

Does landscape management influence communities of *Psyllopsis* and natural enemies on ash trees, *Fraxinus excelsior* L.?

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Abstract

The impact of landscape management was assessed on communities of *Psyllopsis* and natural enemies on ash trees, *Fraxinus excelsior* L. over two growing seasons, 2019 and 2020, in the Shorabil park, Iran. Experimental treatments were cultivating of (1) red clover (C), *Trifolium pratense* L., (2) rosemary (R), *Rosmarinus officinalis* L., (3) ornamental cabbage (O), *Brassica oleracea*, and (4) grass (G), as cover plants around ash trees (A). Three psyllids: *Psyllopsis repens* Loginova, *P. securicola* Loginova, and *P. machinosus* Loginova were collected on ash trees. Which, *P. repens* with a relative abundance of 73.1% - 80.7% was the main *Psyllopsis* species on trees. A significant ($P \leq 0.05$) reduction in the population of *Psyllopsis*, the number of leaf-roll galls, and means of bud-cone-like structures per branch were seen in A-C and A-R plots compared with A-O and A-G treatments. The abundance of *Psyllopsis* predators per branch was higher in A-C plots than in the other three treatments. The greatest values of the Shannon diversity index ($H' = 1.98$ in 2019 and 1.94 in 2020) and the Pielou's evenness index ($J' = 0.90$ in 2019 and 0.88 in 2020) for *Psyllopsis* predators were recorded in A-C plots. The highest parasitism rate of *Psyllopsis* nymphs by *Psyllaephagus claripes* Trijapitzin, among treatments, was seen in A-C plots, 34.2 % in 2019 and 29.4 % in 2020. These results indicated that cultivating clover around ash trees could be an effective environmentally-friendly practice in managing *Psyllopsis* infestations and natural enemies' communities in the parks.

Introduction

The species of *Psyllopsis* (Hemiptera: Psyllidae) are known as pests of *Fraxinus* trees in parks and forests in different countries of the world (Burckhardt 2005; Hodkinson 2009; Burckhardt and Ouvrard 2012; Zendedel et al. 2016). Infestations of *Fraxinus* trees by *P. fraxini* L., *P. fraxinicola* (Förster), and *P. discrepans* (Flor) were reported in the United States, Canada, Australia, New Zealand, and Chile (Hodkinson 1988; Burckhardt and Lauterer 1993; Burckhardt 2005). On contrary, *P. repens* Loginova, *P. securicola* Loginova, and *P. machinosus* Loginova were distributed in the Caucasus, the Middle East, and Serbia (Loginova, 1963 and 1968; Malenovský and Jerinić-Prodanović 2011; Demirözer and Bilginturan 2014; Zendedel et al. 2016; Gushki et al. 2018). *Psyllopsis* species induce the leaf-roll gall and the bud-cone-like structures on *Fraxinus* trees by the first- and second-generation nymphs, respectively (Burckhardt 2005; Hodkinson 2009).

The managing landscape by cultivating different plants around the main crop is an alternative method to reduce pest populations (Altieri 1999 and 2003; Khan et al. 2006; Toledo-Hernández et al. 2016; Münch et al. 2019; Eckert et al. 2020), increasing the diversity and efficacy of predators and parasitoids (Hines et al. 2005; Fathi 2017; Zarei et al. 2019), and improve plant growth (Vandermeer 1989; Mohammadi et al. 2021). The effectiveness of the companion plants in reducing pest population strongly relies on either the repellent effect of volatile organic compounds (VOCs) emitted by companion plants (Grez and González 1995; Landis et al. 2000; Gurr et al. 2003; Khan et al. 2009; Stratton et al. 2019) or the efficacy of enemies (Letourneau et al. 2011). Cropping cover plants around the trees in the park pursue aims such as setting up an ecological balance, efficient use of the natural resources, increasing tree growth, improving soil

fertility (Vandermeer 1989), reducing pest infestations (Andow 1991; Eckert et al. 2020), and enhancing the diversity of enemies' communities (Landis et al. 2000; Letourneau et al. 2011; Betz and Tschamtké 2017). Prior studies reported that intercropping aromatic plants like garlic, *Allium sativum* L., onion, *Allium cepa* L., and coriander, *Coriandrum sativum* L., with the main crops led to reducing the density of pests on suitable hosts (Isman 2006; Fathi 2016; Stratton et al. 2019). For illustration, Mohammadi et al. (2021) demonstrated that intercropping garlic with green bean, *Phaseolus vulgaris* L., reduced the population of *Tetranychus urticae* Koch. Eckert et al. (2020) showed that native cover crops enhanced arthropod diversity compared with exotic cover crops and result in resilient vineyard agroecosystems.

The literature review showed that the generalist predators from Anthocoridae, Chrysopidae, Coccinellidae, Miridae, Araneae, and Acari, and parasitoids from *Psyllaephagus* and *Marietta* are effective in regulating *Psyllopsis* populations on *Fraxinus* trees (Sadeghi et al. 2004; Fallahzadeh and Japoshvili 2010). Therefore, designing practices for conserving biocontrol agents and improving their effectiveness is essential in the management of landscape (Kocourek et al. 2021). Besides, previous studies revealed that cropping some companion plants with host plants promotes natural enemies' preservation and efficacy (Khan et al. 2008; Letourneau et al. 2011; Pereira et al. 2015; Fathi 2019; Zarei et al. 2019). Natural enemies may be attracted to diversified ecosystems by offering dietary supplies such as nectar, pollen, shelter, and frequent insect prey and/or host (Landis et al. 2000; Gurr et al. 2003; Khan et al. 2009; Letourneau et al. 2011; Pereira et al. 2015; Toledo-Hernández et al. 2016; Fathi 2022). The findings of Tajmiri et al. (2017) verified that cropping annual alfalfa, *Medicago scutellata* L., as a companion plant in potato, *Solanum tuberosum* L., field enhanced the efficacy of biocontrol agents in control of *Leptinotarsa decemlineata* Say. Zarei et al. (2019) demonstrated that intercropping sainfoin, *Onobrychis viciifolia* Scop., with tomato, *Solanum lycopersicum* L., reduced the density of *Tuta absoluta* (Meyrick) and boosted the efficacy of enemies. Pereira et al. (2015) reported that cropping flowering basil, *Ocimum basilicum* L., as a companion plant with bell pepper, *Capsicum annuum* L., enhanced pollination and crop yield.

In the current study, it is supposed that the cropping of (a) red clover, *Trifolium pratense* L. subsp. *Pratense*, (b) rosemary, *Rosmarinus officinalis* L., (c) ornamental cabbage, *Brassica oleracea* var. *acephala*, and (d) grass, Poaceae, as cover plants, around ash trees might decrease *Psyllopsis* infestations on ash branches. Clover plants build flower bunches at the end of a peduncle. Besides, this plant raises soil fertility through the biological nitrogen fixation process by bacteria in nodules on their roots (Kumar and Goh 2000). Indeed, the presence of terpenes, ketones, and aromatic compounds in clover plants (Tava et al. 2009) might act as a repellent to specific pests on suitable hosts. Likewise, rosemary is an aromatic plant, and odors emitted from rosemary plants might repel pests, confuse host findings, and reduce egg-laying on preferable hosts (Isman et al. 2008; Rašković et al. 2014). Ornamental cabbage plants are in the *Acephala* group and don't produce flowers. Therefore, it is supposed that this plant would affect *Psyllopsis* populations on ash trees by emitting odors such as flavonoids, phenolics, terpenoids, and glycosides (Aamir et al. 2019) or providing varied niches for enemies. The grass is mainly cropping around the ornamental trees in parks and was chosen as a control treatment. Literature reviews indicated that no study exists to determine the impact of cropping different cover plants around ash trees

on populations of *Psyllopsis* and communities of enemies on tress. Therefore, this study was designed for evaluating the effectiveness of various cover plants on *Psyllopsis* populations and communities of enemies on ash trees in 2019 and 2020 in Iran. The conclusion from this study might be suitable for the management of landscape for controlling *Psyllopsis* infestations on ash trees.

Methods

Experiment set-up and measurements

The experiments were conducted based on a randomized complete block design with four blocks at the Shorabil park in Ardabil (38.25° N, 48.30° E, and 1351 m elevation), Iran during the growing season of 2019 and 2020. Ash trees, *F. excelsior*, were about ten-year-old in all plots, 12 × 5 m. Each plot contained four ash trees. Our treatments were cropping one of the ornamental plants: (1) red clover (C), (2) rosemary (R), (3) ornamental cabbage (O), and (4) grass (G) around ash trees (A). Experiments in the two growing seasons were accomplished from May to September.

Samplings were weekly taken from mid-May 2019 and 2020, after observation of *Psyllopsis* nymphs on the leaves of ash trees, and continued to September. At each sampling date, a new branch with 30 cm length and seven leaves, was chosen without prior planning from upper, middle, and lower parts per tree. Four trees per plot were investigated at each sampling date. During the field investigation, we were unable to differentiate the eggs and nymphs of the *Psyllopsis* species. Therefore, the densities of *Psyllopsis* eggs and nymphs and the number of leaf-roll galls and bud-cone-like structures were censused on the branches through a 10× hand lens. All counts were done between 9 to 12 AM. The densities of *Psyllopsis* eggs and nymphs per plot were averaged across the entire growing season of 2019 and 2020 to compare the treatments. For identification of *Psyllopsis* species, a sample of 150 last instar nymphs per plot was taken into the laboratory and maintained in a climate chamber at 25 ± 1 °C, 60 ± 5 RH%, and a photoperiod of 16:8 (L: D) for adult emergence. Then, *Psyllopsis* species were mounted for identification by the morphological features under a stereomicroscope.

The predators of *Psyllopsis* were also assessed on the same samples chosen in the prior experiment by direct counting using a 10× hand lens. Suspected predators were taken to the laboratory for identification through morphological characters under a stereomicroscope (Bei-Bienko et al. 1967; Gordon 1985; Brooks and Barnard 1990). Average abundances of *Psyllopsis* predators per plot were calculated across the whole growing season in 2019 and 2020 to compare the treatments.

The numbers of parasitized nymphs of *Psyllopsis*, by changing their color, were also counted in leaves and buds of the same branches taken in the abovementioned experiments over the growing season of 2019 and 2020. Then, the parasitism rates of *Psyllopsis* nymphs were calculated through dividing the number of parasitized nymphs by the total number of *Psyllopsis* nymphs. For identification of parasitoid species, a sample of 50 parasitized nymphs per plot was taken into the laboratory and maintained in a climate chamber at 25 ± 1 °C, 60 ± 5 RH%, and a photoperiod of 16:8 (L: D) for adult emergence. Then,

parasitoid species were identified by the morphological characters using a stereomicroscope (Tobias 1995).

At the end of the growing season in early September, five branches per tree in each plot were randomly chosen and the length of the new branch (length of the leaf-producing branches), number of leaves per branch, and the dry mass of leaves (by randomly selecting three leaves per branch and drying at 50°C for 48 h and weighing by scale) were measured.

Data analysis

Data on the populations of *Psyllopsis*, the number of leaf-roll galls and bud-cone-like structures, and the densities of predators were log-transformed and the parasitism rate was arcsine-transformed to meet the assumptions of the test. Then, data were analyzed with an ANOVA (four treatments and four blocks), and means were compared among treatments through Tukey's test at $P \leq 0.05$ (IBM SPSS v.24.0). Besides, the values of the Shannon diversity index and the Pielou's evenness index after calculation for each plot were analyzed using an ANOVA and compared through Tukey's test at $P \leq 0.05$. The similar analysis was done for the estimated growth parameters of ash trees (IBM Corp 2016).

Results

Psyllopsis species, their densities, and gall formation

In this study, *P. repens*, *P. securicola*, and *P. machinosus* were collected on the branches of ash trees. *P. repens*, with a relative abundance of 73.1% in 2019 and 80.7% in 2020, was the main *Psyllopsis* species on the branches of ash trees in two growing seasons ($F_{3,9} = 109.26$; $P \leq 0.001$ in 2019; $F_{3,9} = 137.08$; $P \leq 0.001$ in 2020) (Fig. 1). *P. securicola* and *P. machinosus* occurred at low abundances on the branches of ash trees over the growing seasons of 2019 and 2020 (Fig. 1).

The cultivation of four ornamental plant around ash trees significantly influenced the populations of *Psyllopsis* eggs ($F_{3,9} = 58.59$; $P \leq 0.001$ in 2019; $F_{3,9} = 44.29$; $P \leq 0.001$ in 2020) and nymphs ($F_{3,9} = 35.62$; $P \leq 0.001$ in 2019; $F_{3,9} = 29.37$; $P \leq 0.001$ in 2020) on ash branches. The lowest densities of *Psyllopsis* eggs and nymphs per branch were seen on A-C plots. In addition, A-R treatment statistically decreased *Psyllopsis* eggs and nymphs compared with A-O and A-G plots (Table 1). Similarly, the least number of leaf-roll galls ($F_{3,9} = 14.03$; $P \leq 0.001$ in 2019 and $F_{3,9} = 13.74$; $P = 0.001$ in 2020) and bud-cone-like structures ($F_{3,9} = 11.92$; $P = 0.002$ in 2019 and $F_{3,9} = 9.88$; $P = 0.003$ in 2020) per branch were recorded in A-C plots. Furthermore, a significant decrease in the number of leaf-roll galls and bud-cone-like structures per branch was observed in A-R treatment than in A-O and A-G (Fig. 2 and 3).

Natural enemies

In this study, nine species of *Psyllopsis* predators were collected on the infested ash trees during two growing seasons (Table 2). Among them, *Anthocoris nemoralis* (Fabricius) and *Temnostethus reduvinus*

parilis (Horváth) (Hemiptera: Anthocoridae), as well as *Chilocorus bipustulatus* (L.) (Coleoptera: Coccinellidae) were the main predators of *Psyllopsis* on ash trees in two seasons (Table 2). Afterward, *Orius niger* (Wolff) (Hemiptera: Anthocoridae), *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae), *Episyrphus balteatus* (De Geer) (Diptera: Syrphidae), *Anthocoris nemorum* (L.) (Hemiptera: Anthocoridae), *Deraeocoris punctulatus* (L.) (Heteroptera, Miridae), and *Anystis baccarum* (L.) (Acari: Anystidae), respectively occurred at low abundances (Table 2). The discrepancy in *A. nemoralis* abundance was greater in A-C treatment compared with A-R, A-O, and A-G in 2019 ($F_{3,9} = 38.25$; $P \leq 0.001$) and 2020 ($F_{3,9} = 42.19$; $P \leq 0.001$). The least abundance of *A. nemoralis* occurred in A-R plots in 2020 (Table 2). The density of *C. bipustulatus* was statistically enhanced in A-C than in A-R and A-G in 2019 ($F_{3,9} = 16.31$; $P \leq 0.001$) and 2020 ($F_{3,9} = 19.06$; $P \leq 0.001$; Table 2). The populations of *T. reduvinus parilis* were strongly enhanced in A-C than in other treatments in 2019 ($F_{3,9} = 24.30$; $P \leq 0.001$) and 2020 ($F_{3,9} = 19.73$; $P \leq 0.001$; Table 2). Moreover, the least abundance of *T. reduvinus parilis* was recorded in A-R in two years (Table 2). The densities of other predators of *Psyllopsis* including *O. niger*, *C. carnea*, *E. balteatus*, *A. nemorum*, *D. punctulatus*, and *A. baccarum* on ash branches were amended in A-C plots compared with the other three treatments in two seasons (Table 2). In general, the greatest total abundance of *Psyllopsis* predators was documented in A-C plots. Besides, the discrepancy in total abundance of *Psyllopsis* predators was greater in A-O and A-G compared with A-R in 2019 ($F_{3,9} = 114.71$; $P \leq 0.001$) and 2020 ($F_{3,9} = 136.84$; $P \leq 0.001$) (Table 2). The maximum values of the Shannon diversity index ($F_{3,9} = 8.63$; $P = 0.005$ in 2019 and $F_{3,9} = 9.34$; $P = 0.004$ in 2020) and the Pielou's evenness index ($F_{3,9} = 6.71$; $P = 0.011$ in 2019 and $F_{3,9} = 7.01$; $P = 0.010$ in 2020) for the complex of *Psyllopsis* predators were statistically calculated in A-C plots over the whole growing season (Table 2). Moreover, the values of the Shannon diversity index and the Pielou's evenness index were higher in A-O and A-G contrasted with A-R in both years (Table 2).

In the present research, only one parasitoid species *Psyllaephagus claripes* Trjapitzin emerged from the parasitized nymphs of *Psyllopsis* across all treatments. In two years, the average parasitism rate of *Psyllopsis* nymphs per branch was statistically greater in A-C plots than other three treatments ($F_{3,9} = 13.64$; $P = 0.001$ in 2019 and $F_{3,9} = 17.19$; $P \leq 0.001$ in 2020; Fig. 4). Furthermore, the parasitism rate of *Psyllopsis* nymphs was higher in A-O and A-G plots compared with A-R in two seasons (Fig. 4).

Plant growth

Ash trees showed longer new branches in A-C plots contrasted with A-R, A-O, and A-G treatments ($F_{3,9} = 37.42$; $P \leq 0.001$ in 2019 and $F_{3,9} = 23.86$; $P \leq 0.001$ in 2020; Table 3). Similar results were recorded in the number of leaves per branch among the four treatments in 2019 ($F_{3,9} = 19.57$; $P \leq 0.001$) and 2020 ($F_{3,9} = 31.08$; $P \leq 0.001$) (Table 3). In this study, the difference in the dry weight of leaves was not significant among the four treatments in 2019 ($F_{3,9} = 3.14$; $P = 0.080$) and 2020 ($F_{3,9} = 2.61$; $P = 0.116$) (Table 3).

Discussion

In this study, the leaf-roll galls and the bud-cone-like structures were observed on ash trees as a result of the feeding behavior of nymphs of *P. repens*, *P. securicola*, and *P. machinosus*. The infestation of *Fraxinus* trees to three mentioned *Psyllopsis* were reported in the Caucasus, the Middle East, and Serbia (Loginova 1963 and 1968; Burckhardt and Lauterer 1993; Burckhardt and Ouvrard 2012; Demirözer and Bilginturan 2014; Zendedel et al. 2016; Gushki et al. 2018).

In this study, the cultivation of clover and rosemary around ash trees, A-C and A-R, was an efficient practice to manage *Psyllopsis* infestations compared with ornamental cabbage and grass. The reduction of *Psyllopsis* infestations on ash trees in A-C and A-R plots might be connected with a repellent consequence of volatile organic compounds (VOCs) secreted by clover and rosemary plants. The presence of terpenes, phenolic, and aromatic compounds in essential oils of clover (Tava et al. 2009) and rosemary plants (Rašković et al. 2014) might disturb *Psyllopsis* adults, to host finding and egg-laying on ash trees. The combination of VOCs emitted from clover and rosemary with VOCs from ash trees is highly likely to discourage the attraction and establishment of *Psyllopsis* adults toward ash trees. These findings are in contract with former studies that reported managing the landscape could determine the communities of herbivores and natural enemies (Eckert et al. 2020). On the other hand, lower populations of *Psyllopsis* on ash trees in A-C and A-R plots are likely to be explained with the 'appropriate/inappropriate landings' hypothesis (Finch and Collier 2000; Khan et al. 2009; Letourneau et al. 2011). Which, specific herbivores colonize on suitable plants when numerous stimulants such as odors, visuals, and taste are acceptable. Successful landing by specific herbivores on the preferable host is determined mainly by the chemicals perceived through its chemoreceptors at the time of landing on the host plant (Finch and Collier 2000; Letourneau et al. 2011; Münch et al. 2019; Stratton et al. 2019). Therefore, in A-C and A-R plots the adults of *Psyllopsis* might be confused in locating ash trees as a host plant by odors secreted by clover and rosemary plants. Further investigation should be directed for assessing this likely result. Secretion of repellent odors by aromatic plants such as garlic and coriander to prevent pests from settling on the suitable hosts was also reported in previous studies (Fathi 2019; Stratton et al. 2019; Mohammadi et al. 2021).

Another reason for a modification of *Psyllopsis* infestation in A-C plots might be linked with the enhancement in the abundance and diversity of predators that are in concurrence with the results of prior studies (Betz and Tschardtke 2017; Fathi 2017; Tajmiri et al. 2017; Eckert et al. 2020). Which, the abundance of predators, especially *A. nemoralis*, *T. reduvinus parilis*, and *C. bipustulatus*, the diversity of predators, and the parasitism rate by *P. claripes* were greatest in A-C plots. Moreover, the enhancement in the homogeneity of predator's abundance in A-C plots results in larger values of the Shannon diversity index and the Pielou's evenness index for the collection of *Psyllopsis* predators on ash trees. These results are likely to be associated with producing flowers bunches as a resource of pollen and nectar (Tajmiri et al., 2017; Fathi, 2019; Zarei et al. 2019), providing frequent insect prey or host (Betz and Tschardtke 2017; Fathi 2017; Eckert et al. 2020), and implementing diversified niches (Betz and Tschardtke 2017; Tajmiri et al. 2017; Eckert et al. 2020) to biological control agents by clover plants similar to other legumes. The type and frequency of flowers and duration of the flowering period in improving the efficacy of enemies and pollinators were illustrated in preceding studies (Wäckers et al.

2008; Hogg et al. 2011; Pereira et al. 2015; Fathi 2022). Moreover, infested-clover plants by herbivores might emit methyl salicylate like other legumes (James 2006; Gadino et al. 2012), which motivated the attraction of natural biological control agents and improved their efficacy. Former studies reported that predatory bugs (Drukker et al. 2000; James 2003), coccinellids (James 2003; Zhu and Park 2005), lacewings (James 2006), and parasitoids (James 2003; Orre et al. 2010) drew toward methyl salicylate released by insect pest-infested plants. Similarly, earlier studies illustrated the improvement in the abundance and diversity of natural biological control agents in the cropping of some companion plants with the host plants compared with the single crop (Fathi 2017; Tajmiri et al. 2017; Zarei et al. 2019; Kabiri-Abad et al. 2020; Eckert et al. 2020).

Our results indicated the cultivation of clover around ash trees, A-C plots, showed a complementary impact on ash tree growth compared with A-R, A-O, and A-G plots. This result could be linked with the biological nitrogen fixation process by bacteria in nodules on clover roots (Kumar and Goh 2000) and consequently improving soil productivity. On the other hand, another prominent reason for an improvement in ash tree growth in A-C plots could be associated with a reduction in *Psyllopsis* populations on ash trees. Consequently, cropping clover around ash trees is an efficient approach to promote ash tree growth. Our findings are in harmony with former studies that clarified the crop yield improved in intercropping legumes with host plants (Zarei et al. 2019; Kabiri-Abad et al. 2020; Mohammadi et al. 2021; Fathi 2022).

Our conclusions showed that cropping clover around ash trees, A-C plots, showed an influential impression on suppressing *Psyllopsis* infestations. Moreover, cropping clover, among four ornamental plants, under ash trees promoted the abundance and efficacy of *Psyllopsis* predators and parasitoids and consequently improved ash tree growth. Therefore, cultivating clover around ash trees could be an effective environmentally-friendly practice in managing *Psyllopsis* infestations on ash trees in anthropogenic ecosystems.

Declarations

Disclosure statement

No potential conflict of interest was reported by the author.

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Tables

Table 1 Mean ($\pm$ SE) density for the eggs and nymphs of *Psyllopsis* species on the branches of ash trees (A) in cropping clover (C), rosemary (R), ornamental cabbage (O), and grass (G) around trees in two growing seasons 2019 and 2020.

Treatments	Density of eggs/branch		Density of nymphs/branch	
	2019	2020	2019	2020
A-C	4.4 ± 0.5 c	5.0 ± 0.4 c	3.6 ± 0.3 c	4.7 ± 0.4 c
A-R	7.6 ± 0.6 b	8.6 ± 0.7 b	7.0 ± 0.5 b	8.6 ± 0.7 b
A-O	10.8 ± 0.8 a	13.9 ± 1.0 a	8.3 ± 0.9 ab	12.5 ± 0.8 a
A-G	11.7 ± 0.9 a	12.3 ± 1.3 a	9.8 ± 0.8 a	10.1 ± 1.1 ab

Means within a column followed by the same letter are not significantly different (Tukey's HSD test: $P > 0.05$)

Table 2 Average ($\pm$ SE) abundance of predators, Shannon diversity index (H'), and Pielou's evenness index (J') for the complex of predators of *Psyllopsis* on the branches of ash trees (A) in cropping clover (C), rosemary (R), ornamental cabbage (O), and grass (G) around trees in two growing seasons 2019 and 2020.

Predators	Years	A-C	A-R	A-O	A-G
<i>Anthocoris nemoralis</i>	2019	43.5 ± 4.7 a	34.6 ± 4.2 b	29.8 ± 2.6 b	32.8 ± 3.2 b
	2020	50.7 ± 2.3 a	44.3 ± 2.1 b	37.6 ± 2.7 c	43.4 ± 3.2 b
<i>Chilocorus bipustulatus</i>	2019	20.6 ± 1.4 a	17.8 ± 1.1 ab	15.0 ± 1.3 b	16.7 ± 1.4 b
	2020	25.1 ± 2.7 a	21.2 ± 2.2 ab	17.3 ± 1.8 b	19.7 ± 2.0 b
<i>Temnostethus reduvinus parilis</i>	2019	31.7 ± 2.1 a	20.2 ± 1.5 b	11.4 ± 1.3 c	18.5 ± 1.4 b
	2020	29.7 ± 1.3 a	25.3 ± 1.5 b	19.1 ± 1.2 c	24.5 ± 1.4 b
<i>Orius niger</i>	2019	13.4 ± 0.9 a	8.9 ± 0.8 b	4.2 ± 0.5 c	7.1 ± 0.7 b
	2020	14.6 ± 1.1 a	9.1 ± 1.0 b	6.6 ± 0.8 c	7.3 ± 0.9 bc
<i>Chrysoperla carnea</i>	2019	10.4 ± 0.7 a	7.7 ± 0.8 b	4.4 ± 0.4 c	8.1 ± 0.5 b
	2020	12.1 ± 1.0 a	8.7 ± 0.7 b	5.9 ± 0.6 c	8.2 ± 0.5 b
<i>Episyrphus balteatus</i>	2019	12.2 ± 0.6 a	5.8 ± 0.7 b	3.2 ± 0.4 c	6.3 ± 0.4 b
	2020	10.4 ± 0.7 a	6.3 ± 0.6 b	3.5 ± 0.3 c	5.9 ± 0.4 b
<i>Anthocoris nemorum</i>	2019	9.6 ± 0.5 a	4.8 ± 0.5 b	2.9 ± 0.3 c	3.7 ± 0.3 bc
	2020	8.4 ± 0.9 a	6.4 ± 0.8 b	2.7 ± 0.3 c	3.3 ± 0.4 c
<i>Deraeocoris punctulatus</i>	2019	6.8 ± 0.5 a	2.5 ± 0.4 b	2.1 ± 0.5 b	2.9 ± 0.3 b
	2020	7.5 ± 0.6 a	2.3 ± 0.4 b	1.9 ± 0.4 b	2.1 ± 0.5 b
<i>Anystis baccarum</i>	2019	5.9 ± 0.5 a	2.3 ± 0.2 b	1.7 ± 0.3 b	2.4 ± 0.3 b
	2020	4.6 ± 0.4 a	2.4 ± 0.3 c	2.0 ± 0.2 c	3.2 ± 0.4 b
Total abundance	2019	154.1 ± 9.3 a	104.6 ± 7.2 b	74.7 ± 6.7 c	98.5 ± 6.3 b
	2020	163.1 ± 10.1 a	126.0 ± 8.6 b	96.6 ± 8.5 c	117.6 ± 7.8 b
Shannon diversity index (H') $H' = -\sum P_i \ln P_i$	2019	1.98 ± 0.02 a	1.86 ± 0.02 b	1.75 ± 0.02 c	1.87 ± 0.02 b
	2020	1.94 ± 0.02 a	1.81 ± 0.02 b	1.73 ± 0.02 c	1.81 ± 0.02 b
Pielou's evenness index $J' = H' / \ln(S)$	2019	0.90 ± 0.01 a	0.85 ± 0.01 b	0.80 ± 0.01 c	0.85 ± 0.01 b

2020	0.88 ± 0.01 a	0.83 ± 0.01 b	0.79 ± 0.01 c	0.81 ± 0.01 b
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Means within a row followed by the same letter are not significantly different (Tukey's HSD test: $P > 0.05$)

Table 3 Mean ($\pm$ SE) length of new branches, number of leaves, and dry weight of leaves on ash trees (A) in cropping clover (C), rosemary (R), ornamental cabbage (O), and grass (G) around trees in two growing seasons 2019 and 2020.

Treatments	Length of new branches (cm)		Number of leaves per branch		Dry weight of leaf samples (g/3 leaves)	
	2017	2018	2017	2018	2017	2018
A-C	61.8 $\pm$ 2.2 a	58.1 $\pm$ 4.4 a	12.0 $\pm$ 1.1 a	11.4 $\pm$ 1.0 a	8.21 $\pm$ 0.21 a	8.04 $\pm$ 0.29 a
A-R	47.5 $\pm$ 3.7 b	45.2 $\pm$ 4.0 b	9.5 $\pm$ 0.9 b	8.9 $\pm$ 0.9 b	8.02 $\pm$ 0.37 a	8.13 $\pm$ 0.33 a
A-O	43.2 $\pm$ 3.8 b	38.8 $\pm$ 3.3 b	8.1 $\pm$ 1.0 b	7.6 $\pm$ 1.0 b	8.11 $\pm$ 0.33 a	8.21 $\pm$ 0.28 a
A-G	39.8 $\pm$ 4.2 b	41.2 $\pm$ 6.1 b	7.8 $\pm$ 0.9 b	8.0 $\pm$ 0.8 b	7.98 $\pm$ 0.24 a	8.01 $\pm$ 0.31 a

Means within a column followed by the same letter are not significantly different (Tukey's HSD test: $P > 0.05$)

Figures

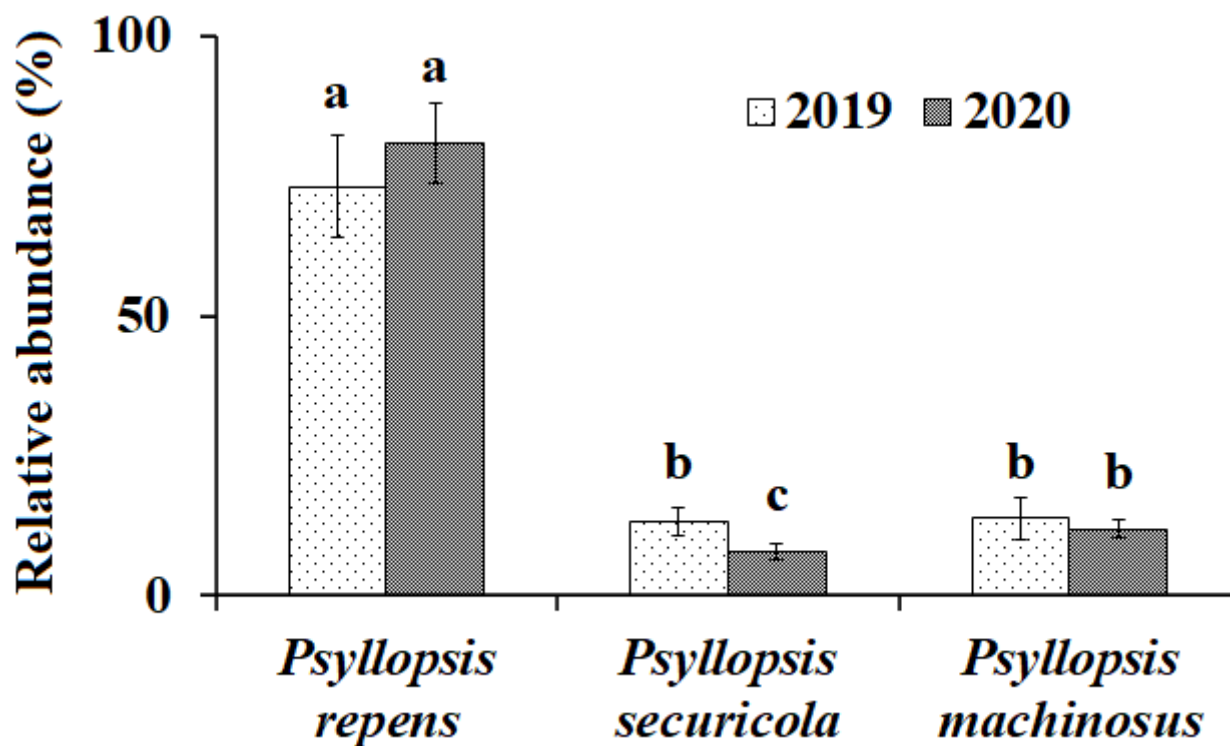


Figure 1

Relative abundance (%) of *Psyllopsis* species on ash trees in two growing seasons 2019 and 2020.

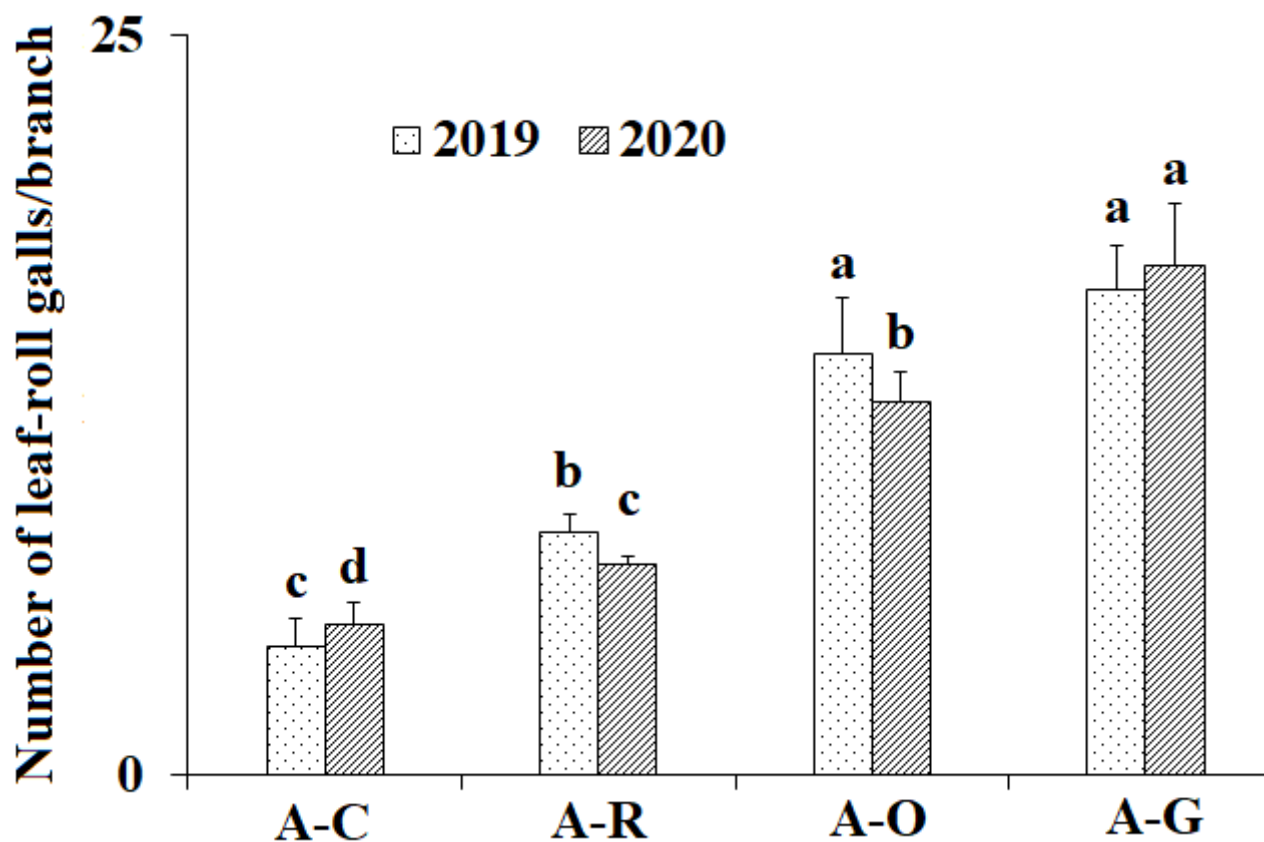


Figure 2

Means ($\pm$ SE) of the leaf-roll galls induced by *Psyllopsis* on ash trees (A) in cropping clover (C), rosemary (R), ornamental cabbage (O), and grass (G) around trees in two growing seasons 2019 and 2020.

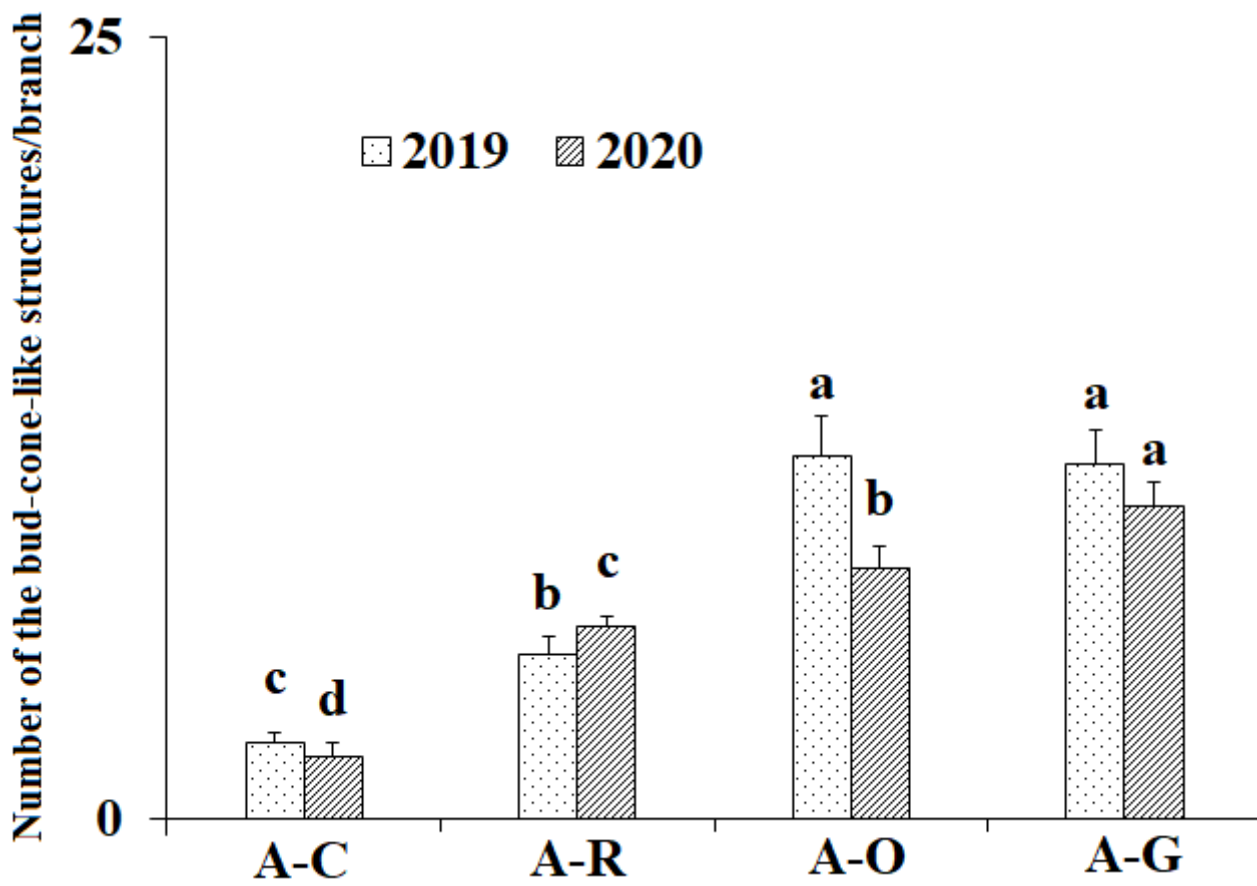


Figure 3

Means ($\pm$ SE) of the bud-cone-like structures induced by *Psyllopsis* on ash trees (A) in cropping clover (C), rosemary (R), ornamental cabbage (O), and grass (G) around trees in two growing seasons 2019 and 2020.

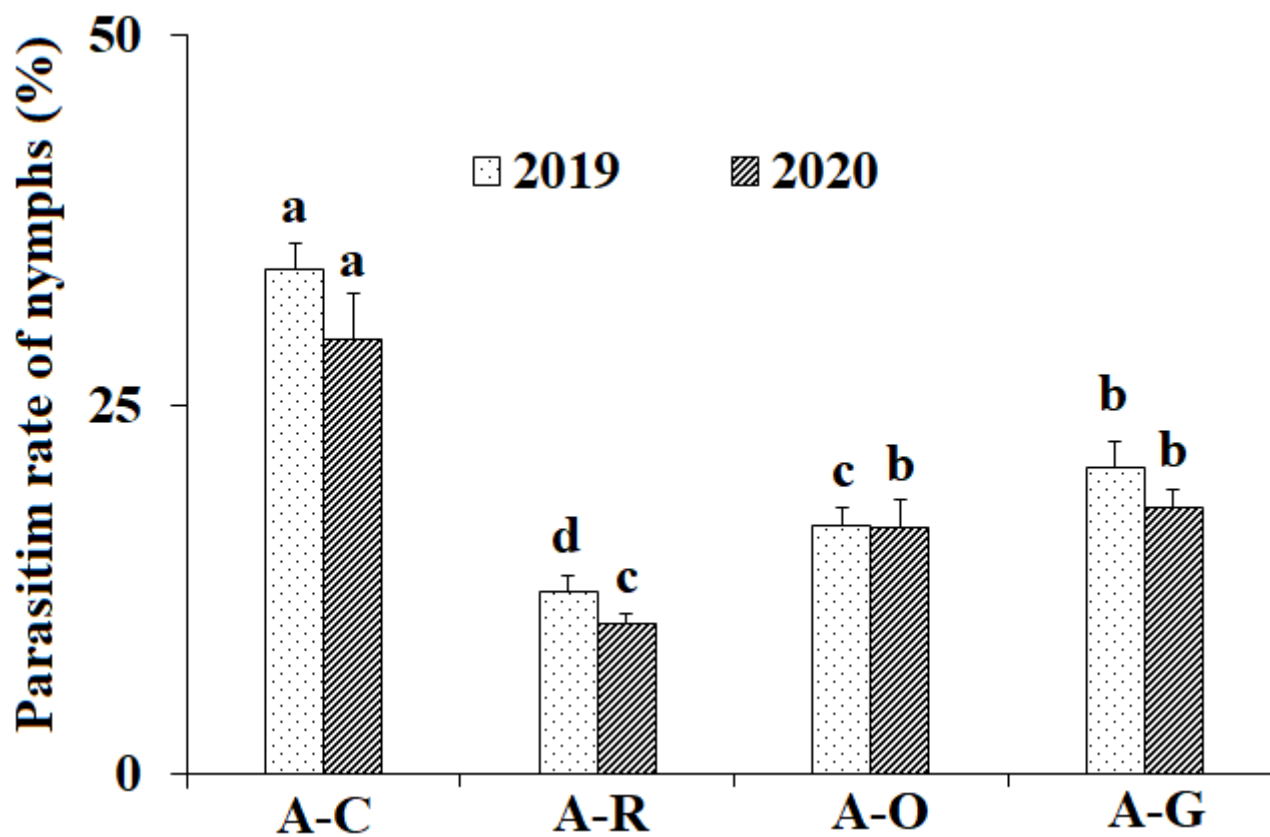


Figure 4

Parasitism rate (%) of *Psyllopsis* nymphs on ash trees (A) in cropping clover (C), rosemary (R), ornamental cabbage (O), and grass (G) around trees in two growing seasons 2019 and 2020.