

Original article (Orijinal araştırma)

Tachinid (Diptera: Tachinidae) parasitoids reared from lepidopterous and hymenopterous hosts in southern forests of Turkey

Türkiye'nin güneyindeki ormanlarda lepidopter ve hymenopter konukçulardan elde edilen tachinid (Diptera: Tachinidae) parazitoitler

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Abstract

This study was conducted to determine the tachinid (Diptera: Tachinidae) parasitoids of lepidopterous and hymenopterous hosts from forests of southern Turkey (Adana, Hatay, Karaman, Mersin, Niğde and Osmaniye) in 2002-2019. For this purpose, host larvae were collected from forests and herbaceous plant communities and brought to the laboratory with their food-plants. As a result of the study, six tachinid species were reared from nine hosts. Four new hosts for Turkey were recorded. These are *Vanessa cardui* (L., 1758) and *Polygonia c-album* (L., 1758) (Lepidoptera: Nymphalidae) for *Sturmia bella* (Meigen, 1824) (Diptera: Tachinidae), *Utetheisa pulchella* (L., 1758) (Lepidoptera: Erebidae) for *Exorista segregata* (Rondani, 1859) (Diptera: Tachinidae) and *Thaumetopoea wilkinsoni* Tams, 1924 (Lepidoptera: Notodontidae) for *Compsilura concinnata* (Meigen, 1824) (Diptera: Tachinidae). In addition, two parasitoid-host couples were recorded for the second time in the world. These are *U. pulchella* for *E. segregata* and *T. wilkinsoni* for *C. concinnata*.

Keywords: Forest, host records, parasitoids, Tachinidae, Turkey

Öz

Bu çalışma Türkiye'nin güneyindeki (Adana, Hatay, Karaman, Mersin, Niğde ve Osmaniye) ormanlarda bulunan lepidopter ve hymenopterlerin, tachinid (Diptera: Tachinidae) parazitoitlerini belirlemek için 2002-2019 yılları arasında yürütülmüştür. Bu amaç için konukçu larvaları orman ağaçları ve yabancı otlar üzerinden toplanarak beslendikleri bitki ile birlikte laboratuvara getirilmiştir. Çalışma sonucunda, dokuz farklı konukçudan altı tachinid tür elde edilmiş, 4 konukçu ise Türkiye için yeni konukçu kaydı olarak belirlenmiştir. Bunlar; *Sturmia bella* (Meigen, 1824) (Diptera: Tachinidae) için *Vanessa cardui* (L., 1758) ve *Polygonia c-album* (L., 1758) (Lepidoptera: Nymphalidae), *Exorista segregata* (Rondani, 1859) (Diptera: Tachinidae) için *Utetheisa pulchella* (L., 1758) (Lepidoptera: Erebidae) ve *Compsilura concinnata* (Meigen, 1824) (Diptera: Tachinidae) için *Thaumetopoea wilkinsoni* Tams, 1924 (Lepidoptera: Notodontidae)'dır. Ayrıca *E. segregata* için *U. pulchella* ve *C. concinnata* için *T. wilkinsoni* konukçu-parazitoit çiftleri dünya için ikinci kez kaydedilmiştir.

Anahtar sözcükler: Orman, konukçu kayıtları, parazitoit, Tachinidae, Türkiye

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Introduction

Forests are terrestrial ecosystems that consists of various trees, shrubs, herbaceous plants, microorganisms, insects and other animals. There are also economically important pests in forests in Turkey. The activities and damage of such pests do not occur suddenly. Forest pests are generally not given sufficient consideration and are even of no interest to the general public with the destruction of the pests only understood after they become an epidemic. It is known that 50 species and more cause damage in Turkish forests. The plant protection operations are conducted against these pests on 205 kHa in 2019. About a million dollars is spent for these activities each year (Anonymous, 2020). In the past, chemical control measures were used intensely. In recent years, mechanical, biological (bird nest construction, ant augmentation, and parasitoid and predator mass production) and biotechnical (pheromone) methods that do not harm nature are applied instead of chemicals. Also, the use of pesticides is very difficult and expensive in huge areas. In addition, pesticides lead to soil, air and water pollution and resistance, and damaging side effects to natural enemies should not be neglected. It is critical to protect natural enemies, so that they can provide effective biological control. Therefore, it is necessary to support the activities of these insects. Declines in beneficial organisms can lead to increased outbreaks of pests. Therefore, it is important to investigate the biology, ecology and host relationships of natural enemies.

Tachinids are an important group of parasitoids and the majority of the hosts are insect pests. Many hosts are lepidopteran pests. Others hosts are species belonging to the orders Coleoptera, Hemiptera, Hymenoptera, Orthoptera, Diptera and Lithobiomorpha (Grenier, 1988; Stireman et al., 2006; Tschorsnig, 2017). Detailed information on Palearctic and Turkish hosts of tachinids can be found in Tschorsnig (2017) and Kara & Tschorsnig (2003), respectively. Kara et al. (2014) have prepared a comprehensive catalog of tachinid-host associations in Turkish forests. It comprises 27 tachinid species reared from 14 hosts belonging to three orders.

Applied biological control studies with tachinid flies against certain forest pests were successfully performed in Canada and the USA in the 1900s (Grenier, 1988). Augmentative releases were conducted with *Blepharipa pratensis* (Meigen, 1824) in 1933 and *Compsilura concinnata* (Meigen, 1824) (Diptera: Tachinidae) in 1976 against the gypsy moth, *Lymantria dispar* (L., 1758) (Lepidoptera: Erebidae). These two parasitoids have been successfully established and are important parasitoids of the gypsy moth in many states of the USA (Blumenthal et al., 1979). Against the winter moth, *Operophtera brumata* (L., 1758) (Lepidoptera: Geometridae), two tachinids, *Lypha dubia* (Fallén, 1810) and *Cyzenis albicans* (Fallén, 1810) (Diptera: Tachinidae), were used in Canada in 1955-1980. Only the latter species was successfully established (Pschorn-Walcher et al., 1969). In Turkey, *Phryxe caudata* (Rondani, 1859) (Diptera: Tachinidae) is produced by means of an islet, a wire cage and a water chambered wire cage technique and released against *Thaumetopoea pityocampa* (Denis & Schiffermüller, 1775) (Lepidoptera: Notodontidae) which causes significant damage to pine trees (Kanat & Türk, 2002; Özdal, 2002).

This paper focuses on the tachinid parasitoids of some forest pests in southern Turkey.

Materials and Methods

This research was conducted to determine the tachinid parasitoids of lepidopterous and hymenopterous hosts from forests of southern Turkey (Adana, Hatay, Karaman, Mersin, Niğde and Osmaniye) in 2002-2019. Host larvae were collected from forests and herbaceous plant communities.

The collected host larvae were brought to the laboratory together with the plants they consume for rearing, transferred to distinct cages, and kept at $25 \pm 2^{\circ}\text{C}$ and 60-70% RH. Daily checks were made, and food was refreshed as needed. Also, parasitoid emergence was observed daily. After adult parasitoids were obtained, flies were prepared for identification. Reared parasitoids were described according to Mesnil (1944-1965), Tschorsnig & Herting (1994) and Tschorsnig & Richter (1998). Herting & Dely-Draskovits

(1993) was also followed for species nomenclature. Lepidopterous samples were identified using the keys of Doğanlar & Avcı (2001), Doğanlar et al. (2005), and Mazzei et al. (2020). Hymenopterous host was identified using the paper of Smith (1974). Plants were identified by Dr. Mehtap Öztekin (Systematic Botany, Department of Collections, National Botanical Gardens Directorate, Ministry of Agriculture and Forestry, Republic of Turkey, Ankara).

The date of emergence, the number of male and female individuals, the host species, the place where the hosts were collected and the plant where the host insect fed are given for each parasitoid separately. In addition, general information is given on distribution, hosts, and biology of reared parasitoids.

Results and Discussion

Six tachinid species were reared as parasitoids of eight lepidopteran and one hymenopteran host.

Subfamily: Exoristinae

Tribe: Exoristini

Exorista segregata (Rondani, 1859)

Reared specimens. 07.10.2017, ♂, reared from *Utetheisa pulchella* (L., 1758) (Lepidoptera: Erebiidae), collected in Yenışehir, Mersin from *Heliotropium* sp. (Boraginaceae); 06.07.2009, ♀, reared from *L. dispar* collected in Tarsus, Mersin from *Quercus coccifera* L., 1753 (Fagaceae); and 03.08.2017, 7♂♂, 4♀♀, reared from *Thaumatopoea ispartaensis* Doğanlar & Avcı, 2001 (Lepidoptera: Notodontidae) collected in Toroslar District, Mersin from *Cedrus libani* A. Rich. (Pinaceae).

Distribution in Turkey. İstanbul (Schimitschek, 1944), Trakya (Gürses, 1975), Erzurum (Doğanlar, 1975; Doğanlar, 1982; Kılıç & Alaoğlu, 1996; Özbek & Çoruh, 2012), Ankara, Kırşehir, Niğde (Kansu et al., 1986), Tokat (Kara, 1998; Kara & Alaoğlu, 2001; Atay & Kara, 2014), Isparta (Avcı & Kara, 2002), Belen (Mückstein et al., 2004), Lakes District (Avcı, 2009), Nevşehir (Bartsch & Tschorsnig, 2010), Mersin (Akdağcık, 2010) and Muğla (Lutovinovas et al., 2018).

Hosts in Turkey. *Thaumatopoea pityocampa* (Schimitschek, 1944), *Euproctis chrysorrhoea* (L., 1758) (Lepidoptera: Erebiidae) (Gürses, 1975), *Leucoma salicis* (L., 1758), *Malacosoma castrensis* (L., 1758), *Malacosoma franconica* (Denis & Schifferrmüller, 1775) (Lepidoptera: Lasiocampidae), *Simyra* sp. (Lepidoptera: Noctuidae) (Herting, 1960; Doğanlar, 1975), *Euproctis* sp., *Phalera bucephala* (L., 1758) (Lepidoptera: Notodontidae), *Simyra dentinosa* Freyer, 1838 (Lepidoptera: Noctuidae) (Doğanlar, 1982; Atay & Kara, 2014), *Hyles centralasiae* (Staudinger, 1887) (Lepidoptera: Sphingidae) (Bartsch & Tschorsnig, 2010), *L. dispar* (Kara & Tschorsnig, 2003; Avcı, 2009), *L. salicis* (Kansu et al., 1986; Kılıç & Alaoğlu, 1996; Kara & Alaoğlu, 2001), *Malacosoma neustria* (L., 1758) (Lepidoptera: Lasiocampidae) (Kara & Alaoğlu, 2001; Özbek & Çoruh, 2012), *Parocneria terebinthi* (Freyer, 1838) (Lepidoptera: Erebiidae) (Kara & Alaoğlu, 2001), *Aporia crataegi* (L., 1758) (Lepidoptera: Pieridae) (Kansu et al., 1986; Kara & Tschorsnig, 2003), *T. ispartaensis* (Avcı & Kara, 2002), *Pieris* sp., *Aglais io* (L., 1758) (Lepidoptera: Nymphalidae), *Zygaena carniolica* (Scopoli, 1763) (Lepidoptera: Zygaenidae) (Kara & Tschorsnig, 2003), *Cucullia lanceolata* (Villers, 1789) (Lepidoptera: Noctuidae) (Mückstein et al., 2004), *Pieris brassicae* (L., 1758) (Lepidoptera: Pieridae) (Akdağcık, 2010) and *Hyles siehei* Püngeler, 1903 (Lepidoptera: Sphingidae) (Bartsch & Tschorsnig, 2010).

Utetheisa pulchella is a new host for *E. segregata* in Turkey. There is only a single record of *E. segregata* reared from *U. pulchella* in the world (Kugler, 1980).

Remarks. In southern Europe has been seen from March to December, in several generations, visits flowers, hosts are species belonging to Erebiidae, Zygaenidae, Noctuidae, Lasiocampidae, Notodontidae, Nymphalidae, Pieridae and Saturniidae (Tschorsnig & Herting, 1994).

***Diplostichus janitrix* (Hartig, 1837)**

Reared specimens. 07.10.2019, ♀, reared from *Diprion pini* (L., 1758) (Hymenoptera: Diprionidae), collected in Aladağlar, Adana from *Pinus nigra* Arnold subsp. *pallasiana* (Lamb.) Holmboe var. *pallasiana* (Pinaceae).

Distribution in Turkey. Ankara (Tunca et al., 2009).

Hosts in Turkey. *Diprion pini* (Tunca et al., 2009) and *Neodiprion sertifer* Geoffroy (Aksu, 2010).

Remarks. This parasitoid is seen till mid-September from end of June in pine forests, it does not visit flowers and probably has only one generation in Europe. It has been only rarely collected in the field, but is usually reared from its hosts. *Diplostichus janitrix* has a narrow host range. Diprionidae (Hymenoptera) is the usual host family and it was mostly reared from *Diprion* spp. (Tschorsnig & Herting, 1994; Tschorsnig, 2017).

Tribe: Blondeliini

***Compsilura concinnata* (Meigen, 1824)**

Reared specimens. 28.04.2017, 2♂♂, 10♀♀, reared from *Thaumetopoea wilkinsoni* Tams, 1824 (Lepidoptera: Notodontidae), collected in Central District, Mersin from *Pinus brutia* Ten. (Pinaceae).

Distribution in Turkey. Ankara (Tuatay et al., 1972), Uşak, Denizli (Öncüler et al., 1977), Erzurum (Doğanlar, 1982; Kılıç & Alaoğlu, 1996), Ankara, Kırşehir, Niğde (Kansu et al., 1986), Artvin, Erzurum, Gümüşhane, Trabzon (Eroğlu, 1995), Samsun (Tuncer & Ecevit, 1996; Sullivan et al., 2012), Tokat (Kara, 1998; Atay & Kara, 2014), Bursa (Kovancı et al., 1999), Eskişehir (Kara & Özdemir, 2000; Aksu, 2005), Isparta (Avcı & Kara, 2002), Hatay (Kaya & Kornoşor, 2008), Lakes District (Avcı, 2009), Hatay (Kaya et al., 2016), Sakarya (Balkan et al., 2015), Muğla (Lutovinovas et al., 2018) and Edirne (Tek & Okyar, 2018).

Hosts in Turkey. *Euproctis* sp. (Lepidoptera: Erebidae) (Tuatay et al., 1972), *E. chrysorrhoea* (Öncüler et al., 1977; Soydanbay, 1978; Eroğlu, 1995; Kara, 1998), *L. salicis* (Doğanlar, 1982; Kansu et al., 1986; Kılıç & Alaoğlu, 1996), *M. neustria*, *L. dispar* (Kansu et al., 1986; Avcı, 2009), *Hyphantria cunea* (Drury, 1773) (Lepidoptera: Erebidae) (Tuncer & Ecevit, 1996; Sullivan et al., 2012), *Parnassius apollo* (L., 1758) (Lepidoptera: Papilionide) (Kovancı et al., 1999), *P. brassicae* (Kara, 1998; Kaya & Kornoşor, 2008; Akdağcık, 2010), *Yponomeuta padella* (L., 1758) (Lepidoptera: Yponomeutide) (Kara & Özdemir, 2000), *T. pityocampa* (Oğurlu, 2000), *Autographa gamma* (L., 1758) (Lepidoptera: Noctuidae) (Kara & Tschorsnig, 2003), *P. terebinthi* (Kara & Alaoğlu, 2001), *T. ispartaensis* (Avcı & Kara, 2002), *Pontia daplidice* (L., 1758) (Lepidoptera: Pieridae), *Helicoverpa armigera* (Hübner, 1808) (Lepidoptera: Noctuidae) (Kaya & Kornoşor, 2008), *Helcystogramma triannulella* (Herrich-Schäffer, 1854) (Lepidoptera: Gelechiidae) (Kaya et al., 2016) and *Thaumetopoea solitaria* (Freyer, 1838) (Lepidoptera: Notodontidae) (Atay & Kara, 2014).

Thaumetopoea wilkinsoni is a new host for *C. concinnata* in Turkey. There is only one record of *C. concinnata* being reared from *T. wilkinsoni* (Tschorsnig, 2017).

Remarks. In Europe, this common parasitoid has two generations and is seen from May-September on flowers or foliage. It is reared from numerous Lepidoptera, whereas Microlepidoptera and Tenthredinidae are only rarely parasitized (Tschorsnig & Herting, 1994; Tschorsnig, 2017).

Tribe: Eryciini

***Phryxe caudata* (Rondani, 1859)**

Reared specimens. 20.10.2005, ♂, 3♀♀, reared from *T. wilkinsoni* collected in Mezitli, Mersin from *P. brutia*; 10.11.2005, ♀, reared from *T. wilkinsoni* collected in Beylice Village, Tarsus, Mersin from *P. brutia*; 11.11.2005, ♀, reared from *T. wilkinsoni* collected in Karaman on *Pinus nigra* Arnold (Pinaceae); 15.11.2005, ♂, reared from *T. wilkinsoni* collected in Çamalan Village, Tarsus, Mersin from *P. brutia*; 15.11.2005, ♂,

reared from *T. wilkinsoni* collected in Tekir, Adana from *P. nigra*; 21.04.2006, ♂, reared from *T. wilkinsoni* collected in Mut, Mersin from *P. brutia*; 21.04.2006, ♀, reared from *T. wilkinsoni* collected in Silifke, Mersin from *P. brutia*; 28.10.2007, ♀, reared from *T. wilkinsoni* collected in Pozantı, Adana from *P. nigra*; 25.04.2009, 2♀♀, reared from *T. wilkinsoni* collected in Sarıçam, Adana from *P. brutia*; 25.04.2009, ♂, ♀, reared from *T. wilkinsoni* collected in Osmaniye from *P. brutia* and *Pinus halepensis* Miller (Pinaceae); 25.04.2009, ♀, reared from *T. wilkinsoni* collected in Ceyhan, Adana from *P. halepensis*; and 26.04.2009, ♀, reared from *T. wilkinsoni* collected in Serinyol, Hatay from *P. brutia*.

Distribution in Turkey. Antalya (Tosun, 1976), İzmir (Soydanbay, 1978), Isparta (Avcı & Kara, 2002), Lakes Districts (Avcı & Oğurlu, 2002), Muğla (Özçankaya & Can, 2004) and Tokat (Atay & Kara, 2014).

Hosts in Turkey. *Thaumetopoea ispartaensis*, *T. pityocampa* (Denis & Schiffermüller, 1775) (Soydanbay, 1978; Avcı & Oğurlu, 2002, Kanat & Türk, 2002; Özdal, 2002; Kara & Tschorsnig, 2003; Özçankaya & Can, 2004; Atay & Kara, 2014), and *T. wilkinsoni* (Battisti et al., 2015).

Remarks. Thaumetopoeidae (currently placed in Notodontidae) is the usual host family for *P. caudata* and which is commonly reared from *Thaumetopoea* spp., especially *T. pityocampa* (Tschorsnig, 2017). In Turkey, *P. caudata* is produced and released in nature against *T. pityocampa* (Kanat & Türk, 2002; Özdal, 2002).

***Drino inconspicua* (Meigen, 1830)**

Reared specimens. 01.04.2005, ♀, reared from *D. pini*, collected in Mut, Mersin from *P. brutia*; 21.04.2006, ♀, reared from *D. pini*, collected in Mut, Mersin from *P. brutia*; 07.06.2007, 2♂♂, reared from *D. pini*, collected in Karaman from *P. nigra*; and 20.10.2012, ♀, reared from *D. pini*, collected in Alihoca Village, Niğde from *P. nigra*.

Distribution in Turkey. Erzurum (Doğanlar, 1975; Doğanlar, 1982), Kırklareli (Haeselbarth, 1983), Konya (Tschorsnig, 2005), Bolu (Korkmaz, 2007), Lakes District (Avcı, 2009) and Burdur, Muğla (Lutovinovas et al., 2018).

Hosts in Turkey. *Malacosoma neustria* (Doğanlar, 1975), *L. dispar* (Herting, 1983; Avcı, 2009) *D. pini* (Tschorsnig, 2005), *Neodirion sertifer* (Geoffroy, 1785) (Hymenoptera: Diprionidae), (Akıncı & Avcı, 2016) and *P. bucephala* (Schimitschek, 1944; Doğanlar, 1982).

Remarks. In Europe, this parasitoid is commonly found in pine forests. It is collected from early June to Mid-September and mostly has two generations per year. In the field it is rather rare, but is more commonly reared from its hosts. *Diprion* spp. Schrank, 1802 (Hymenoptera: Diprionidae) are common hosts, but it is also reared from a few Lepidoptera, especially *L. dispar* and *Dendrolimus pini* L. (Lepidoptera: Lasiocampidae) (Tschorsnig & Herting, 1994; Tschorsnig, 2017).

Tribe: Goniini

***Sturmia bella* (Meigen, 1824)**

Reared specimens. 12.09.2002, ♀; 17.09.2002, ♀; 21.09.2002, 2♂♂; 30.09.2002, 2♂♂, reared from *Aglais urticae* (L., 1758) (Lepidoptera: Nymphalidae), collected in Aladağlar, Adana from *Urtica* sp. (Urticaceae); 16.07.2003, 2♀♀; 24.07.2003, 2♂♂, reared from *A. urticae*, collected in Alihoca Village, Niğde from *Urtica* sp.; 17.09.2002, ♂, reared from *Vanessa cardui* (L., 1758) (Lepidoptera: Nymphalidae) collected in Aladağlar, Adana from *Malva* sp. (Malvaceae); 29.03.2003, ♀, reared from *V. cardui* collected in Karabucak, Tarsus, Mersin from *Malva* sp.; 22.02.2003, ♂; 21.03.2003, ♀; 29.03.2003, ♂, ♀; 29.03.2003, ♀; 07.04.2003, ♂; 13.03.2004, ♂; 14.03.2004, ♂; 08.04.2007, ♂, 2♀♀; 16.04.2007, ♂, reared from *Vanessa atalanta* (L., 1758) (Lepidoptera: Nymphalidae) collected in Karabucak, Tarsus, Mersin from *Urtica* sp.; 2.07.2007, ♂, reared from *V. atalanta* collected in Alihoca Village, Niğde from *Urtica* sp.; 22.08.2002, 3♀♀;

23.08.2002, ♂, ♀, reared from *Polygonia c-album* (L., 1758) (Lepidoptera: Nymphalidae) collected in Aladağlar, Adana from *Urtica* sp.; 3.08.2005, 3♀♀; 3.08.2005, 2♂♂, ♀, reared from *P. c-album* collected in Alihoca Village, Niğde from *Urtica* sp.; and 12.09.2007, ♀, reared from *P. c-album* collected in Tekir, Adana from *Urtica* sp.

Distribution in Turkey. Erzurum (Doğanlar, 1975), Marmara Region (Atak & Atak, 1984), Tokat (Kara, 1998), Sakarya (Balkan et al., 2015) and Kayseri (Atay et al., 2018).

Hosts in Turkey. *Aglaia urticae* (Doğanlar, 1975; Kara, 1998; Atay et al., 2018), *P. brassicae* (Atak & Atak, 1984) and *V. atalanta* (Atay et al., 2018).

Vanessa cardui and *P. c-album* are new hosts for *S. bella* in Turkey.

Remarks. This parasitoid is commonly found in warmer areas and is generally seen from mid-July to mid-September in meadows, bushes and forest edges in Europe. In warmer central Europe in open areas it is not rare and much more often reared from its hosts. This tachinid is usually reared from Nymphalidae, rarely from other Macrolepidoptera (Tschorsnig & Herting, 1994; Tschorsnig, 2017).

In this study, tachinid parasitoids of some species belonging to the order Lepidoptera and Hymenoptera were studied in the southern forests of Turkey. Six tachinid species were reared from nine hosts. These were *C. concinnata*, *D. inconspicua*, *D. janitrix*, *E. segregata*, *P. caudata* and *S. bella* from the subfamily Exoristinae. These species were previously reared from different hosts in Turkey. In addition, four new hosts for Turkey were recorded. These were *U. pulchella* for *E. segregata*, *P. c-album* and *V. cardui* for *S. bella*, and *T. wilsoni* for *C. concinnata*. In addition, two parasitoid-host couples were recorded for only the second time worldwide. These were *T. wilsoni* for *C. concinnata* and *U. pulchella* for *E. segregata*.

Turkey has a wide range of ecosystems under different climatic conditions. Forest areas are mostly natural ecosystems free from human activities. In these areas, natural balance usually occurs, but from time to time this balance deteriorates in favor of pests and irreversible ecosystem losses occur with this damage. For this reason, it is necessary to know the species diversity, habitat associations and the host complexes of harmful and beneficial organisms. Concurrently, it is important to support their populations. Although Tachinidae species, an important parasitoid group, are important for suppressing populations of many forest pests, studies on this family have been relatively limited in the Turkish forests. The areas studied have diverse habitats which have many insect species. Therefore, it is expected that more host-parasitoid interactions will be found in these forests with further research.

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