Journal of Plant Diseases and Protection (2026) 133:41
https://doi.org/10.1007/s41348-026-01229-y

ORIGINAL ARTICLE

# Isolation, morpho-molecular identification, and pathogenicity evaluation of entomopathogenic fungi from the Pear psylla [*Cacopsylla pyri* L.)] in Turkey

**Hasan Ali Kucuk**[1] · **Fedai Erler**[1] · **Cengiz Ikten**[1]

Received: 24 April 2025 / Accepted: 23 December 2025
© The Author(s) 2026

**Abstract**

The Pear psylla, *Cacopsylla pyri* L. (Hemiptera: Psyllidae), is the main pest of pears in all pear-growing regions of Turkey as well as in Antalya province (southwestern part of Turkey). Its control mainly relies on the use of synthetic chemical insecticides; however, in last decade, desired levels of control have not been achieved due to development of resistance to these insecticides. Previous studies have shown that entomopathogenic fungi (EPFs) may be a good alternative to pesticides to suppress pear psylla populations. Therefore, the objectives of this study were: (i) to isolate native EPFs from naturally infected individuals of pear psylla in Korkuteli county of Antalya province, (ii) to identify the collected EPF isolates, and (iii) to assess the effectiveness of these isolates against various developmental stages [eggs, young (1st and 2nd instars) and older (3rd and 5nd instars) nymphs, and adults of the pest under laboratory conditions. A total of 19 fungal isolates, including 12 *Beauveria bassiana* (Balsamo) Vuillemin (Deuteromycota: Hyphomycetes), 3 *Penicillium raistrickii* Smith, 2 *P. chrysogenum* Tom and 2 *Aspergillus ochraceus* Wilhelm (Ascomycota: Eurotiomycetes)] were recovered from 63 fungal-infected psyllid cadavers during a two-year survey. In initial screening tests, 9 *B. bassiana* isolates, producing ≥ 20% mortality in the nymphal (young or older) stages of *C. pyri*, were also confirmed by molecular identification and included in the virulence assays for further evaluation against the pest. All 9 isolates were tested at three different conidial concentrations ($1 \times 10^5$, $1 \times 10^6$ and $1 \times 10^7$ conidia/ml), using spray method. The results of virulence assays showed that all 9 *B. bassiana* isolates had low ovicidal and adulticidal activity (both egg and adult mortalities were below 20%) while they caused significant mortalities on young nymphs. Of the 9 *B. bassiana* isolates tested, two isolates (AKBBPN2 and AKBBPN6) were the most virulent, causing 94.2 and 92.7% mortalities, respectively, in young nymphs within 14 days at the highest concentration ($1 \times 10^7$ conidia/ml). The findings of the current study indicated that these two *B. bassiana* isolates from *C. pyri* nymphal cadavers may provide an essential basis for the development of bioproducts, as well as a promising alternative method for controlling the pest.

**Keywords** Cacopsylla pyri · Entomopathogenic fungi · Pathogenicity · Pear psylla

## Introduction

Pear psylla, *Cacopsylla pyri* (L.) (Hemiptera: Psyllidae), is the most serious insect pest of pears in all pear-growing regions of Turkey. The pest causes damage to pear trees both directly and indirectly. The most direct damage is caused by the feeding of sap-sucking nymphs, which leads to growth inhibition, malformation of leaves and fruits, and low yield and poor fruit quality (Julien 1984; Civolani et al. 2023). Pear psylla causes three primary types of indirect damage: Presence of honeydew and black sooty mold on fruits, psylla shock (blackening and burning of leaf tissue), and carrying some pear diseases like 'pear decline' (Carraro 1998; Carraro et al. 2001).

In many districts of Turkey, pear growers have suffered from massive psyllid infestations, due to their direct and indirect damages to pear trees (Kovanci et al. 2000; Erler 2004). The pest has caused severe outbreaks in the last

✉ Fedai Erler
erler@akdeniz.edu.tr

[1] Department of Plant Protection, Faculty of Agriculture, Akdeniz University, 07070 Antalya, Turkey

Published online: 26 February 2026

decade in pear orchards in Korkuteli county of Antalya province (Western-Mediterranean Region of Turkey), where about 20% of Turkey's pear production is produced, probably due to the application of broad-spectrum insecticides with adverse effect on natural enemies, the decreased susceptibility of psyllid populations to most insecticides, and suitable climatic conditions in the district (Erler 2004; Civolani 2012; Reeves et al. 2024).

In Turkey, the most commonly employed method in the control of pear psylla depends heavily on applying contact insecticides belonging to different groups, even when integrated with other control methods. Relying only on pesticides for psyllid control has led to the development of insecticide resistance in local psyllid populations, and psyllid control by means of conventional insecticides, i.e., organophosphates, pyrethroids, neonicotinoids, etc., has failed to produce satisfactory results in intensive pear orchards in Korkuteli county. Considering the experience with multiple pesticide-resistance in psyllid populations in other parts of the world (Pree et al. 1990; Berrada and Nguyen 1994; Schaub et al. 1996, 2001; Bues and Boudinhon 2002), it is not surprising that resistant local psyllid populations have developed after 20 years of use of these pesticides in Antalya. Increasing problems with pear psylla management in pear orchards with resistant psyllid populations in recent years, have necessitated alternative pest management methods which can be compatible with the preservation of natural enemies. Several previous studies indicate that entomopathogenic fungi (EPFs), with no or low-hazard effects on non-target organisms and environment, can be a promising, eco-friendly alternative to chemical insecticides for controlling resistant pear psyllid populations (Puterka 1999; Erler et al. 2014). Therefore, the aims of this study were; (i) to isolate native EPFs from naturally infected psyllid individuals in pear orchards in Korkuteli county, (ii) to identify them, and (iii) to assess the effectiveness of these fungal isolates against the pest in order to generate knowledge for their use as an integrated pest management (IPM) component in pear orchards.

## Materials and methods

### Study area and sample collection

The study was carried out in Korkuteli county (37°07′36″N − 30°15′36″E; 1020 m a.s.L.), a large plateau among the mountains and major pear-growing region in Turkey, located in the northwest of Antalya province in southwestern Turkey (Fig. 1), which covers an area of 2.271 $km^2$. The study region has a climate similar to that of the Mediterranean area, which is characterized by hot dry summers and mild wet winters. The region's yearly temperature is 21 °C, which is 6.1% higher than Turkey's averages. Korkuteli typically receives about 87.2 millimeters (3.4 inches) of precipitation and has 85.1 rainy days (23.3% of the time) annually (MGM 2024). During the past 20 years, farmlands in Korkuteli county have been extensively converted into pear orchards, which account for about 35% of arable land (BAKA 2021).

Fifty-seven orchards in 11 locations, where pear orchards are densely located, were sampled over a two-year period (from October 2022 to October 2023). (Fig. 1). Based on previous studies, indicating that EPFs occur more commonly in cultivated areas adjacent to natural habitats (Klingen et al. 2002; Sánchez-Peña et al. 2011), places adjacent to forest, aquatic ecosystem, reforestation habitats, etc. were selected as sampling sites. A particular attention was also paid to; (i) taking samples from the pesticide-free orchards, (ii) taking samples from the north side of a place, which has intense humidity, but not much sunlight, and (iii) taking samples just after the rainy period especially in autumn and spring, while seeking naturally fungal-infected psyllid samples from the selected sites. During our non-periodic survey studies, insect samples (with signs of fungal attack) were taken to the laboratory in sterile tubes (10 ml). All samples were labeled and kept in a refrigerator at 4 °C until isolations were made.

### Isolation of EPFs from field-collected psyllid samples

For isolation of EPFs, field-collected psyllid (mostly nymphal) cadavers, potentially having a fungal infection, were surface-sterilized using 1% sodium hypochlorite (NaOCl) for 3 min, followed by 3 distinct washes with 100 ml of sterilized water, and placed on sterile blotting paper sheet to dry for 20 min. Surface-disinfected cadavers were then placed in 9-cm diameter Petri dishes (one cadaver per dish) lined with moistened sterile filter paper discs and incubated in the dark in an incubator set to 26 ± 2°C and 70 ± 5% RH to stimulate the conidial germination (Baki et al. 2021a). Fungal growth over the psyllid cadavers was examined on daily basis. When a fungal growth was observed, the conidia and hyphae were harvested by a sterilized inoculating wire loop and transferred to new Petri dishes (90 cm diameter) containing potato dextrose agar (PDA; Merck Ltd., Darmstadt, Germany) for purification and identification. All dishes were incubated at 26 ± 2°C and 70 ± 5% RH and inspected daily for fungal growth. If there was more than one fungal growth in the same Petri dish, they were purified by

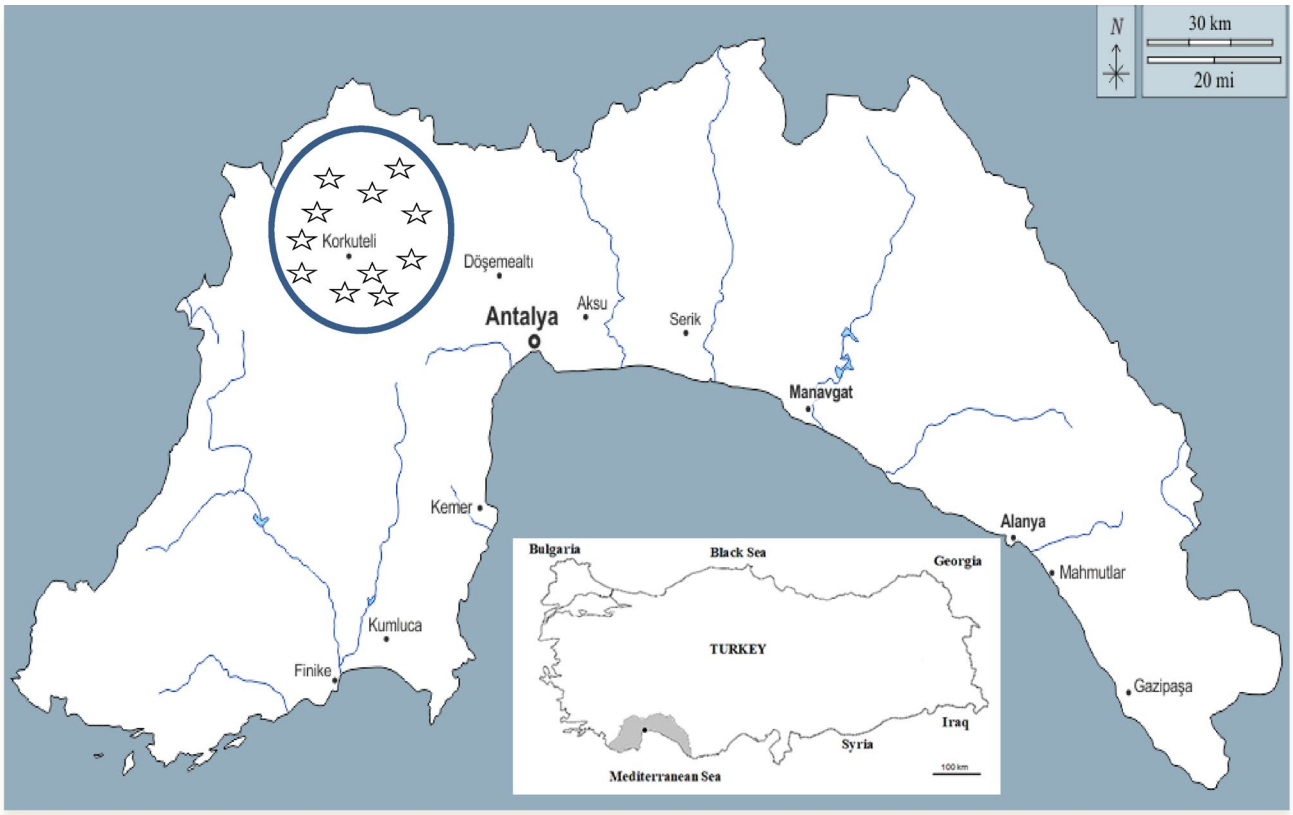



**Fig. 1** Map showing Korkuteli county of Antalya province, from which dead/infected psyllid samples were taken to isolate entomopathogenic fungi. Sampling locations selected in Korkuteli county are indicated by stars in the circle

sub-culturing on newly prepared sabouraud dextrose agar (SDA) media. Pure cultures were preserved with glycerol and maintained on agar at -20 °C for further work.

## Morphological and molecular identification of fungal isolates

Morphological identification was carried out based on cultural and morphological features of single-spore cultures of fungal isolates and was done by observing the growth pattern and colony formation of the fungal cultures using the identification key of mycology (Samson 1981; Samson et al. 1988; Humber 1997, 2005, 2012). Microscopic characterization of fungal isolates was also done by preparing slides from each isolate to identify its morpho-taxonomic characters (conidial length and diameter, hyphal growth, and conidiogenous cells) under an inverted light microscope (Leica DM IL, Leica Microsystems) with LED illumination (Lacey 1997; Baki et al. 2021a). After identification, the fungal isolates were deposited in the Collection of EPFs at the Plant Protection Department of Akdeniz University (Antalya, Turkey).

Based on the results of initial screening tests, we selected 9 *B. bassiana* isolates, producing ≥ 20% mortality in the nymphal (young or older) stages of *C. pyri*, for further evaluation in virulence assays against the pest, and these isolates were also molecularly identified by PCR. Genomic DNA of selected *B. bassiana* isolates were extracted, following the modified CTAB method described by Doyle and Doyle (1990). The PCR was performed in a Thermal Cycler by using two different primers, ITS1 (5′-TCCGTAGGTGAACCTGCG G-3′) and ITS4 (5′-TCCTCCGCTTATTGATATGC-3′), based on ITS-rDNA region gene sequences (White et al. 1990). The phylogenetic analysis was done based on the ITS region sequence of selected *B. bassiana* isolates and the nucleotide sequence of the other fungi retrieved from GenBank. The accession numbers of selected 9 *B. bassiana* isolates are presented in Table 2.

## Virulence assays against Pear psylla

After pre-screening evaluation of all fungal isolates recovered from the surveys [totally, 19 isolates belonging to 4 fungal species; 12 *Beauveria bassiana* (Balsamo) Vuillemin (Deuteromycota: Hyphomycetes), 3 *Penicillium raistrickii* Smith, 2 *P. chrysogenum* Tom and 2 *Aspergillus ochraceus* Wilhelm (Ascomycota: Eurotiomycetes)],




**Fig. 2** Different biological stages of *Cacopylla pyri* used in virulence assays; **a** control (non-infected) eggs, **b** fungal-infected (parasitized) eggs; **c**) non-infected young nymph, **d** fungal-infected young nymph, **e** non-infected older nymph, **f** fungal-infected older nymph, **g** non-infected adult, **h** fungal-infected adult

experimental bioassays were conducted for further evaluation of the virulence of promising isolates (9 *B. bassiana* isolates, which caused ≥ 20% mortalities at different nymphal stages) against various developmental stages [eggs, young (1st and 2nd instars) and older (3rd − 5nd instars) nymphs, and adults] of *C. pyri* under the controlled conditions (26 ± 2℃ and 70 ± 5% RH) in the laboratory. In all bioassays, all 9 *B. bassiana* isolates were tested at three conidial concentrations ($1 \times 10^5$, $1 \times 10^6$ and $1 \times 10^7$ conidia/ml), using spray method.

### Insect material and maintenance

Insect material used in the assays were taken from a laboratory colony of *C. pyri* that originated with field-collected adults from untreated pear orchards in Korkuteli county. Rearing was carried out on two-year-old potted pear (*Pyrus communis* L. var. 'Ankara') seedlings in screen cages (90 × 90 × 175 cm; L × W × H) in a climate room set to 25 ± 1℃, 60 ± 5% R.H., and 16:8 (L: D) hours photoperiod. Subsequent cultures were maintained in small screen cages (50 × 50 × 75 cm; L × W × H) to obtain a fresh (known age) insect material. In the assays, 0–48-h-old eggs, young and older nymphs, and adults of *C. pyri* were used.

### Viability of EPF isolates and Preparation of conidial suspensions

Before the assays, conidial viability of the 9 *B. bassiana* isolates was determined by the method described by Goettel and Inglis (1997). For this purpose, a spore suspension of each isolate was adjusted to $1 \times 10^7$ conidia/ml and 0.1 ml was sprayed onto each Petri dish (9 cm diameter, containing SDA medium. Three replicates (dishes) per isolate were used. The dishes were then incubated in complete darkness at 25 ± 2℃ for 24 h. After incubation, conidial germination ratio for each isolate was determined by examining a minimum of 200 conidia from each of three replicate plates under the light microscope (400×) (Saruhan et al. 2015). A conidium was considered as germinated when the germ tube had exceeded half the length of the spore. The viability of all tested fungal isolates was above 95%.

### Bioassay against C. pyri eggs

In ovicidal assays, twenty summer-form adults (10 males: 10 females) obtained from the *C. pyri* culture in the laboratory were transferred onto fresh pear shoots with their cut ends dipped into the 0.5-liter plastic bottles containing water (1 shoot per bottle) in screen cages (50 × 50 × 75 cm; L × W × H) and allowed to lay eggs for 48 h. The insects were carefully removed after 48 h and the eggs laid on each shoot were counted using a forehead loupe with 35x magnification. Then, each shoot (replicate) was sprayed from 30-cm distance with a hand-held sprayer, using 2.0 ml of any conidial concentration of any fungal isolate. Three replicates (shoots) were used for any conidial concentration of any fungal isolate and the control. Control shoots were treated with distilled water only. Experiments were repeated twice. The efficacies of the treatments were evaluated by counting the number of hatched and unhatched (live and dead) eggs of *C. pyri* in all applications 3, 7, 10 and 14 days after the application. At each count day, each treated shoot was examined using a forehead loupe with 35x magnification. During data collection, unhatched eggs which were conspicuously shrunk and usually turned orange-brown and had more or less fungal outgrowths (with a white fuzzy appearance) on their surface (Fig. 2a, b), that could be easily distinguished from those dead from other reasons which had a wrinkled and light brownish appearance (especially those in water-treated controls), were counted to have died as a result of fungal infection and included in the mortality data (Erler et al. 2014).

### Bioassay against C. pyri nymphs

Nymphicidal effect of fungal isolates was evaluated using young (1st and 2nd instars) and older (3rd − 5th instars) nymphs of pear psylla. For this purpose, thirty nymphs (15 young and 15 older instars) were first collected from the laboratory culture of *C. pyri* maintained in screen cages and transferred onto a fresh pear shoot in a 0.5-liter plastic bottle containing water in a screen cage using a fine camel's hair brush, and then treated with 2.0 ml of any conidial concentration of any fungal isolate or distilled water only for control (as described above in the ovicidal assays). There were three replicates (shoots) for any conidial concentration of any fungal isolate or water-treated control, and experiments were repeated twice. In order to determine the effect of the treatments on different nymphal stages of the pest on sprayed pear shoots, all nymphs, live or dead, were counted 3, 7, 10 and 14 days after each application. At each count day, each treated shoot was examined using a forehead loupe with 35x magnification. During data collection, shriveled and blackened nymphs including fungal outgrowths (with a white fuzzy appearance), more or less (Fig. 2c–f) that could be easily distinguished from those dead from other reasons which had a light brownish appearance (especially those in water-treated controls) were presumed

dead from fungal infection and included in the nymphal mortality data (Erler et al. 2014).

#### Bioassay against C. pyri adults

To assess the efficacy of selected 9 *B. bassiana* isolates against adult pear psylla, twenty summer-form adults (10 females + 10 males) taken from pear psyllid culture in the laboratory were kept in the refrigerator (-2°C) for 2 min to temporarily stop their activities, then transferred to a Petri dish (15 cm diameter) containing a double layer of filter paper. Before the insects regained activity, they were immediately treated with a selected concentration of a selected *B. bassiana* isolate. As in the ovicidal and nymphicidal assays, three different conidial concentrations ($1 \times 10^5$, $1 \times 10^6$ and $1 \times 10^7$ conidia/ml) were used in the adult experiments. Spore suspensions were sprayed, at the rate of 2 ml per dish (replicate), using a hand-held sprayer. After spraying, each Petri dish containing the treated insects was transferred with the lid open into a mesh cage ($60 \times 60 \times 75$ cm) containing three fresh pear shoots (as food) immersed in a 0.5-liter plastic bottle filled with water to keep the shoots alive. Mouths of the bottles were covered with cotton to prevent the adults from falling into water. Three replicates (cages) were used for any conidial concentration of any fungal isolate or distilled water-treated control, and experiments were repeated twice on different dates. Adult experiments were carried out in a climate chamber with 25 ± 1°C temperature and 70 ± 5% R.H. Treated and control insects were examined 3, 7, 10 and 14 days after the application to record the mortality data. As in the ovicidal and nymphicidal assays, all dead insects were separated and placed in an incubator (25°C and 90% R.H.) for 3 days to check the fungal development and sporulation (Fig. 2g, h). The deaths of individuals that did not show any fungal structure were attributed to other factors and were not included in the records (Erler et al. 2014).

### Statistical analysis

All mortality data obtained from virulence assays were normalized by arcsine square-root transformation and then subjected to analysis of variance (ANOVA). Duncan's Multiple Range Test (DMRT; $P \leq 0.05$) was used to determine the significant differences among the treatments (SPSS® 17.0).

## Results

### EPFs from Pear psyllid cadavers

A total of 19 fungal isolates belonging to 4 fungal species [12 *B. bassiana*, 3 *P. raistrickii*, 2 *P. chrysogenum* and 2 *(A) ochraceus*] were recovered from 63 fungal-infected psyllid cadavers during a two-year survey (2022 and 2023). After the morphological identification, all the isolates were given a code name (isolate name) (Table S1). Of the 4 fungal species detected in the study, *(B) bassiana* had the highest frequency of occurrence (63.2%) and was followed by *P. raistrickii* (15.8%). Other *Penicillium* species (*P. chrysogenum*) and *A. ochraceus* had the same occurrence rate (10.5%). While 11 of the 19 fungal isolates were obtained from older nymph cadavers, 4 isolates were obtained from young nymph cadavers and 4 isolates were obtained from adult cadavers of pear psylla.

Based on the results obtained from the preliminary screening tests, the number of isolates included in virulence tests was reduced to 9, all of which belong to the *B. bassiana* complex (AKBBPN1, AKBBPN2, AKBBPN3, AKBBPN4, AKBBPN6, AKBBPN7, AKBBPN8, AKBBPN9 and AKBBPN10). The selection of 9 *B. bassiana* isolates for virulence tests was based on their producing ≥ 20% mortality at the nymphal (young or older) stages of *C. pyri*. These 9 isolates were also confirmed by confirmed by ITS sequencing (Table 2).

### Effectiveness of the nine *B. bassiana* isolates against *C. pyri* eggs

The results obtained from the virulence assays with 0–48-h-old psyllid eggs showed that all *B. bassiana* isolates tested had low ovicidal activity and none of them caused 20% or higher mortality at all the conidial concentrations throughout the experimental period (Fig. 3). The percentage of unhatched eggs for all *B. bassiana* isolates was not significantly different in all the concentrations tested 3 days after application, or even 7 days with a few exceptions (Data on days 3 and 7 are not shown in Fig. 3). However, significant differences between the conidial concentrations of each isolate occurred on the 10th and 14th days of treatment (DMRT, $P \leq 0.05$).

### Effectiveness of the nine *B. bassiana* isolates against *C. pyri* nymphs

The results from the nymphal assays showed that all *B. bassiana* isolates tested had a high virulence against *C. pyri* nymphs. Generally, virulence of the isolates

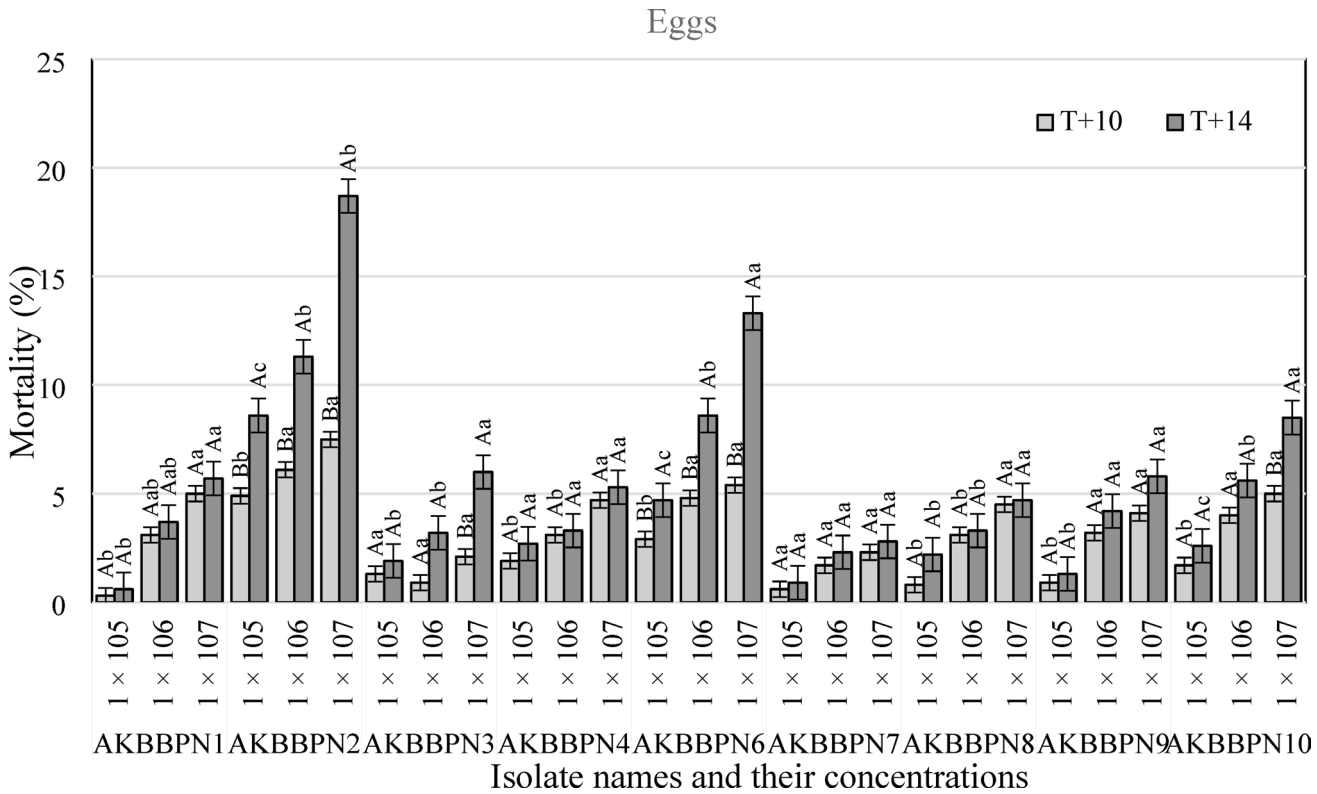



**Fig. 3** Percentage mortality of *Cacopsylla pyri* eggs exposed to three different conidial concentrations ($1\times10^5$, $1\times10^6$ and $1\times10^7$) of selected 9 indigenous *Beauveria bassiana* isolates (T+10 and T+14; 10 days and 14 days after treatment, respectively). In each treatment, means within a row followed by the same capital letter are not significantly different (DMRT, $P\leq0.05$), and means within a column followed by the same lower-case letter are not significantly different (DMRT, $P\leq0.05$). No mortality occurred in water-treated controls throughout the experiment

increased significantly with increasing conidial concentration and elapsed time up to 14 days after inoculation. For each fungal isolate, mortality rates of young and older nymphs of the pest, at different conidial concentrations, were significantly different (DMRT, $P\leq0.05$). Percent mortalities of both young and older nymphs are presented in Figs.4and 5, but data on days 3 and 7 are not shown here.

Figures 4 and 5 showed that mortality percentages were obviously higher to young nymphs than to older ones. In young nymphs, mortality varied significantly between the nine *B. bassiana* isolates with two isolates (AKBBPN3 and AKBBPN9) having the lowest mortalities of 26.1 and 28.8% and the other two isolates (AKBBPN2 and AKBBPN6) having the highest mortalities of 94.2 and 92.7%, respectively, at the highest concentration ($1\times10^7$ conidia/ml) and the longest evaluation time (14 days after treatment). Moreover, at a shorter evaluation time (10 days after treatment), the last two isolates caused 82.5 and 85.6% mortalities, respectively, at the highest concentration. These two isolates also had a mortality rate of more than 75 at a lower concentration ($1\times10^6$ conidia/ml) at the longest evaluation time (Fig. 4). In older nymphs, except for isolate AKBBPN6, no significant differences in mortality on the 3rd day of treatment were observed between the conidial concentrations of each *B. bassiana* isolate (DMRT, $P\leq0.05$). All the *B. bassiana* isolates tested except for AKBBPN6 had a mortality rate of less than 50 at all conidial concentrations and evaluation times (Fig. 5). Isolate AKBBPN6 caused a mortality rate of 53.4 at the highest concentration ($1\times10^7$ conidia/ml) and the longest evaluation time (14 days after treatment), which was followed by the isolates AKBBPN10 having a mortality rate of 43.5 and AKBBPN2 having a mortality of 41.9%. The latter had the highest mortality rate of young nymphs with 94.2 at the highest conidial concentration and the longest evaluation time (Fig. 4)

## Effectiveness of the nine *B. bassiana* isolates against *C. pyri* adults

The results of bioassays against adult pear psylla showed that the nine *B. bassiana* isolates tested generally had low adulticidal activity and mortalities at all conidial concentrations and evaluation times were below 20%, as in

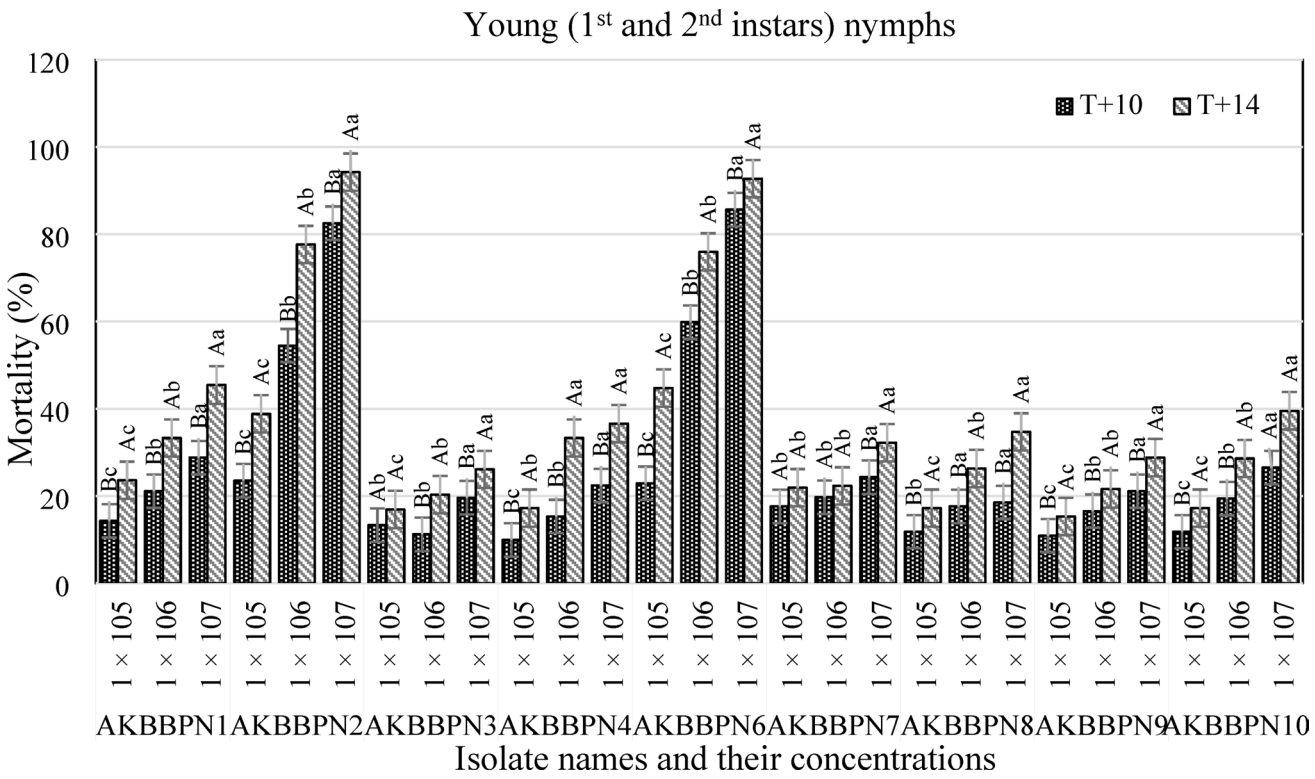



**Fig. 4** Mortality percentage of young (1st and 2nd instars) nymphs of *Cacopsylla pyri* in response to three different conidial concentrations ($1 \times 10^5$, $1 \times 10^6$ and $1 \times 10^7$) of selected 9 indigenous *Beauveria bassiana* isolates (T+10 and T+14; 10 days and 14 days after treatment, respectively). In each treatment, means within a row followed by the same capital letter are not significantly different (DMRT, $P \leq 0.05$), and means within a column followed by the same lower-case letter are not significantly different (DMRT, $P \leq 0.05$). No mortality occurred in water-treated controls throughout the experiment

the ovicidal assays (Fig. 6). The percentage mortality of pear psylla adults for all nine *B. bassiana* isolates did not differ significantly at all conidial concentrations 3 days after application, even except for isolates AKBBPN2 and AKBBPN6, all other *B. bassiana* isolates tested did not caused any mortality at all conidial concentrations on the 3rd and 7th day of treatment. So, data on days 3 and 7 are not shown in the figure. Indeed, with some exceptions especially on the 10th and 14th days of treatment, mortality was dependent on the time elapsed rather than the concentration, and significant differences between the mortalities in each isolate (except for isolate AKBBPN1) were observed with the time elapsed (DMRT, $P \leq 0.05$).

## Discussion

Our results revealed that the insect pathogen *B. bassiana* was the most abundant EPF species recovered in the current study. This observation is in agreement with previous reports from Antalya province (Topuz et al. 2016; Baki et al. 2021a, b; Kirisik and Erler 2024). Other fungal species recovered, *P. raistrickii*, *P. chrysogenum* and *(A) ochraceus* are ubiquitous fungi, usually found as saprophytes on decaying organic matter, and as storage rots or pathogens of fruits and vegetables (Ramirezs 1982; Tsang et al. 2018). It is interesting that, apart from *(B) bassiana*, no other EPF species were obtained throughout the study period. However, this is not surprising considering previous studies indicating that *B. bassiana* was the most abundant species and had the greatest distribution in Antalya province (Topuz et al. 2016; Baki et al. 2021a, b; Kirisik and Erler 2024). Moreover, some previous studies also indicate that *B. bassiana* is widely distributed worldwide and its presence is not associated with habitat type and it can be found in almost all habitats throughout the world (Bidochka et al. 1998; Klingen et al. 2002; Quesada-Moraga et al. 2007; Meyling et al. 2012; Pérez-González et al. 2014).

Our review of related literature revealed that no fungal pathogens isolated from pear psylla have been reported so far. Since this was the first study to isolate EPFs from pear psyllid cadavers, we could not compare our results with those of previous studies. However, there have been only two studies on mycoinsecticidal approach to pear psylla

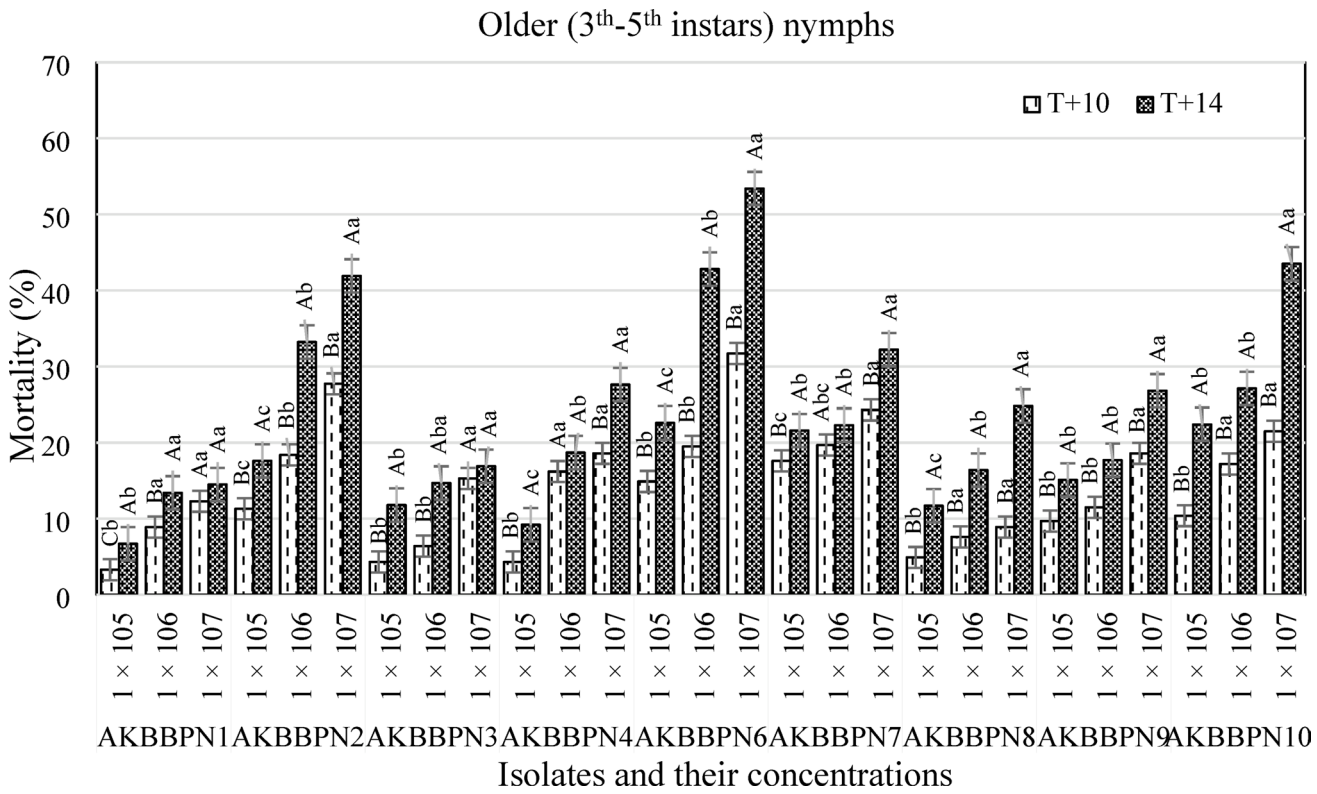



**Fig. 5** Mortality percentage of older (3rd -5th instars) nymphs of *Cacopsylla pyri* in response to three different conidial concentrations ($1\times10^5$, $1\times10^6$ and $1\times10^7$) of selected 9 indigenous *Beauveria bassiana* isolates (T+10 and T+14; 10 days and 14 days after treatment, respectively). In each treatment, means within a row followed by the same capital letter are not significantly different (DMRT, $P\leq0.05$), and means within a column followed by the same lower-case letter are not significantly different (DMRT, $P\leq0.05$). No mortality occurred in water-treated controls throughout the experiment

control (Puterka et al. 1994; Erler et al. 2014). In the former, some indigenous and exotic isolates of *B. bassiana* obtained from USDA-ARS (United States Department of Agriculture-The Agricultural Research Service) Collection of Entomopathogenic Fungal Cultures (ARSEF) were tested against 2nd and 3rd instars nymphs at $1\times10^7$ conidia/ml in laboratory bioassays and all *B. bassiana* isolates tested caused nymphal mortalities ranged from 92.5 to 99.6% 7 days after treatment. Although the results of Puterka et al. (1994) are not directly comparable with those from the current study because they used different nymphal stages of pear psylla [2nd and 3rd instars versus 1st and 2nd instars], their and our results on young nymphs are reasonably consistent. In the latter, the efficacy of an emulsifiable concentrate (EC) formulation of the entomopathogenic fungus, *Metarhizium brunneum* Petch strain F52 (Hypocreales: Clavicipitaceae), containing $5.5\times10^9$ conidia/ml, was evaluated by Erler et al. (2014) against *C. pyri* under the field conditions in southwestern Turkey (Antalya) in two successive years. The results from the study showed that the *M. brunneum* F52 product at 100 ml/100 l water caused 79 and 88% mortality of psyllid eggs and young nymphs (1st and 2nd instars), respectively, 7 days after treatment in the first year, and 72 and 82% mortality in the second year. However, it was less active against the older nymphs older (3rd − 5nd instars) and achieved 51% mortality 7 days after treatment in the first year, and 48% mortality in the second year. Since different fungal species were used in both studies, we cannot directly compare the results of Erler et al. (2014) with those from the current study.

Results from both current and previous studies indicate that young nymphs are the most susceptible stages of the pest to fungal infection. That is why it is necessary that applications be made at a time when the majority of psyllids are at young nymphal stages of development in any possible future control of pest with EPFs.

In conclusion, the two most virulent local *B. bassiana* isolates (AKBBPN2 and AKBBPN6) tested in the current study and perhaps their combinations offer great potential as new materials in controlling pear psyllids and may provide more effective control against pear psylla compared to many available insecticides. In addition, the use of EPFs in

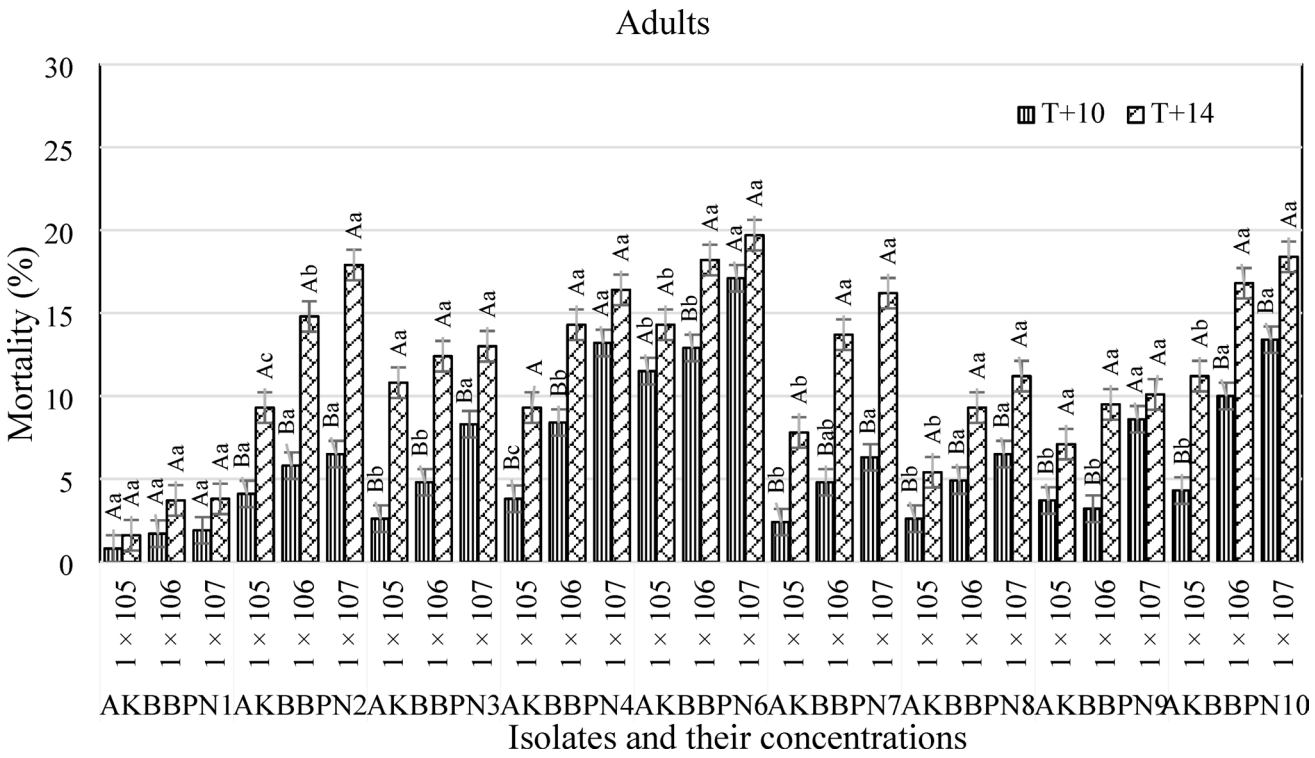



**Fig. 6** Percentage mortality of *Cacopsylla pyri* adults exposed to three different conidial concentrations ($1\times10^5$, $1\times10^6$ and $1\times10^7$) of selected 9 indigenous *Beauveria bassiana* isolates (T+10 and T+14; 10 days and 14 days after treatment, respectively). In each treatment, means within a row followed by the same capital letter are not significantly different (DMRT, $P\leq0.05$), and means within a column followed by the same lower-case letter are not significantly different (DMRT, $P\leq0.05$). No mortality occurred in water-treated controls throughout the experiment

controlling pear psyllids instead of synthetic insecticides may reduce unacceptable residues in pear crop and preserve both human health and environmental quality.

**Supplementary Information** The online version contains supplementary material available at https://doi.org/10.1007/s41348-026-01229-y.

**Acknowledgements** The authors thank Dr. Hilal Sule TOSUN (Akdeniz Univ., Fac. Agric., Dep. Plant Protec., Antalya, Turkey) for her helps in data analyses and evaluation.

**Author contributions** All the authors substantially contributed to the conception and design of the manuscript. Data curation and analysis were maintained by HAK and FE. All molecular studies for the identification of EPF isolates included in virulence assays for further evaluation against the pest were carried out by CE. Writing the entire manuscript was done by FE.

**Funding** Open access funding provided by the Scientific and Technological Research Council of Türkiye (TÜBİTAK). Not applicable.

**Data availability** All data are within the manuscript and supplementary materials.

## Declarations

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical approval and consent to participate** Not applicable.

**Consent for publication** All authors approve the manuscript and give their consent for submission and publication.

**Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

## References

BAKA (2021) Antalya Korkuteli Current Situation Analysis. BAKA Publication No: 2021/129, 105 pages

Baki D, Erler F, Tosun HS, Imrek B (2021a) Isolation and morpho-molecular identification of Indigenous soil-borne entomopathogenic fungi, and their pathogenicity to *Galleria Mellonella* L. (Lepidoptera: Pyralidae) as a model insect. Fresen Environ Bull 30:8138–8148

Baki D, Tosun HS, Erler F (2021b) Indigenous entomopathogenic fungi as potential biological control agents of Rose sawfly, *Arge Rosae* L. (Hymenoptera: Argidae). Turk J Zool 45:517–525

Berrada S, Nguyen TX (1994) Resistance of Pear psylla to phosphorus compound, monocrotophos. IOBC/WPRS Bull 17:34–38

Bidochka MJ, Kasperski JE, Wild GAM (1998) Occurrence of the entomopathogenic fungi *Metarhizium anisopliae* and *Beauveria Bassiana* in soils from temperate and near- Northern habitats. Can J Bot 76:1198–1204

Bues R, Boudinhon L (2002) Insecticide resistance in the Pear psylla. Acta Hortic 596:567–570

Carraro L (1998) Transmission of Pear decline by using naturally infected *Cacopsylla pyri* L. Acta Hortic 472:665–668

Carraro L, Loi N, Ermacora P (2001) The life cycle of Pear decline Phytoplasma in the vector *Cacopsylla pyri*. Plant Pathol J 83:87–90

Civolani S (2012) The past and present of Pear protection against the Pear psylla, *Cacopsylla pyri* L. Insecticides - Pest Engin 65:385–408

Civolani S, Soroker V, Cooper WR, Horton DR (2023) Diversity, biology, and management of the Pear psyllids: a global look. Ann Entomol Soc Am 116:331–357

Doyle J, Doyle J (1990) Isolation of plant DNA from fresh tissue. Focus 12:13–15

Erler F (2004) Natural enemies of the Pear psylla *Cacopsylla pyri* in treated *vs* untreated Pear orchards in Antalya, Turkey. Phytoparasitica 32:295–304

Erler F, Pradier T, Aciloglu B (2014) Field evaluation of an entomopathogenic fungus, *Metarhizium brunneum* strain F52, against Pear psylla, *Cacopsylla pyri*. Pest Manag Sci 70:496–501

Goettel MS, Inglis GD (1997) Fungi hyphomycetes: manual of techniques in insect pathology. Academic, San Diego

Humber RA (1997) Fungi: identification. In: Lacey L (ed) Manual of techniques in insect pathology. Academic, London, pp 153–185

Humber RA (2005) Entomopathogenic fungal identification. USDA-Agricultural Research Service, New York

Humber RA (2012) Identification of entomopathogenic fungi. In: Lacey LA (ed) Manual of techniques in invertebrate pathology. Academic, London, pp 151–187

Julien J (1984) The economic importance of Pear psyllids for the production of Pears in France. IOBC/WPRS Bull 7:7–12

Kirisik M, Erler F (2024) Isolation and molecular identification of entomopathogenic fungi from the Western flower thrips [*Frankliniella occidentalis* (Pergande)], and evaluation of their efficacy against the pest. J Plant Dis Prot 131:719–730

Klingen I, Eilenberg J, Meadow R (2002) Effects of farming system, field margins and bait insect on the occurrence of insect pathogenic fungi in soils. Agric Ecosyst Environ 91:191–198

Kovanci B, Gencer NS, Kaya M, Akbudak B (2000) Investigations on the population fluctuations of *Cacopsylla pyri* (L.) (Homoptera: Psyllidae) in Uludag university agricultural faculty Pear orchard. Turk J Entomol 24:289–300

Lacey LA (1997) Manual of techniques in insect pathology. Academic, San Diego

Meyling NV, Schmidt NM, Eilenberg J (2012) Occurrence and diversity of fungal entomopathogens in soils of low and high Arctic Greenland. Polar Biol 35:1439–1445

MGM (Turkish Meteorological Service) (2024) Weather and Climate. https://www.mgm.gov.tr/eng/forecast-cities.aspx?m=ANTALYA. Accessed 7 February 2025

Pérez-González VH, Guzmán-Franco AW, Alatorre-Rosas R, Hernández-López J, Hernández-López A, Carrillo-Benítez MG, Baverstock J (2014) Specific diversity of the entomopathogenic fungi Beauveria and metarhizium in Mexican agricultural soils. J Invertebr Pathol 119:54–61

Pree DJ, Archibald DE, Ker KW, Cole KJ (1990) Occurrence of pyrethroid resistance in Pear psylla (Homoptera: Psyllidae) populations from Southern Ontario. J Econ Entomol 83:2159–2163

Puterka GJ (1999) Fungal pathogens for arthropod pest control in orchard systems: mycoinsecticidal approach for Pear psylla control. Biocontrol 44:183–210

Puterka GP, Humber RA, Poprawski TJ (1994) Virulence of fungal pathogens (Imperfect fungi: Hyphomycetes) to Pear psylla (Homoptera: Psyllidae). Environ Entomol 23:514–520

Quesada-Moraga E, Navas-Cortés JA, Maranhao EAA, Ortiz-Urquiza A, Santiago-Álvarez C (2007) Factors affecting the occurrence and distribution of entomopathogenic fungi in natural and cultivated soils. Mycol Res 111:947–966

Ramirezs C (1982) Manual and atlas of the penicillia. Elsevier Biomedical, Amsterdam

Reeves LA, Garratt MPD, Fountain MT, Senapathi D (2024) A whole ecosystem approach to Pear psyllid (*Cacopsylla pyri*) management in a changing climate. J Pest Sci 97:1203–1226

Samson RA (1981) Identification: entomopathogenic deuteromycetes. In: Burges HD (ed) Microbial control of pests and plant diseases 1970–1980. Academic, London, pp 93–105

Samson RA, Evans HC, Jatgé JP (1988) Atlas of entomopathogenic fungi. Springer-, Berlin

Sánchez-Peña SR, Lara JSJ, Medina RF (2011) Occurrence of entomopathogenic fungi from agricultural and natural ecosystems in Saltillo, Mexico, and their virulence towards thrips and whiteflies. J Insect Sci 11:1

Saruhan I, Erper I, Tuncer C, Akca I (2015) Efficiency of some entomopathogenic fungi as biocontrol agents against *Aphis fabae* scopoli (Hemiptera: Aphididae). Pak J Agric Sci 52:1–6

Schaub L, Bloesch B, Bencheikh M, Pigeaud A (1996) Spatial distribution of Teflubenzuron resistance by Pear psylla in Western Switzerland. Acta Hortic 422:311–314

Schaub L, Bloesch B, Aeschlimann U, Garnier G (2001) Monitoring resistance of Pear psylla *Cacopsylla pyri* to Amitraz. IOBC/WPRS Bull 24:151–153

Topuz E, Erler F, Gumrukcu E (2016) Survey of Indigenous entomopathogenic fungi and evaluation of their pathogenicity against the Carmine spider mite, *Tetranychus cinnabarinus* (Boisd.), and the whitefly, *Bemisia tabaci* (Genn.) biotype B. Pest Manag Sci 72:2273–2279

Tsang CC, Tang JYM, Lau SKP, Woo PCY (2018) Taxonomy and evolution of *Aspergillus*, *Penicillium* and *Talaromyces* in the omics era – Past, present and future. Comput Struct Biotechnol J 16:197–210

White TJ, Bruns T, Lee S, Taylor JW (1990) Amplification and direct sequencing of fungal ribosomal RNA genes for phylogenetics. In: Innis MA, Gelfand DH, Sninsky JJ, White TJ (eds) PCR protocols: a guide to methods and applications. Academic, New York, pp 315–322

**Publisher's note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.