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Diversity and interactions of the parasitoids (Hymenoptera: Braconidae: Aphidiinae) of aphids from a lagoon habitat in northwest Turkey

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Abstract The aim of this study was to reveal the diversity of parasitoids and ascertain tritrophic parasitoid-host aphid-host plant interactions in a lagoon habitat very close to orchards, vegetable gardens, and cereal fields in the Çanakkale Province of northwest Turkey between April and September from 2020 to 2021. In total, 23 tritrophic parasitoid-host aphid-host plant interactions, including new association records for Europe and Turkey, were revealed on 12 parasitoid species belonging to six genera from the subfamily Aphidiinae (Hymenoptera: Braconidae) reared from 15 aphid species (Hemiptera: Aphididae) on 17 host plants from different plant families. Also, we present three tritrophic parasitoid-host aphid-host plant interactions new for Europe and five tritrophic interactions new for Turkey. Of the identified parasitoid species, *Aphidius* (*Aphidius*) *artemisicola* Tizado et Nunez-Perez, 1994 is recorded for the first time for the parasitoid fauna of Turkey. A morphological diagnosis of the newly recorded parasitoid is provided. The results of this study of the tritrophic interactions between parasitoids and their aphid hosts on host plants in a lagoon habitat enable us to more meaningfully interpret these interactions and provide data of potential significance for the biological control of pest aphids in the region. These results showed that research on the interactions of parasitoids and their host aphids on non-crop host plants in non-crop areas close to crop fields can yield data of potential significance for the biological control of aphids in agriculture.

Keywords Tritrophic interactions · Parasitoids · Host aphids · Host plants · Lagoons · Northwest Turkey

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Introduction

Aphid parasitoids (Hymenoptera: Braconidae: Aphidiinae) are one of the most important groups of natural enemies evaluated as potential agents for the biocontrol of aphid pests on crops, and their host specificity mostly depends on aphid hosts feeding on host plants with different distributions (Völkl & Mackauer, 2000; Žikić et al., 2017). Throughout the world, aphidiine parasitoids, which are solitary koinobiont endoparasitoids, are distributed in different habitats, including both crop and non crop areas, depending on their associated host aphids. With more than 500 species belonging to 38 genera, representatives of the subfamily Aphidiinae are mostly distributed in the Holarctic region. The aphid parasitoid fauna in Turkey contains 64 species belonging to 12

genera (Aslan et al., 2004; Ergene, 2019; Ölmez & Ulusoy, 2003).

Tritrophic associations between parasitoids and host aphids on host plants in different habitats have been investigated by researchers from many parts of the world (Dey & Akhtar, 2007; Kavallieratos et al., 2001, 2004; Kök et al., 2020; Kos et al., 2012a; Mejías et al., 2010; Rakhshani et al., 2015, 2019; Starý et al., 2007, 2010; Tomanović et al., 2009). The trophic associations between parasitoids can be classified in different patterns. Aphidiine parasitoids, which have a highly variable range of host specificity, were classified into five groups according to their host range by Starý (1981), mostly on the basis of aphid phylogeny. Žikić et al. (2017) created a new classification using a kind of artificial neural network visualization in line with the needs arising from determining new interactions between parasitoids, aphid hosts, and host plants, in the process mentioning new parasitoid and aphid species and new synonymizations. According to this classification, aphidiine parasitoids are divided into categories such as monophagous, narrowly oligophagous, moderately oligophagous, broadly oligophagous, and polyphagous. Their results showed that about half of the analysed parasitoids species (225 of 505 species) belong to the group of solid specialists, consisting of monophagous parasitoids that attack only one aphid species. On the other hand, it has been reported that *Lysiphlebus testaceipes* (Cresson), an invasive species in the Palaearctic, was recorded attacking 162 aphid species from 58 genera belonging to seven subfamilies of the family Aphididae. These data provide a framework for the use of parasitoids, which are successful biocontrol agents, in the biological control of aphid pests.

Host plant species in different habitats were found to play an important role in host aphid acceptance and suitability of the host for parasitoids (Albittar et al., 2016). The success of parasitism is highly dependent on tritrophic parasitoid-host aphid-host plant interactions in terms of the host's location, acceptance, and suitability (Hatano et al., 2008; Rasekh et al., 2010). Many plants distributed in a non-crop area near agricultural crops may be an alternative host plant for phytophagous insects (aphids) and their natural enemies (parasitoids) during the production season and beyond (Starý & Havelka, 2008; Stenberg, 2017). Host plants such as flowering herbaceous plants, shrubs, and trees in non-crop areas can host pest insects and their natural enemies such as parasitoids and potentially minimize any negative impacts on biodiversity and biological control in agricultural areas (Amoabeng et al., 2020; Landis et al., 2000; Tomanović et al., 2009). Appropriate habitat management, including non-crop plants in close proximity to agricultural land, is important in terms of providing alternative prey or host to natural enemies and protection from adverse conditions by providing. Also, conservation of natural enemies (parasitoids and predators) in non-crop habitats can prevent the negative impacts of potential exotic pests (Jonsson et al., 2010).

Different habitats significantly contribute to the diversity of parasitoids, aphids, and host plants (Kos et al., 2012a). For example, Alhmedi et al. (2018) found 43 aphids associated with 28 parasitoids on 46 non-crop herbaceous plants and 17 aphids associated with 17 parasitoids on 11 non-crop shrub and tree plants in fruit agroecosystems of Belgium in 2015. In a study conducted by Tomanović et al. (2012) in wetland habitats in the western Palaearctic, which has features similar to our sampling area, a total of 66 tritrophic parasitoid-aphid-plant associations, including 24 parasitoids associated with 24 host aphid species on over 30 host plants, were noted on the basis of records from 25 countries. Also, seven of these interactions were reported as new associations. Similarly, Kavallieratos et al. (2013) noted 22 parasitoid species on 40 aphids from herbaceous and shrubby ornamental plants in national parks, along roads and avenues, and in gardens of Southeast Europe. They indicated that 126 out of the recorded 266 parasitoid-aphid host plant associations were new reports. These results and those obtained in our study show that non-crop habitats significantly enrich both parasitoid and aphid biodiversity, as well as tritrophic parasitoid-aphid-host plant associations.

Coastal wetlands are important protected areas with high faunal and floral biodiversity worldwide. The danger of losing these areas due to both human activity and natural processes increases day by day. Coastal wetlands, including lagoon areas, are rare geomorphological formations which provide opportunities in terms of food, refuge, and overwintering areas for many pest species and their natural enemies such as aphid parasitoids (Starý, 1970). These habitats, especially those located close to agricultural areas, are important reservoir areas for both

herbivorous insects and insects that are natural enemies (Tomanović et al., 2012). Faunal and floral studies carried out in lagoon areas in Turkey and throughout the world are very limited. So far, there have been no studies conducted on parasitoids and their host aphids, the most important economic pests of crop plants in lagoon habitats, most of which are close to agricultural areas in Turkey. To close this gap, it is thought that important data can be obtained in studies of parasitoid-aphid interactions on host plants in non-crop lagoon habitats. Such data could be useful in developing strategies for biological control of these pests on agricultural crops.

In this connection, the goals of our study were to determine the parasitoid composition of aphids from the non-crop Çardak lagoon habitat, which is very close to agricultural fields, and stress the possible role of the discovered parasitoids as biocontrol agents for surrounding crops in the Çanakkale province of the northwestern part of Turkey. This research will provide basic data for further strategies designed to ensure the conservation of lagoon areas.

Material and methods

Sampling site

The Çardak lagoon is located in the northern part of the Dardanelles Strait, which opens to the Sea of Marmara and is one of the two waterways that separate the European and Asian continents. The lagoon area is located on coordinates of 40° 22′ 36"—40° 23′ 36" N and 26° 42′ 45"—26° 44′ 18" E. The sampling area has a spit and a lagoon lake between it and the mainland (Fig. 1). The soil structure of the sampling area consists of alluviums, brown forest soils, and coastal sand soils. Moreover, the sampling area has

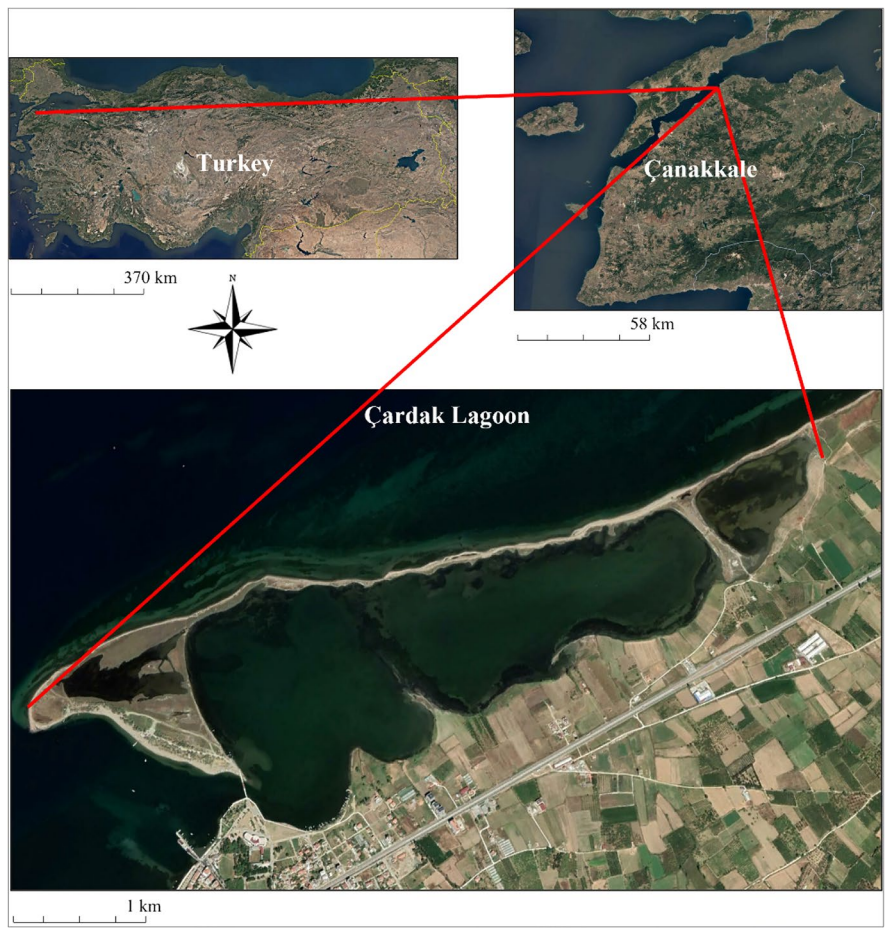

Fig. 1 Map showing sampling area in the Çardak Lagoon in the Çanakkale Province of northwest Turkey (Anonymous, 2021)

a transitional character between Mediterranean and Black Sea climate types. As for vegetation of the sampling area, reeds are present along the mainland shore of the lagoon. Also, there are some trees to the east of the lagoon and dune plants such as *Anchusa undulata* L. (Boraginaceae), *Bromus tectorum* L. (Poaceae), *Centaurea spinosa* L. (Asteraceae), *Juncus maritimus* Lam (Juncaceae), *Sarcopterium spinosum* (L.) Spach (Rosaceae), and *Vulpia fasciculata* (Forssk.) Samp. (Poaceae) are distributed on the surface of the spit. Dune plants such as *Eryngium maritimum* L. (Apiaceae), *Eupharbia paralias* L. (Euphorbiaceae), *Xanthium strumarium* L. (Asteraceae), and *Convolvulus arvensis* L. (Convolvulaceae) are also distributed in the sampling area (Çalışkan & Tosunoğlu, 2010; Çavuş & Akbulak, 2006; Kaplan, 2009). Additionally, there are many cultivated crop areas such as cereals, vegetables and orchards very close to the sampling lagoon area (Fig. 1).

Collection, preparation, and identification of parasitoids and their host aphids

To reveal the potential contributions of a lagoon area, which is a non-crop habitat and located very close to agricultural areas, for the to biological control of pest aphids on agricultural crops, specimens of parasitoids and host aphids were collected from herbaceous plants, shrubs and trees. Size of the sampling area is about 2.5 km^2 (Fig. 1). The parasitoid and host aphid specimens were collected once a week from infested host plants found in the Çardak Lagoon in the Çanakkale Province of northwest Turkey between April and September from 2020 to 2021.

For sampling of parasitoid species, mummified aphids were collected from a number of host plants that included flowering herbaceous plants, shrubs, and trees found in the lagoon area. Parasitoids were collected by sampling mummified aphids. The mummies collected from aphid-infested host plants were brought in boxes to the laboratory for emergence of adult parasitoid specimens. For parasitoid emergence, mummified aphids in colonies on the host plants were put in plastic bottles and kept in laboratory conditions (22.5 °C, 65% humidity, 16:8 L:D photoperiod).

Parasitoids were morphologicaly identified by the second author using several keys (Kos et al., 2012b; Tomanović et al., 2007, 2014, 2021).

To identify the aphid hosts of parasitoids, apterous and alate aphids from the colonies on infested host plants were transferred with a soft brush (#00) into the Eppendorf tubes containing 70% ethyl alcohol and then brought to the laboratory for preparation and identification. The preparation of aphid specimens followed the method of Hille Ris Lambers (1950). Identification of aphids was done by the first author using a LEICA DM 2500 microscope with a mounted HD camera and LAS software (version 4.1) according to Blackman and Eastop (2006, 2021). The current taxonomic status and names of identified aphid species are given as in Favret (2021).

The specimens of identified parasitoids were deposited in the Institute of Zoology, University of Belgrade, Faculty of Biology, Serbia, while those of host aphids were deposited in the Department of Plant Protection, Faculty of Agriculture, Çanakkale Onsekiz Mart University, Turkey.

Parasitoid-host aphid-host plant interactions

To visualize structural patterns of the tritrophic parasitoid-host aphid-host plant network in the sampling area, graphs of tripartite interactions were constructed on the basis of data on parasitoid, aphid, and host plant relative abundances using the "plotweb2" function in the bipartite package of R software (version 3.6.1) (R Development Core Team, 2021).

Results and discussion

In this study conducted on a lagoon habitat located near agricultural areas such as fruit, vegetable, and cereal fields in nortwest Turkey from 2020 to 2021, 12 parasitoid species belonging to six genera from the subfamily Aphidiinae (Hymenoptera: Braconidae) emerged from 15 aphid species (Hemiptera: Aphididae) on 17 host plants. Of these parasitoids, *Aphidius* (*Aphidius*) *artemisicola* Tizado et Nunez-Perez, 1994 is recorded for the first time for the parasitoid fauna of Turkey. Also, a total of 23 tritrophic parasitoid-host aphid-host plant associations, including new records for Europe and Turkey, were determined from the lagoon area.

These tritrophic associations are listed below as a catalogue that includes parasitoid species; the number of individuals of parasitoids, host aphids,

and host plants; the sampling date; and locations according to each taxonomic order.

Order Hymenoptera.

Family Braconidae.

Subfamily Aphidiinae.

***Aphidius (Aphidius) artemisicola* Tizado et Nunez-Perez, 1994**

1♂, *Macrosiphoniella* (*Macrosiphoniella*) *pulvera* (Walker, 1848) on *Artemisia* sp. (Asteraceae), 18.05.2020, Çanakkale.

*Note: *Aphidius artemisicola* is a new record for the parasitoid fauna of Turkey. It is morphologically similar to *A. iranicus* Rakhshani & Starý, but the examined male specimen showed that it possesses a very short forewing vein R1 (=metacarpus) and equal length of the first and second flagellomere, which clearly indicates that it belongs to *A. artemisicola* (Fig. 2).

***Aphidius (Aphidius) colemani* Viereck, 1912**

3♀3♂, *Brachycaudus* (*Brachycaudus*) *helichrysi* (Kaltenbach, 1843) on *Silybium marianum* (L.) Gaertn. (Asteraceae); 4♀6♂, *B.*(*B.*) *helichrysi* on *Artemisia santolina* Schrenk (Asteraceae); 7♀6♂, *B.*(*B.*) *helichrysi* on *Senecio vulgaris* L. (Asteraceae); 2♀1♂, unknown aphid species 1 on unknown host plant 1, 12.04.2020, Çanakkale; 3♂, *B.*(*B.*) *helichrysi* on *Myosotis* sp. (Boraginaceae); 5♀2♂, *B.*(*B.*) *helichrysi* and **Macrosiphoniella* (*Macrosiphoniella*) *tapuskae* (Hottes & Frison, 1931) on *Anthemis* sp. (Asteraceae),19.04.2020, Çanakkale.

*Note: This is a new parasitoid-host aphid association in Europe and Turkey.

Host aphids in Turkey: *Acyrthosiphon* (*Acyrthosiphon*) *pisum* (Harris, 1776), *Aphis* sp., *Aphis* (*Aphis*) *craccivora* Koch, 1854, *Aphis* (*Aphis*) *fabae* Scopoli, 1763, *Aphis* (*Aphis*) *gossypii* Glover, 1877, *Aphis* (*Aphis*) *nerii* Boyer de Fonscolombe, 1841, *Aphis* (*Aphis*) *pomi* De Geer, 1773, *Aphis* (*Aphis*) *punicae* Passerini, 1863, *Aphis* (*Aphis*) *spiraecola* Patch, 1914, *Aphis* (*Aphis*) *umbrella* (Börner, 1950), *B.* (*B.*) *helichrysi*, *Brachycaudus (Scrophulaphis) persicae* (Passerini, 1860), *Brachycaudus* (*Appelia*) *prunicola schwartzi* (Börner, 1931), *Brevicoryne brassicae* (Linnaeus, 1758), *Capitophorus elaeagni* (Del Guercio, 1894), *Hyalopterus amygdali* (Blanchard, 1840), *Hyalopterus pruni* (Geoffroy, 1762), *Hyperomyzus* (*Hyperomyzus*) *lactucae* (Linnaeus, 1758), *Myzus* (*Myzus*) *ornatus* Laing, 1932, *Myzus* (*Nectarosiphon*) *persicae* (Sulzer, 1776), *Ovatus* (*Ovatus*) *mentharius* van der Goot, 1913, *Rhopalosiphum maidis* (Fitch, 1856), *Rhopalosiphum padi* (Linnaeus, 1758), *Sarucallis kahawaluokalani* (Kirkaldy, 1907), and *Uroleucon* (*Uroleucon*) *sonchi* (Linnaeus, 1767) (Aslan et al., 2004; Bayram et al., 2018; Erkin, 1983; Ghaliow et al., 2018; Gücük & Yoldaş, 2000; Güleç, 2011; Güncan et al., 2006; Güz, 2003; Güz & Kılınçer, 2005; Karakaya,

Fig. 2 *Aphidius artemisicola* Tizado et Nunez-Perez, male, dorsal view

2014; Kök et al., 2017; Narmanlıoğlu, 2013; Ölmez & Ulusoy, 2003; Satar et al., 2014; Starý, 1976; Tomanović et al., 2012; Tozlu et al., 2002).

***Aphidius (Aphidius) funebris* Mackauer, 1961**

6♀5♂, *H.*(*H.*) *lactucae* and *U.*(*U.*) *sonchi* on *Sonchus oleraceus* (L.) L. (Asteraceae), 12.05.2020, Çanakkale; 10♀5♂, *U.*(*U.*) *sonchi* on *Sonchus* sp. (Asteraceae), 18.05.2020, Çanakkale; 1♀1♂, *H.*(*H.*) *lactucae* and *U.*(*U.*) *sonchi* on *Sonchus* sp., 18.05.2020, Çanakkale; 15♀10♂, *U.*(*U.*) *sonchi* on *Sonchus* sp., 28.05.2020, Çanakkale; 19♀7♂, unknown aphid species 2 on Asteraceae, 12.05.2020, Çanakkale.

Host aphids in Turkey: *Brachycaudus* (*Prunaphis*) *cardui* (Linnaeus, 1758), *H.* (*H.*) *lactucae*, *M.* (*N.*) *persicae*, *U.*(*U.*) *sonchi*, *Uroleucon*sp., *Uroleucon* (*Uromelan*) *aeneum* (Aslan et al., 2004; Güleç, 2011; Güz, 2003; Güz & Kılınçer, 2005).

***Aphidius (Aphidius) matricariae* Haliday, 1834**

9♀10♂, *B.* (*B.*) *helichrysi* on *Anthemis* sp., 19.04.2020, Çanakkale.

Host aphids in Turkey: *Aphis* (*Aphis*) *affinis* Del Guercio, 1911, *A.*(*A.*) *fabae*, *A.*(*A.*) *gossypii*, *Aphis* (*Aphis*) *illinoisensis* Shimer, 1866, *A.*(*A.*) *pomi*, *A.*(*A.*) *punicae*, *Aphis* (*Aphis*) *viticis* Ferrari, 1872, *Brachycaudus* (*Appelia*) *tragopogonis* (Kaltenbach, 1843), *B.*(*P.*) *cardui*, *B.*(*B.*) *helichrysi*, *Capitophorus hippophaes* (Walker, 1852), *Capitophorus* sp., *Diuraphis* (*Diuraphis*) *noxia* (Mordvilko, 1913), *Dysaphis* (*Dysaphis*) *devecta* (Walker, 1849), *Dysaphis* (*Pomaphis*) *plantaginea* (Passerini, 1860), *Dysaphis* (*Pomaphis*) *pyri* (Boyer de Fonscolombe, 1841), *H. pruni*, *H.*(*H.*) *lactucae*, *Macrosiphum* (*Macrosiphum*) *euphorbiae* (Thomas, 1878), *Monellia caryella* (Fitch, 1855), *Myzus* (*Myzus*) *cerasi* (Fabricius, 1775), *M.*(*N.*) *persicae*, *R. maidis*, *R. padi*, *Schizaphis* (*Schizaphis*) *graminum* (Rondani, 1852) (Aslan, 2004, 2015; Aslan & Karaca, 2005; Aslan et al., 2004; Ayyıldız & Atlıhan, 2006; Bayram et al., 2018; Daşcı & Güçlü, 2008; Erkin, 1983; Güleç, 2011; Karakaya, 2014; Kaya Apak & Akşit, 2016; Kök et al., 2017; Ölmez & Ulusoy, 2003; Öztürk, 2017; Satar et al., 2014; Starý, 1976; Tanigoshi et al., 1995; Yanpar, 2013; Yaşarakıncı & Hıncal, 1997, 2000a).

***Aphidius* sp.**

1♀,**Capitophorus similis* van der Goot, 1915 on *Elaeagnus angustifolia* L. (Elaeagnaceae), 12.05.2020, Çanakkale.

*Note: This is a new parasitoid-host aphid association in Turkey. The pattern of its wing venation puts the examined specimen in *A. matricariae*, but it possesses four maxillary and three labial palpommeres (*A. matricariae* has three maxillary and two labial palpommeres).

***Aphidius (Aphidius) uzbekistanicus* Luzhetzki, 1960**

2♂, *R. padi* on *Hordeum murinum* subsp. *leporinum* (Link) Arcang. (Poacae), 18.05.2020, Çanakkale.

Host aphids in Turkey: *Metopolophium* (*Metopolophium*) *dirhodum* (Walker, 1849), *R. padi, S.* (*S.*) *graminum, Sitobion* (*Sitobion*) *avenae* (Fabricius, 1775) (Aslan et al., 2004; Bilgin, 2006; Ölmez & Ulusoy, 2003; Sertkaya & Yiğit, 2002; Starý, 1981; Yiğit et al., 2007).

***Binodoxys acalephae* (Marshall, 1896)**

1♂, *A.* (*A.*) *fabae* on *Sonchus* sp., 18.05.2020, Çanakkale.

Host aphids in Turkey: *A.* (*A.*) *pisum*, *Anuraphis* sp., *A.* (*A.*) *craccivora*, *A.* (*A.*) *fabae*, *Aphis* (*Aphis*) *galiiscabri* Schrank, 1801, *Aphis* (*Bursaphis*) *grossulariae* Kaltenbach, 1843, *Aphis* (*Aphis*) *vallei* Hille Ris Lambers & Stroyan, 1959, *B.* (*B.*) *helichrysi*, *Staegeriella necopinata* (Börner, 1939), and *Staegeriella* sp. (Alaserhat, 2015; Bayram et al., 2018; Ghaliow et al., 2018; Güleç, 2011; Güz, 2003; Güz & Kılınçer, 2005; Kök et al., 2017; Ölmez & Ulusoy, 2003; Starý, 1976).

***Binodoxys heraclei* (Haliday, 1833)**

1♀3♂,**Hyadaphis foeniculi* (Passerini, 1860) on *Anthriscus caucalis* M. Bieb. (Apiaceae), 25.06.2020, Çanakkale.

*Note: This is a new parasitoid-host aphid association in Europe and Turkey.

Host aphids in Turkey: *Cavariella* (*Cavaraiellia*) *aquatica* (Gillette & Bragg, 1916), *Pterocomma pilosum* Buckton, 1879 (Güçlü et al., 2015; Kavaz, 2006).

***Diaeretiella rapae* (McIntosh, 1855)**

1♀1♂, **Brachycaudus* (*Thuleaphis*) *amygdalinus* (Schouteden, 1905) on *Prunus dulcis* (Mill.) D.A. Webb (Rosaceae), 12.05.2020, Çanakkale; 1♀, *B. brassicae* on *Brassica nigra* (L.) K. Koch (Brassicaceae), 25.06.2020, Çanakkale.

*Note: This is a new parasitoid-host aphid association in Turkey.

Host aphids in Turkey: *A.*(*A.*) *fabae*, *A.*(*A.*) *gossypii*, *Aphis* sp., *Aulacorthum* (*Aulacorthum*) *solani* (Kaltenbach, 1843), *B.*(*B.*) *helichrysi*, *B. brassicae*,

Brevicoryne sp., *D.*(*D.*) *noxia*, *D.*(*P.*) *pyri*, *Hayhurstia atriplicis* (Linnaeus, 1761), *Hyadaphis coriandri* (Das, 1918), *H. foeniculi*, *Hyadaphis tataricae* (Aizenberg, 1935), *H. pruni*, *H.*(*H.*) *lactucae*, *Lipaphis* (*Lipaphis*) *erysimi* (Kaltenbach, 1843), *Lipaphis* sp., *M.*(*N.*) *persicae*, *R. maidis*, *U.*(*U.*) *sonchi*, *Uroleucon* sp. (Aslan, 2015; Aslan et al., 2004; Bayram et al., 2018; Elmalı, 1993; Erkin, 1983; Güleç, 2011; Güz, 2003; Güz & Kılınçer, 2005; Kılınçer, 1982; Ölmez & Ulusoy, 2003; Özder & Kılınçer, 1999; Satar et al., 2014; Tanigoshi et al., 1995; Tozlu et al., 2002; Yaşarakıncı & Hıncal, 2000a, 2000b; Zeren & Düzgüneş, 1983).

***Ephedrus (Ephedrus) persicae* Froggatt, 1904**

3♀2♂, *B.* (*T.*) *amygdalinus* on *P. dulcis*, 12.05.2020, Çanakkale.

Host aphids in Turkey: *A.*(*A.*) *craccivora*, *A.*(*A.*) *fabae*, *Aphis* (*Aphis*) *passeriniana* (Del Guercio, 1900), *A.* (*A.*) *pomi*, *Aphis* sp., *A.*(*A.*) *spiraecola*, *B.*(*T.*) *amygdalinus*, *B.*(*P.*) *cardui*, *B.*(*B.*) *helichrysi*, *D.* (*D.*) *devecta*, *D.*(*P.*) *plantaginea*, *D.*(*P.*) *pyri*, *Dysaphis* sp., *H. amygdali*, *H. pruni*, *M.*(*N.*) *persicae*, *M.*(*M.*) *cerasi* (Aslan, 2004, 2015; Aslan & Karaca, 2005; Aslan et al., 2004; Erkin, 1983; Güleç, 2011; Ölmez & Ulusoy, 2003; Özder, 1998, 1999; Satar et al., 2014; Yiğit & Uygun, 1982; Zarkani, 2018; Zeren & Düzgüneş, 1983; Žikićet al., 2009).

***Praon yomenae* Takada, 1968**

8♀3♂,**Uroleucon* (*Uromelan*) *jaceae* (Linnaeus, 1758) on *Centaurea spinosa* L. (Asteraceae), 12.05.2020, Çanakkale.

*Note: Güz and Kılınçer (2005) identified *P. yomenae* as "*P. dorsale* auct.".

Host aphids in Turkey: *U.* (*U.*) *sonchi* (Kavallieratos et al., 2003, 2004; Tomanović et al., 2003).

***Trioxys (Trioxys) pallidus* (Haliday, 1833)**

1♂, **Tuberculatus* (*Tuberculoides*) *moerickei* Hille Ris Lambers, 1974 on *Quercus* sp. (Fagaceae), 28.06.2020, Çanakkale.

*Note: This is a new parasitoid-host aphid association in Europe and Turkey.

Host aphids in Turkey: *Chromaphis juglandicola* (Kaltenbach, 1843), *D.*(*P.*) *plantaginea, D.*(*P.*) *pyri, D.*(*D.*) *devecta, Eriosoma lanigerum* Hausmann, 1802*, M. caryella, Panaphis juglandis* (Goeze, 1778)*, Rhopalosiphum nymphaeae* (Linnaeus, 1761), *Tuberculoides* sp. (Alaserhat, 2015; Aslan et al., 2004; Atlıhan et al., 2011, 2015; Kaya Apak & Akşit, 2016; Ölmez & Ulusoy, 2003; Starý, 1976).

We have here recorded *A. artemisicola* for the first time in Turkey. It was found in association with *M. pulvera* on the host plant *Artemisia* sp. Although there are several records in the literature indicating association of this parasitoid with *Macrosiphoniella* aphid hosts on *Artemisia* spp. as the host plant, the usual hosts for this parasitoid are aphids from the genus *Titanosiphon* Nevsky, 1928, but it is possible that it is present on aphids in mixed colonies of *Macrosiphoniella* + *Titanosiphon*. *Aphidius* (*A.*) *artemisicola* is distributed in Mediterranean and sub-Mediterrnnean steppe habitats (Tizado & Núñez-Pérez, 1994; Tomanović et al., 2003). Of the identified parasitoid species, *A.* (*A.*) *colemani* reared from three aphid species feeding on seven host plants and *A.* (*A.*) *funebris* from three aphid species feeding on five host plants were the most common parasitoids in the sampling area. The aphid species that hosted the most parasitoid species were *B.* (*T.*) *amygdalinus* and *B.* (*B.*) *helichrysi* (Fig. 3). It was also determined that the aphid *C. similis* fed on the host plant *E. angustifolia,* where it was parasitized by an unidentified *Aphidius* sp. As we have already mentioned, the sampled specimen of *Aphidius* sp. shared morphological characters which are unusual and require additional taxonomic evaluation. Moreover, *B.* (*B.*) *helichrysi,* and *B.* (*T.*) *amygdalinus*, which are important pests of plum, peach, and almond in Turkey and in the world, were hosts to four different parasitoid species.

Several parasitoid-aphid associations new for both Europe and Turkey were recorded in the present study. The associations *A.* (*A.*) *colemani-M.* (*M.*) *tapuskae* on the host plant *Anthemis* sp.*, B. heraclei-H. foeniculi* on the host plant *A. caucalis,* and *T.* (*T.*) *pallidus-T.* (*T.*) *moerickei* on the host plant *Quercus* sp. are new to Europe. Similarly, the associations *A.* (*A.*) *colemani-M.* (*M.*) *tapuskae* on the host plant *Anthemis* sp., *Aphidius* sp.*-C. similis* on the host plant *E. angustifolia*, *B. heraclei-H. foeniculi* on the host plant *A. caucalis*, *D. rapae-B.* (*T.*) *amygdalinus* on the host plant *P. dulcis*, and *T.* (*T.*) *pallidus-T.* (*T.*) *moerickei* on the host plant *Quercus* sp. were recorded for the first time in Turkey.

Non-crop habitats with rich parasitoid diversity and close to agricultural areas can contribute to success of the biological control of aphid pests on agricultural crops, which depends on the structure and distribution of those habitats. Tomanović et al. (2009) reported that 42 out of 79 taxa of the aphid hosts of

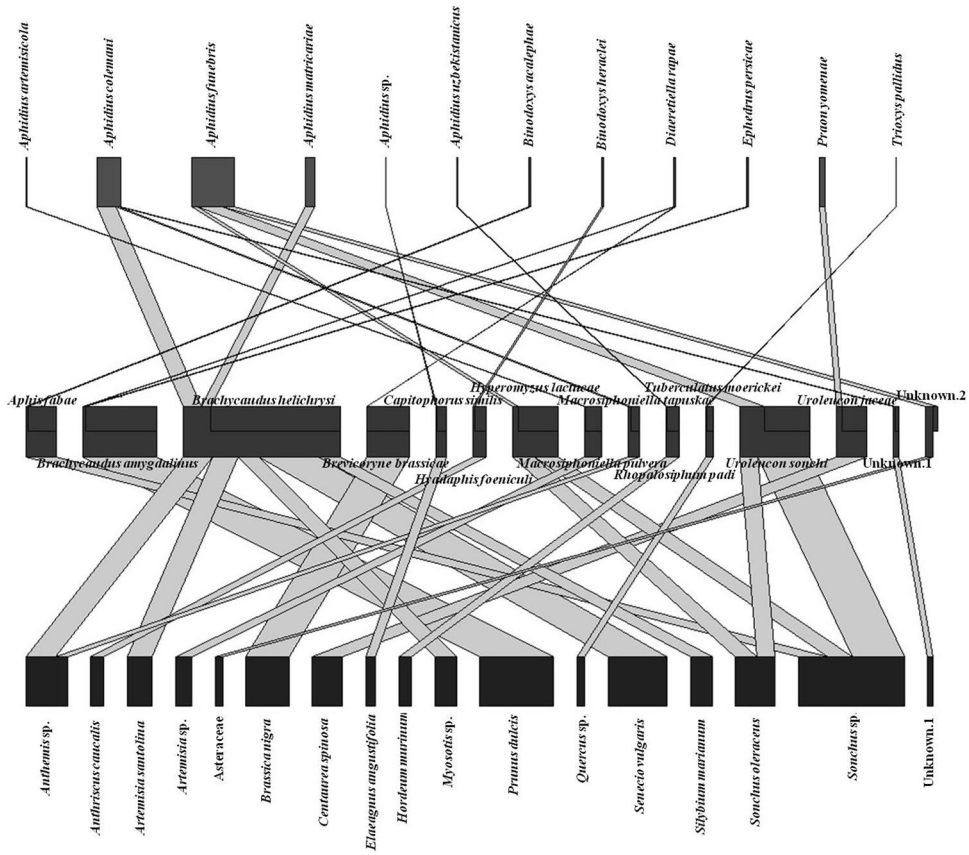

Fig. 3 Quantitative tripartite network of interactions between parasitoids (top), host aphids (middle), and host plants (bottom) in a lagoon habitat in northwest Turkey. Black bars represent abundance of the species and grey bars represent interactions (width of the bars indicates the intensity of interactions)

parasitoids in Southeast Europe were recorded from non-crop plants. They also stated that 74% of all parasitoid-aphid interactions discovered in the sampling area were entirely or partially associated with non-crop plants. In addition, the authors emphasized that the host aphids on non-crop plants can significantly contribute to the population density of such important parasitoids as *Lysiphlebus fabarum* (Marshall), *Praon volucre* (Haliday), and *A. colemani* in the vicinity of agroecosystems. Similar results were obtained in the present study. Specifically, one of the most important findings of our study is that *A.* (*A.*) *colemani* and *A.* (*A.*) *matricariae* were reared from *B.* (*B.*) *helichrysi* on five non-crop host plants (*S. marianum*, *A. santolina*, *S. vulgaris*, *Myosotis* sp., and *Anthemis* sp.) in the sampling area. Such data are important to us because the Lâpseki and Çardak regions of the Çanakkale province, which are very close to our sampling area, are agricultural areas in Turkey where plum and peach production is very common. Our observations in fruit orchards close to the study area during the period of sampling show that *B.*(*B.*) *helichrysi* was the most important aphid pest of plum and peach during the months of March to May in 2020. Considering this situation, we can say that our sampling area, where *A.* (*A.*) *colemani* and *A.* (*A.*) *matricariae* were found on host aphids feeding on non-crop plants, indirectly contributes to the biological control of *B.* (*B.*) *helichrysi* in fruit orchards of the region. In connection with this, it should be noted that *A.* (*A.*) *colemani* and *A.* (*A.*) *matricariae* have been reported as parasitoids of *B.* (*B.*) *helichrysi* in countries such as Algeria, Costa Rica, Greece, India, Iran, Serbia and Montenegro, and Turkey by many researchers (Akhtar et al., 2011; Kavallieratos et al., 2001, 2004; Laamari et al., 2012; Mejíaset al., 2010; Rakhshani,

2012; Satar et al., 2014; Tomanović et al., 2003). In addition to them, we recorded *E.* (*E.*) *persicae* and *D. rapae* in lagoon non-crop habitats. Those species are also important members of the parasitoid guilds in Turkish orchard agroecosystems. Our samples contained *A.* (*A.*) *uzbekistanicus*, an important parasitoid of wheat aphids (Kavallieratos et al., 2004; Starý, 1972), on wild grasses in lagoon habitats.

Clearly, to enhance the abundance of many natural enemies in agricultural areas, the local semi-natural habitats and hedgerows near and around agricultural areas should be protected and managed (Garratt et al., 2014). Accordingly, flowering plants that have the potential to be secondary hosts for pest aphids and distributed in-around agricultural areas are known to be an important resource, especially for hoverflies and parasitoids (Ramsden et al., 2015). A study of Rodrigues et al. (2006) revealed that *Aphis* (*Toxoptera*) *aurantii* Boyer de Fonscolombe, an important pest in lemon orchards, was only determined on three plants in-ground cover vegetation in the study orchard., i.e., *Erodium moschatum* (L.) L'Hér. (Geraniaceae), *S. vulgaris* and *Trifolium campestre* Schreb. (Fabaceae). When this result is considered together with our results presented here, it can be interpreted that *S. vulgaris* has the potential to be an important companion plant for pest aphids and their parasitoids in orchards. Similarly, the results of the study investigating the interactions of parasitoids- aphids-host plants in wheat-growing areas and nearby natural areas showed that *S. marianum* hosted numerous aphids (*B.* (*A.*) *cardui*, *A.* (*A.*) *fabae*, *U.* (*U.*) *cichorii* (Koch), *Capitophorus elaeagni* (Del Guercio), *M.* (*N.*) *persicae*, *A.* (*A.*) *solani*) and parasitoids (*A. ervi*, *D. rapae*, *L. fabarum*, *P. volucre*) (Bayram et al., 2018). These data, which are similar to our results, support that *S. marianum* should be protected and managed in both crop and non-agricultural habitats in terms of being a source that increases the diversity of pest aphids and their parasitoids. Generally, landscape heterogeneity and diversity of non-crop habitats nearby crop areas support aphid-parasitoid complexity, their species richness and biological control of pest aphids (Plećaš et al., 2014; Letourneau et al., 2015). In this context, we consider that the results of our study present basic data on the use of different plant species growing in habitats close to agricultural areas for biological control of pest aphids on crops. Using non-crop plants and managing the wild vegetation in and around agricultural areas can contribute to the conservation of biological control in agricultural areas.

Considering all the situations mentioned, we conclude that non-crop areas located close to agricultural areas where fruit, vegetable, and cereal crops are grown can be of potential significance as places of interaction between parasitoids and their aphid hosts on non-crop host plants. The interactions in these areas may have positive effects on the success of biological control of pest aphids, but can also increase their population densities in agricultural areas housing their secondary and overwintering host plants. In the present study, tritrophic interactions between parasitoids and their aphid hosts on host plants were investigated in a lagoon habitat containing mostly salty and dune host plants, a circumstance which affected the composition of parasitoids present. Results of the study enable us to more meaningfully interpret these interactions and provide data of potential significance for the biological control of pest aphids in the region. It seems clear that more studies are needed to better understand parasitoid-host aphid-host plant interactions in non-crop areas close to agricultural areas.

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The authors declare that the work is in compliance with ethical standards.

Declarations

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Conflict of interest The authors declare that the work involves no conflict of interests.

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