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ORIGINAL ARTICLE

Population dynamic of the parasitoid *Encarsia protransvena* Viggiani (Hymenoptera: Aphelinidae) on its host, ficus whitefly *Singhiella simplex* singh (Hemiptera: Aleyrodidae)

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Abstract
Ficus whitefly *Singhiella simplex* is a pest of Asian origin that causes economic damage to various species of *Ficus* spp. In this study, the population fluctuation of the parasitoid *Encarsia protransvena* on *S. simplex* was investigated in Antalya, Turkey, between August 2018 and August 2020. Yellow sticky traps were hung as one trap per direction of the *F. retusa* trees, and a total of 120 shoots were sampled from each direction of the *F. retusa* plants at weekly intervals. On the shoots, *S. simplex* larval stages, and parasitized larvae were counted. In both years, whitefly adults began appearing on yellow sticky traps in the second half of February, whereas parasitoid adults appeared at the beginning of March. The number of *E. protransvena* began to increase in May, but the increase was limited over the summer months. The number of *E. protransvena* in the yellow sticky trap reached its highest level, with 106.5 adults per trap in October 2018 and 120.25 adults per trap in October 2019. In shoot sampling, the highest numbers of *E. protransvena* larvae and pupae were observed in October 2018 and 2019, with 7.55 and 5.65 individuals per shoot, respectively. In August, September, October, and November of 2018, parasitism rates were recorded as 16, 18, 27, and 34, respectively. In August, September, October, and November of 2019, parasitism rates were observed at 14, 12, 21, and 23%, respectively. The data obtained as a result of this study may contribute to the management of *S. simplex*.

Keywords Chalcidoidea · *Ficus retusa* · Landscape · *Parasitism rate* · Seasonal relationship

Introduction

Pests not only reduce the aesthetic value of indoor and outdoor ornamental plants but also cause economic damage (Eileen 2013; Lee et al. 2005). In recent years, whiteflies have become one of the most important pests affecting and causing aesthetic damage, particularly to ornamental plants (Lee et al. 2005).

The ficus whitefly *Singhiella simplex* Singh is one of the whiteflies that cause economic and aesthetic damage to *Ficus* trees (Mannion 2010; Ahmed et al. 2022). *Singhiella simplex* is a whitefly species that originated in Asia. It is widespread in China, Myanmar, India, Taiwan, the United States, Cyprus, Israel, Colombia, Brazil, Puerto Rico, Jamaica, the Cayman Islands (Hodges 2007; Mannion et al. 2008; Jesus et al. 2010; Velasco et al. 2011; Kondo and Evans 2012; Vichiato et al. 2013; Da-Silva and Coelho 2015; Ko et al. 2015; EPPO 2018). In Turkey, this pest was first detected in Antalya in 2016 (Yukselbaba et al. 2017). Later ficus whitefly was reported in 2017 in France (Germain et al. 2017), in 2018 in Spain (Alonso et al. 2019), in Italy in 2019 (Laudani et al. 2019), and in 2022 in Tunisia (Laarif and Bouslama 2022; Kamel et al. 2022). It appears to be restricted to developing on several *Ficus* species and is commonly recorded from *F. benjamina* L. and *F. microcarpa* L. Some *Ficus* species (inc. *F. carica* L.) appear to be unsuitable for its development (Ko et al. 2015; EPPO 2018).

Adults and immature stages of the ficus whitefly feed on both sides of the leaves**.** *Singhiella simplex* adults are tiny, measuring about 1–1.6 mm in length. The body of the whitefly is yellow. The wings are white and have light gray bands, one in the middle and one at the apex of each wing (Hodges 2007; Mannion 2010; Avery et al. 2011; Yükselbaba et al. 2017; Laudani et al. 2019; Ahmed et al. 2022). larvae of

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the *S.simplex* are generally flat, oval, and transparent in the initial stage, which makes them difficult to see. Then they become yellow, more convex (1.3 mm long), and have red eyes, making them easier to see (Hodges 2007; Mannion 2010; Jesus et al. 2010; Yükselbaba et al. 2017; Eppo 2018; Laudani et al. 2019). *Singhiella simplex*, like other whiteflies, usually deposit eggs on the underside of leaves, mostly adjacent to the midvein and near the base of the leaf. The eggs are elongate and banana-shaped. Initially, the color of the eggs is pearly white and changes to brown over time. The eggs are connected to the leaf by a stalk (Yükselbaba et al. 2017; Laudani et al. 2020; Laarif and Bouslama 2022). Legaspi et al. (2011) reported that a female can deposit 46 eggs over its lifespan. The total immature development time of *S. simplex* was 25.2 d at 30 °C and adult life takes about 4 days (Legaspi et al. 2011).

It causes significant damage to *Ficus* spp. in urban landscapes. (Kondo and Evans 2012; EPPO 2018). As a result of the severe damage caused by the Ficus whitefly on the plant, yellowing and shedding of leaves and branch dieback usually occur before the death of the plant (Mannion 2010). Defoliation is the most obvious symptom of a *S. simplex* infestation (Mannion 2010; Avery et al. 2011; Ahmed et al. 2022; Yükselbaba et al. 2023). Five mated females of *S. simplex* can to defoliate a single *F. benjamina* plant within three generations, which corresponds to approximately three months, at a temperature of around 25 °C (Ahmed et al 2022).

According to Manion (2010), natural enemies may suppress *S. simplex* populations in the landscape. Predators and parasitoids of *S. simplex* have been reported from different countries. In Miami and Florida *E. protransvena, Baeoentedon balios* Wang, Huang & Polaszek, and *Amitus bennetti* Viggiani & Evans were identified as parasitoids, while *Chrysopa* spp. (Neuroptera: Chrysopidae), *Brachiacantha dentipes* (Fabricius), *Chilocorus nigritis Coelophora inaequalis* (Fabricius), *Curinus coeruleus* (Mulsant), *Exochomus children* (Mulsant), *Harmonia axyridis* (Pallas), *Olla-v nigrum* (Mulsant), and (Coleoptera: Coccinellidae) were found to be predators of *S. simplex* (Mannion 2010; Ahmed et al 2017, 2022; Lahey and Polaszek 2017). Yükselbaba et al. (2023) reported a single species, *E. protransvena*, as the parasitoid, while *Chrysoperla mutata* (McLachlan), *Semidalis aleyrodiformis* (Stephens), *Conwentzia psociformis* (Curtis), *Conwentzia* sp., *Oenopia conglobata* (L.), and *Serangium parcesetosum* Sicard were identified as predators of *S. simplex* in a study conducted in Turkey between 2018 and 2020. *Encarsia hispida* De Santis was reported from Mexico and Italy as a parasitoid of ficus whitefly (Myartseva et al. 2014; Zugno et al. 2024) *Encarsia singhiellae* Shih & Polaszek was identified as a parasitoid of *S. simplex* in Taiwan in 2015 (Ko et al. 2015).

When a new pest spreads to a new location and establishes a huge population, it becomes extremely harmful. To control this pest, insecticides are widely used, and the presence of natural enemies is ignored to reduce the pest population. Knowing the existence and effectiveness of these species plays a key role in deciding how to control pests, particularly with insecticides. Biological control stands out as one of the best options because it does not generate residue or resistance and does not harm the environment. It is critical to conduct research aimed at the management of the pest to minimize or even reduce the economic losses it causes. This study aimed to determine the seasonal relationship between the parasitoid *E. protransvena* and its hosts, *S. simplex*, on the *Ficus* plant. For this objective, the population fluctuation of *E. protransvena* on *S. simplex*, which is harmful to *Ficus* species, was determined. Furthermore, the natural parasitism rate was determined.

Material and methods

Study site

The study was conducted for two years, from August 2018 to August 2020, in Antalya, Turkey. Antalya province is in the Mediterranean region of Turkey. The climatic conditions in Antalya province, are ideal for the survival of *S. simplex* and the growth of *Ficus* species. *Ficus retusa* trees are grown in parks, along roadsides, and in residential gardens in Antalya. This study was carried out on *F. retusa* plants in two separate locations in the metropolitan areas of Antalya (Coordinates: 36.918737°N, 30.741199°E and 36.899295°N, 30.650214°E).

Yellow sticky trap samplings

Yellow sticky traps (25 × 10 cm) were set up on green sections of *F. retusa* to catch the adult parasitoid *E. protransvena* and its host, *S. simplex*. Position them around 20 cm apart from the tree in the North, South, West, and East directions. The traps were hung on *F. retusa* trees where there were no other trees for at least 25 m (Fig. 1). These traps were replaced weekly and examined under a stereo microscope (Nikon SMZ445, Tokyo, Japan) in the laboratory for

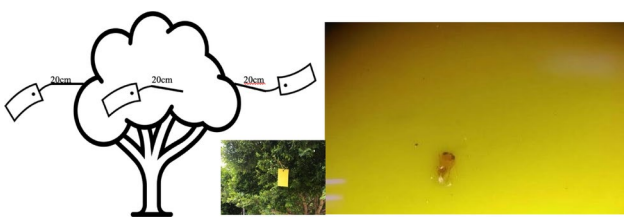


Fig. 1 Yellow Sticky Trap hung on *Ficus retusa* with an image of *Encarsia protransvena* caught on trap

whiteflies and parasitoids, with their counts recorded. As described in Sect. 4, parasitoids were regularly extracted from sticky traps and identified (Fig. 1).

Shoot sampling

Shoot samples were collected weekly from the North, South, East, and West sides of *F. retusa*. To represent the location, sample units were randomly selected from five different spots. The survey of *E. protransvena* and *S. simplex* populations included 120 shoots, with four branches randomly selected from each tree.

During the sampling, shoots approximately 8 cm in length were collected. Each sample was placed in a separate paper bag, stored in plastic ice bags, and sent to the laboratory for analysis. The larvae and pupae of *S. simplex* on the shoots were counted individually. Concurrently, pre-adult stages parasitized by *E. protransvena* were noted. The larval and pupal stages of the parasitoid *E. protransvena* on the whitefly were recorded separately (Fig. 2).

Obtaining and identifying the parasitoids

To obtain parasitoids, parasitoid emergence boxes were used (Fig. 3). The parasitoid emergence box is a completely closed wooden box, measuring 26.5 × 35.5 × 28 cm (width × height × length), designed not to let in any light. There is an opening on one side of the box, large enough for a round glass tube to be placed, to ensure that the parasitoids are attracted toward the light. Parasitoids located in a dark environment move toward the light and enter the glass tube (Fig. 3). The collected shoots were kept in parasitoid emergence boxes for 15 days to obtain and then identify the parasitoids. Parasitoids emerging to the glass tubes of the boxes were collected, placed in 80% ethanol, and stored at −20 °C for morphological identification studies. Slide mounting of parasitoids was carried out according to the method outlined in Polaszek et al. (2014). Identification of the parasitoids was conducted using the morphological characters and identification keys provided by Huang and Polaszek (1998). Every week at least 10 parasitoids were mounted on slides and identified.



Fig. 3 Parasitoid emergence boxes

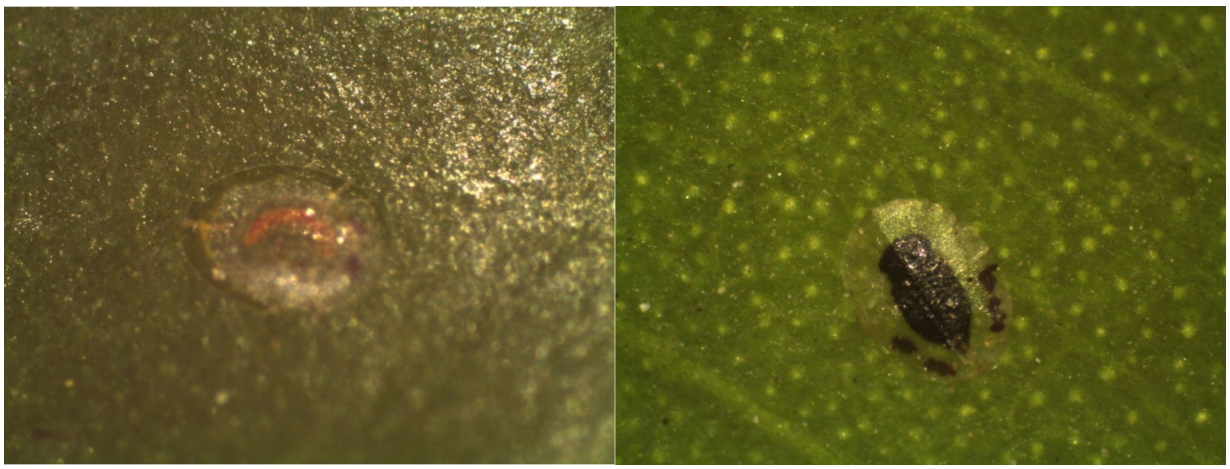


Fig. 2 *Encarsia protransvena* larva and Pupa

Determination of the parasitism rate

The parasitism rate of the *S. simplex* was determined by counting the parasitized and unparasitized larvae stages on the shoots (Fig. 2). Parasitoid larvae and pupae in the whitefly larvae were also counted separately. When using the parasitoid emergence box to determine the parasitism rate, the number of parasitoids and whiteflies obtained differed from the numbers on the shoots. Therefore, the parasitism rate was determined by counting the parasitized and non-parasitized larvae of the whitefly on the shoots. The Parasitism rate (%) was calculated according to (Telli and Yiğit 2012) with the formula:

$$\text{Parasitism rate (\%)} = \frac{\text{Parasitized Whitefly individuals}}{\text{Total number of whitefly individuals}} \times 100$$

Data analysis

Initially, a normality test was performed on the data to see if the data showed a normal distribution. The Shapiro-Wilks test was used to assess the normality assumption (Shapiro and Wilk 1965). The direction of the yellow sticky traps was assessed statistically to see if it impacted the capture of whiteflies and parasitoids. The Kruskal–Wallis test (Kruskal and Wallis 1952) was performed to analyze the number of parasitoids and whiteflies on the sticky traps in different directions because the data were not normally distributed. A correlation analysis was conducted to determine the relationship between average temperature, average humidity, whitefly population, and *E. protransvena* population. Because the data did not show a normal distribution, the Spearmen test was employed to do correlation analysis. The statistical analysis was performed using the SPSS 23.0 statistical software (Chicago, IL, USA). Differences at $P < 0.05$ were considered to be significant.Meteorological data (temperature and relative humidity) (Fig. 4) were provided by the General Directorate of Meteorology of Antalya, Turkish Ministry of Environment, Urbanization and Climate Change.

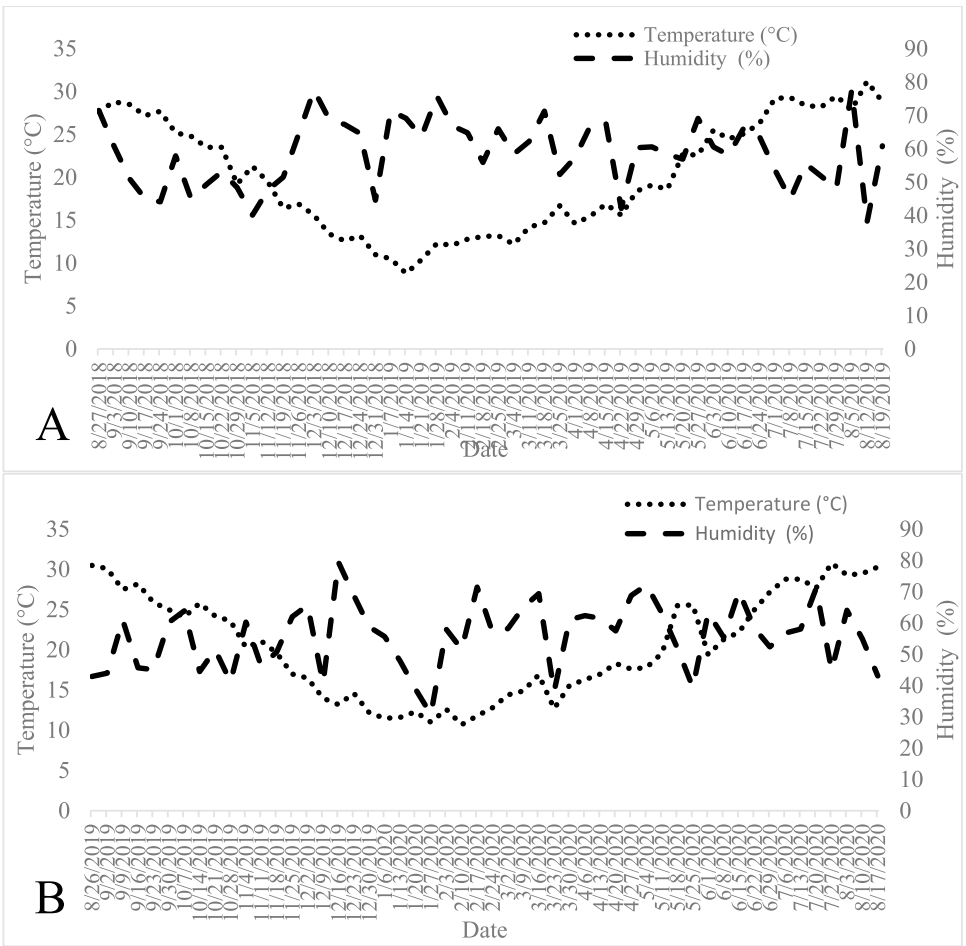


Fig. 4 Meteorological data **a**: between August 2018-August 2019 **b**: between August 2019-August 2020

Results

Yellow sticky trap sampling

Encarsia protransvena was the only parasitoid species found on *S. simplex* during the samplings. The population fluctuations of *E. protransvena* and *S. simplex* in the first location of the *F. retusa* are illustrated in Fig. 5. The total number of whiteflies and parasitoids trapped on yellow sticky traps was not statistically affected by the direction of the trap ($P_{S.simplex} = 0.945$ $P_{E.protransvena} = 0.917$).

When examining Fig. 5a from August 2018 to August 2019, it was found that *S. simplex* adults peaked on yellow

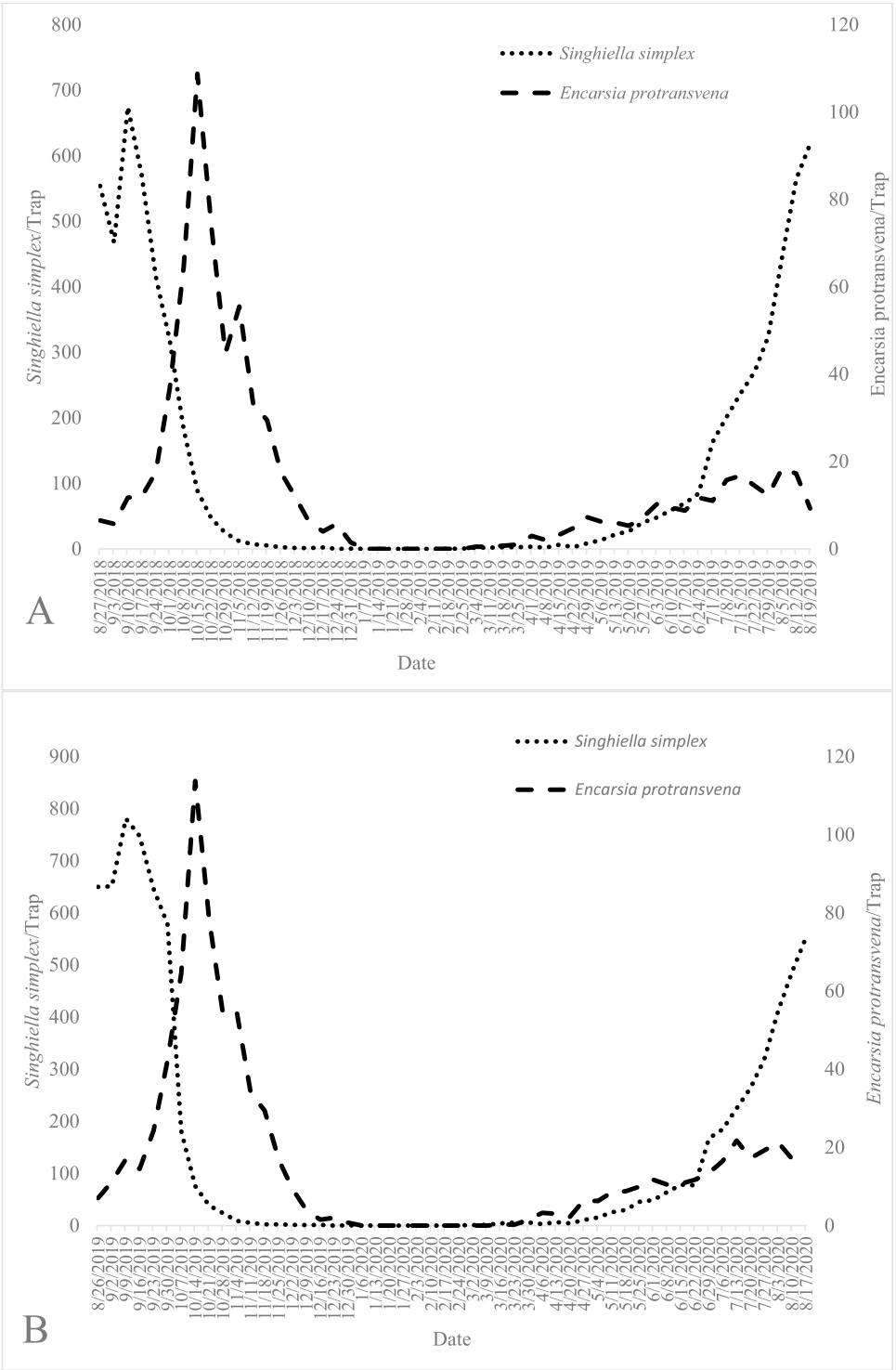


Fig. 5 Yellow Sticky Trap Sampling of *Encarsia protransvena* and *Singhiella simplex* at the 1st location **a**: between August 2018-August 2019 **b**: between August 2019-August 2020

sticky traps on September 10, 2018, with 674.5 adults per trap, while parasitoids were recorded with 11.75 adults per trap on the same date. Although the parasitoid population continued to increase in September, the density of *S. simplex* gradually decreased. The highest number of *E. protransvena* was recorded on October 15, 2018, with 108.75 adults per trap, while the *S. simplex* population was determined to be 88.5 adults per trap on the same date. In the subsequent periods, both the parasitoid and whitefly populations on yellow sticky traps gradually decreased and were last detected as 1.5 adults per trap and 0.25 adults per trap, respectively, on December 31, 2018. *Singhiella simplex* reappeared on yellow sticky traps with 0.25 adults per trap on February 25, 2019, and *E. protransvena* with 0.5 adults per trap on March 4, 2019. Since then, the number of whiteflies and parasitoids in yellow sticky traps has steadily increased.

Between August 2019 and August 2020, *S. simplex* reached its peak on September 9, 2019, with 781 adults per trap, while *E. protransvena* was found at 17 adults per trap on this date. The population of *E. protransvena* peaked on October 14, 2019, with 113.75 adults per trap. On this date, the *S. simplex* population was determined to be 75.5 adults per trap. *Encarsia protransvena* and *S. simplex* populations were last noted on traps on December 30, 2019, with 0.75 and 0.25 adults per trap, respectively. The reoccurrence of *S. simplex* and *E. protransvena* on the traps was 0.25 adults per trap on February 24, 2020, and 0.25 adults per trap on March 16, 2020 (Fig. 5b). From these dates, the population density of *S. simplex* and *E. protransvena* followed a similar trend as the previous year. The correlation analysis revealed that the relationships between *E. protransvena* and weekly average temperature, weekly average humidity, and *S. simplex* population were positive and high ($r = 0.737$; $P = 0.000$), negative and low ($r = -0.317$; $P = 0.001$), and positive and high ($r = 0.712$; $P = 0.000$), respectively. Overall, the parasitoid exhibited a population fluctuation similar to that of *S. simplex*.

The population fluctuations of *E. protransvena* and *S. simplex* in the second location of the *F. retusa* are depicted in Fig. 6. The total number of parasitoids and whiteflies captured on yellow sticky trap samples did not show a significant difference based on direction. ($P_{S.simplex} = 0.989$ $P_{E.protransvena} = 0.979$).

Figure 6a illustrates that in the first year (between August 2018 and August 2019), *S. simplex* adults peaked on September 10, 2018, with 661.5 adults per trap, while the number of parasitoidwas nine adults per trap on the same date. Although the parasitoid population increased in September, the population density of *S. simplex* began to decrease in the second half of the month. The population of *E. protransvena* reached its peak on October 15, 2018, with 106.5 adults per trap. On this date, the *S. simplex* population was found to be 89.5 adults per trap. In the following months, whitefly and parasitoid populations on traps decreased, with the last detection being one adult per trap on December 17, 2018, for whiteflies, and December 31, 2018, for parasitoids, respectively. *Encarsia protransvena* and *S. simplex* were detected on the traps again on March 4, 2019, at 1.5 and 2.5 adults per trap, respectively. Since this date, the number of whiteflies and parasitoids on yellow sticky traps has steadily increased.

According to Fig. 6b, between August 2019 and August 2020, the *S. simplex* population peaked at 876 adults per trap on September 16, 2019, while *E. protransvena* was found at 18.5 adults per trap on the same date. On October 14, 2019, the population of *E. protransvena* peaked at 120.25 adults per trap. The *S. simplex* population was determined to be 101.25 adults per trap on the same date. The populations of *E. protransvena* and *S. simplex* were observed to be 0.75 adults per trap on December 30, 2019, and 0.5 adults per trap on December 16, 2019, respectively. *Singhiella simplex* and *E. protransvena* populations were detected on the traps again on March 2, 2020, and determined to be 1.75 adults and 0.25 adults per trap, respectively. Similar to the previous year, the population density of *S. simplex* and *E. protransvena* continued to increase in parallel from these dates onwards. Correlation analysis revealed that *E. protransvena* has positive and high correlations with the weekly average temperature ($r = 0.775$, $P = 0.000$), negative and low correlations with the weekly average humidity ($r = -0.317$, $P = 0.001$), and positive and high correlations with S. simplex ($r = 0.728$, $P = 0.000$). The correlation between the parasitoid and other variables was highly significant.

Shoot samplings

As can be understood from Fig. 7a, the numbers of *E. protransvena* larvae and pupae, as well as *S. simplex* larvae and pupae, increased simultaneously during the summer months between August 2018 and August 2020. The maximum number of *E. protransvena* per shoot was observed in October, while the highest number of whiteflies per shoot was observed in September and October.

When Fig. 7a was examined, in the first year (between August 2018 and August 2019), the maximum number of *S. simplex* individuals was recorded at 23.90 whiteflies per shoot on October 15, 2018. On the same date, there were 4.19 parasitoids per shoot. Subsequently, on October 22, 2018, when the number of *E. protransvena* peaked at 7.56 parasitoids per shoot, the number of *S. simplex* decreased to 21.27 whiteflies per shoot. The number of *S. simplex* and *E. protransvena* individuals decreased gradually after these dates, reaching their lowest levels on January 21, 2019, with 0.01 whiteflies/shoot and 0 parasitoids/shoot, respectively (Fig. 7). Detection of the parasitoid and whitefly on shoots continued to a limited extent over the winter months, but the number of individuals began to increase in April. On April

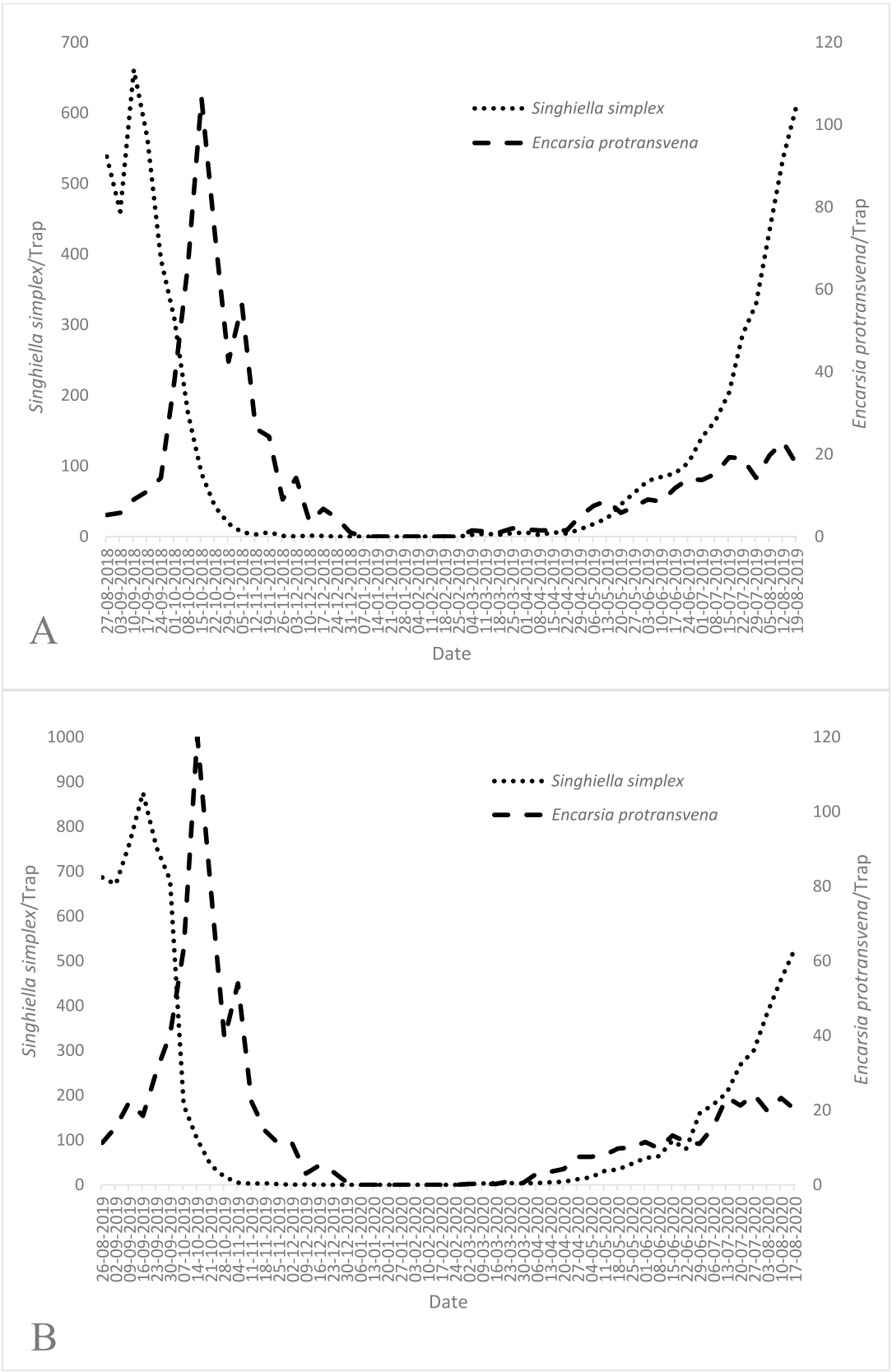


Fig. 6 Yellow Sticky Trap Sampling of *Encarsia protransvena* and *Singhiella simplex* at the 2nd location **a**: between August 2018-August 2019 **b**: between August 2019-August 2020

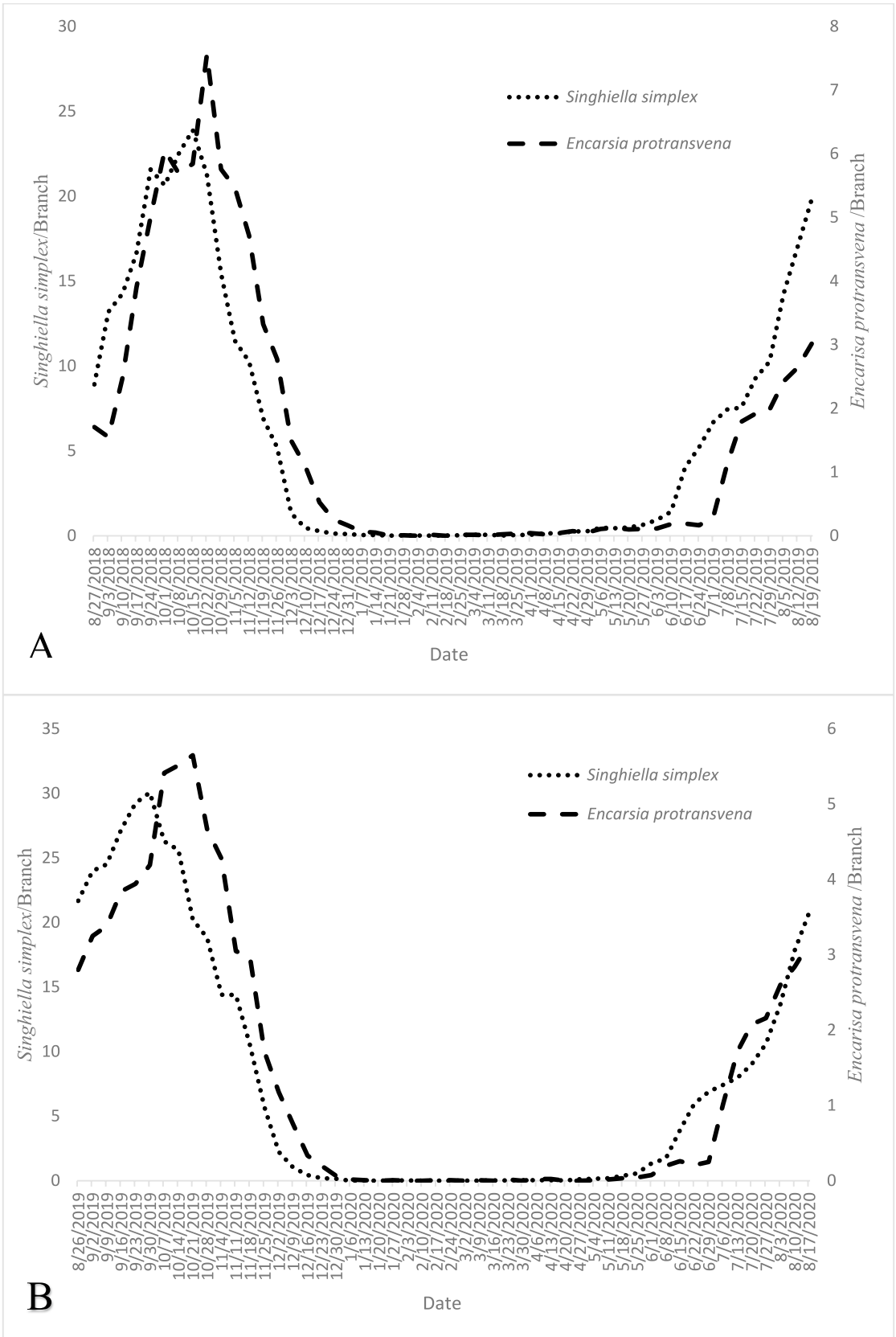


Fig. 7 Shoot Sampling of *Encarsia protransvena* and *Singhiella simplex* **a**: between August 2018-August 2019 **b**: between August 2019-August 2020

8, 2019, they were detected as 0.15 whiteflies per shot and 0.03 parasitoids per shoot. Later, the number of whiteflies and parasitoids on shoots continued to increase.

When examining Fig. 7b from August 2019 to August 2020, the maximum *S. simplex* population density on shoots was observed on September 30, 2019, with 30.08 whiteflies per shoot. On the same date, the *E. protransvena* density was recorded at 4.19 parasitoids per shoot. However, the maximum number of *E. protransvena* was recorded on October 21, 2019, with 5.65 parasitoids per shoot, while the density of *S. simplex* was found to be 20.24 whiteflies per shoot. Subsequently, the total number of whiteflies and parasitoids notably decreased over the following weeks, reaching their lowest population densities on January 20, 2020, with 0.01 whiteflies and 0 parasitoids per shoot. Similarly to the previous year, densities of *E. protransvena* and *S. simplex* in shoot samplings began to increase again in April.

Correlation analysis revealed that *E. protransvena* has positive and high correlations with the weekly average temperature ($r=0.656$, $P=0.000$), negative and low correlations with the weekly average humidity ($r=-0.333$, $P=0.001$), and positive and high correlations with *S. simplex* ($r=0.939$, $P=0.000$). The correlation between the parasitoid and other variables was highly significant.

Parasitism rate

Shoot sampling served as the method to assess the parasitism rate (Fig. 8). When Fig. 8 was examined over both years, the parasitism rate exhibited a similar pattern, beginning to rise in April and gradually increasing until December. Subsequently, starting in mid-December, it began to decline.

This trend coincided with the increase in parasitoid and whitefly densities observed during shoot sampling. The peak of the parasitism rate occurred in December of both years, with significant fluctuations, particularly during the winter months. Notably, there were instances of dramatic shifts in the parasitism rate, such as a rise from 0% in the sampling week of February 4, 2019, to 60% in the following week, only to return to 0% the subsequent week. These fluctuations were attributed to the low populations of whiteflies and parasitoids during December, January, and February, sometimes reaching counts as low as one. This variability may be due to the limited population size or the presence of deceased parasitoid pupae that failed to emerge, thus potentially compromising the reliability of these rates. As a result, these rates were not considered relevant. The periods when populations became active, or when they began to develop and became dense, were taken into account for determining parasitism rates and shown in the graph. In the sampling periods of August 2018 and August 2019, parasitism rates were observed in September and October at rates of 18.99 and 27.13%, respectively. During the sampling periods of August 2019 and August 2020, parasitism rates were detected in September and October at 12.38% and 21.82%, respectively. In both sampling years, parasitism rates were recorded in November at 34.76 and 23.12%. On December 10, 2018, and December 23, 2019, the rates were 70.43 and

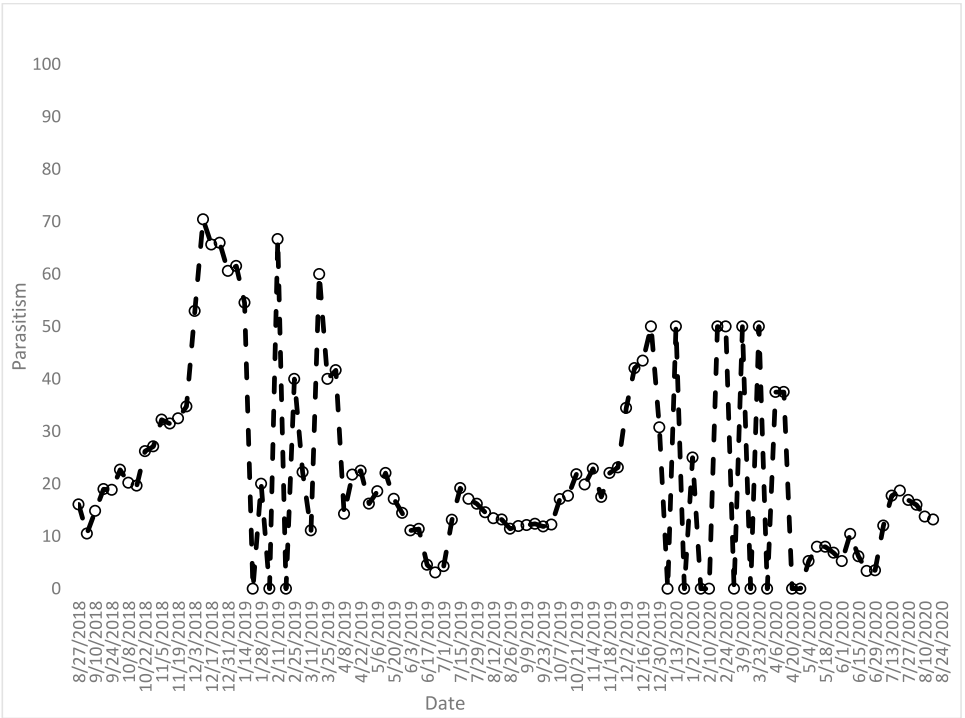


Fig. 8 Parasitism rate

50%, respectively. When examining Fig. 7a and b from both years in December, *E. protransvena* and *S. simplex* counts were found to be lower than in the previous months.

Discussion

Ficus spp., with their rapid growth and low susceptibility to pests and diseases, are commonly grown as urban plants along roadsides, in parks, and gardens. They are also widely used as hedge plants. The ficus whitefly, *S. simplex*, initially identified in India, causes damage to *Ficus* spp. (Singh 1931). This study focuses on the seasonal interaction between the parasitoid *E. protransvena* and its host, *S. simplex*. Parasitoids of *S. simplex* have been reported in several countries. Avery et al. (2011) reported *E. protransvena* and *A. bennetti* on *S. simplex* in Florida. In Mexico *E. protransvena* and *E. hispida* were reported as parasitoid of *S. simplex* in 2014 by Myartseva (2014). Ko et al. (2015) identified the native parasitoid species *E. singhiellae* as a potential candidate for classical biological control of *S. simplex*. Lahey and Polaszek (2017) reported *B. balios* and *E. protransvena* as the parasitoids of *S. simplex* in Florida. They stated that *B. balios* was always found in much greater numbers than *E. protransvena.* Ahmed et al. (2017) observed three parasitoid species in Florida, namely *A. bennetti, B. balios*, and *E. protransvena*. Ahmed et al. (2022) conducted a comprehensive survey of natural enemies of *S. simplex* in the United States, identifying the parasitoids *B. balios*, *A. bennetti*, and *E. protransvena*, as noted in previous studies. *B. balios* was predominantly found in 87% of the samples collected from 190 sites. The second highest density was observed in the parasitoid species *A. bennetti,* which was present in about 35% of the samples. Among the parasitoids, *E. protransvena* ranked third. The parasitoid wasp *Baeoentodon balios* is the most dominant among its natural enemies in the United States (Ahmed et al. 2022). Yükselbaba et al. (2023) found that *E. protransvena* was the most widespread and single parasitoid of *S. simplex* in the western Mediterranean region. Except for *E. protransvena* the species listed above have not yet been documented in Turkey. Additionally, *E. protransvena* has been identified as a parasitoid of *Dialeurodes citri* (Ashm.) and *Tetraleurodes neemani* Bink-Moenen in Turkey (Ulusoy and Ülgentürk 2003). In 2024 *E. hispida* was reported on *S. simplex* for the first time in Europe in Italy (Zugno et al. 2024).

The population dynamics of *E. protransvena* on *S. simplex* were studied for two years using yellow sticky traps and shoot sampling. The parasitoid *E. protransvena* was observed in low numbers in shoot samples in January and February but not in yellow sticky traps during these months. Individuals of *E. protransvena* were found on shoots and in yellow sticky traps in March, and the parasitoid population gradually increased during the next few months, peaking in September and October. Subsequently, the parasitoid population began to decline in November and December. Following the increase in the whitefly population, the population of *E. protransvena* began to increase. During the summer months, the parasitoid population increased in parallel with the whitefly population, although the increase was found to be limited.

Encarsia protransvena population fluctuations were observed in line with whitefly population fluctuations. The positive and high correlation between the parasitoid and whitefly, as well as temperature, suggested that *E. protransvena* population fluctuation was strongly related to both whitefly and temperature. When the *S. simplex* population density reached its peak in September, the parasitoid population began to increase. While the parasitoid population peaked in October, the number of whiteflies decreased.

As a result of damage by *S. simplex*, especially in the autumn, leaf shedding was intense. In contrast, it was observed that shedding was minimal in the winter (Personel observation). It was believed that the main reason for the shedding in winter was seasonal stress, as during shoot sampling, between 0 and 1 *S.simplex* and *E.protransvena* per shoot were detected. The low detection of the whitefly and parasitoids in winter is thought to be due to temperature and humidity. Results from the correlation analysis support this, showing a strong positive relationship with temperature and humidity.

The rates of parasitism and population densities exhibited a similar trend. The parasitism rate started to increase in April and remained high during September, October, and November when both the ficus whitefly and parasitoid populations were high. The parasitism rate peaked in December. The peak in the parasitism rate in December was thought to be due to the decrease in the *S. simplex* population in the shoots, which was caused by temperature effects and the parasitoid population, as well as the presence of *E. protransvena* larvae, particularly the pupae that have not yet emerged, still detected in the shoots. In the following months, the parasitism rate decreased and was observed at its lowest level until April. When parasitism rates and seasonal relationships were taken into consideration, it was thought that the primary reasons for the observed decrease in the whitefly population after September were not just climate but also an increase in the parasitoid population.

To the best of our knowledge, no literature yet on the population fluctuation, parasitism rate, or seasonal relationship of the parasitoid *E. protransvena* on *S. simplex* or another host whitefly. However, research on other parasitoids and whiteflies revealed similar findings consistent with our study.

Riley and Ciomperlik (1997) From 1991 to 1995, studied the population dynamics of *Bemisia* sp. and its

parasitoids. They reported that the populations of *Eretmocerus tejanus* Rose & Zolnerowich, *Encarsia pergandiella* Howard, *E. meritoria* Gahan, *Encarsia* nr., and *E. formosa* Gahan, as well as *Eretmocerus* sp. (Hymenoptera: Aphelinidae) increased steadily during the summer months, peaking in September. Parasitoid populations decreased after September, reaching their lowest levels in December. Liu and Sengonca (1997) showed that *Eretmocerus longipes* Compere had the highest parasitization rate in September, with rates of 17.5% and 32% on citrus and jasmine plants, respectively, as hosts of *Aleurotuberculatus takahashi* David. They also observed that the number of *E. longipes* pre-adults was reduced by the end of November and that the percentage of parasitism in both plants rapidly declined below 10% by the end of September, remaining zero until the end of the sampling.

According to Hoelmer and Simmons (2008), the density of *Eretmocerus* populations in yellow sticky trap samples was related to an increase in whitefly numbers. Throughout the study, they noted that *Eretmocerus* parasitized 23–84% of *B. tabaci*'s pre-adult stages. Lin et al., (2018) found that the parasitism rate increased with parasitoid density up to a specific population level. However, they revealed that the parasitism rate decreased as parasitoid populations became more denser.

In comparison with our study, there were studies with higher parasitism rates and slight differences in parasitoid population fluctuations. Miklasiewicz and Walker (1990) studied the population dynamics of *Aleurothrixus floccosus* (Maskell) and its parasitoids, *Cafes noocki* Howard and *Eretmocerus* sp. They reported that *C. noocki* appeared for the first time in late July and *Eretmocerus* sp. in August. In the first weeks of August, September, and October, parasitism rates were determined at 16.7, 32, and 50%. Leite et al. (2005) studied the population dynamics of *B. tabaci* and its parasitoid, *Encarsia* sp. They stated that the population density was highest in April and September. Malik and Karut (2012) studied the population fluctuations and parasitism status of *B. tabaci* on various crops in the Cukurova Region between 2008 and 2009. They reported that the parasitism rates of *Eretmocerus mundus* Mercet and *Encarsia lutea* (Masi) (Hymenoptera: Aphelinidae), which were low in July, increased in August and September. In 2008, they reported the highest parasitism rates for *Er. mundus* (73.94%) and *En. lutea* (24.3%). In 2019, they reported that *Er. mundus* and *En. lutea* exhibited the greatest parasitism rates, at 50% and 20%, respectively. Özger (2014) reported in her research on population fluctuation of *A. floccosus*, *D. citri*, and their parasitoids in citrus orchards in Antalya, Turkey that parasitoid population densities were generally higher in the summer months, paralleling the increase in the populations of *A. floccosus* and *D. citri* larvae.

Conclusion

The *S. simplex* population reached higher levels as of June compared to the *E. protransvena* population and continued to increase significantly until September. In other words, during the summer months, the population fluctuation of the parasitoid was lower compared to the whitefly. Considering the population fluctuation and parasitism rates in the study, protective measures for the parasitoid population, such as pruning or chemical control, should be taken into account, particularly in the early summer months, by paying attention to the presence of *E. protransvena*. Insecticides can be severely detrimental to parasitoids. However, the timing of insecticide applications can be adjusted to minimize exposure to them. This study may help optimize insecticide application timing while taking parasitoids into account.

Parasitoids are important agents for the biological control of whiteflies. In this context, it is essential to consider the locally found parasitoid species, the initial attack by the parasitoid, the field performance, and the population density of the whiteflies. The data obtained from this study, including the population fluctuations and natural parasitism rates of *E. protransvena*, may contribute to the biological control of *S. simplex* by addressing the issues mentioned above. The data on the seasonal relationship between *S. simplex* and the parasitoid *E. protransvena* may help develop effective biocontrol strategies and determine the optimal management timing for *S. simplex* with its parasitoid *E. protransvena*. It can also contribute to the literature and serve as a reference for future research, including the parasitoids' interactions and concomitant effects with generalist predators and entomopathogenic fungi.

Due to its spread to different countries, further research on the natural enemies of the ficus whitefly, especially its parasitoids, is unavoidable. Research on the mass production, release, and biology of *E. protransvena* on *S. simplex* can contribute to the control of the ficus whitefly.

Author's contribution UY: Writing—review and editing, Supervision, Methodology, Formal analysis, Data curation, Conceptualization. MHK: Writing—review and editing, Methodology, Conceptualization. All authors read and approved the submitted version of the manuscript.

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Declarations

Conflict of interest The authors declare that they have no competing interests.

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

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