P. Lyon, and F. Leclant. 1988.** Post colonisation host range of *Lysiphlebus testaceipes* in Mediterranean area (Hymenoptera: Aphidiidae). *Acta Entomol. Bohemoslov.* 85: 1–11.
- Starý, P., B. Lumbierres, and X. Pons. 2004.** Opportunistic changes in the host range of *Lysiphlebus testaceipes* (Cresson), an exotic aphid parasitoid expanding in the Iberian Peninsula. *J. Pest Sci.* 77: 139–144.
- Tena, A., and F. Garcia Marí. 2011.** Current situation of citrus pests and diseases in the Mediterranean basin. *IOBC Bull.* 62: 365–368.
- Tomanović, Ž., N. G. Kavallieratos, P. Starý, L. Ž. Stanisavljević, A. Četković, S. Stamenković, S. Jovanović, and C. G. Athanassiou. 2009.** Regional tritrophic relationship patterns of five aphid parasitoid species (Hymenoptera: Braconidae: Aphidiinae) in agroecosystem-dominated landscapes of southeastern Europe. *J. Econ. Entomol.* 102: 836–854.
- Tremblay, E. 1984.** The parasitoid complex (Hymenoptera: Ichneumonoidea) of *Toxoptera aurantii* (Homoptera: Aphidoidea) in the Mediterranean area. *Entomophaga* 29: 203–209.
- Uygun, N., İ. Karaca, M. R. Ulusoy, and D. Şenal. 2001.** Citrus pests and their integrated control, pp. 11–57. In **N. Uygun** (ed.), *Integrated pest management in Turkey citrus orchards*. TÜBİTAK - TARP, Adana.
- Uygun, N., A. Hermoso de Mendoza, and H. Başpınar. 2012.** Aphididae, pp. 126–136. In **V. Vacante and U. Gerson** (eds.), *Integrated control of citrus pests in the Mediterranean region*. Bentham eBooks, Bussum.
- Yoldaş, Z., A. Güncan, and T. Koçlu. 2011.** Seasonal occurrence of aphids and their natural enemies in satsuma mandarin orchards in Izmir, Turkey. *Turkish J. Entomol.* 35: 59–74.
- Yumruktepe, R., and N. Uygun. 1994.** Determination of aphid species (Homoptera: Aphididae) and their natural enemies in citrus orchards in eastern Mediterranean region, pp. 1–12. In *Proceedings of the 3rd Turkish National Congress of Biological Control*. Ege Üniversitesi Ziraat Fakültesi Bitki Koruma Bölümü. 25–28 January 1994, İzmir.

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