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Insectary Plant Species Preferences of Predators and Parasitoid Families in a Mediterranean Horticultural Agroecosystem

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ABSTRACT

The use of insectary plants to provide alternative food and shelter resources for enhancing natural enemy activity has been established as a common practice in IPM. Candidate flowering plant species have been screened and evaluated for their contribution to enhance life parameters of beneficial insects. However, less information has been reported on the preference of these natural enemies for different insectary plant species in the field. The relative attractiveness of six insectary plant species to the key natural enemy groups on horticultural crops in the Mediterranean region was assessed by observing the relative frequencies of appearance on six plant species: *Achillea millefolium* L. and *Calendula officinalis* L. (Asterales: Asteraceae), *Daucus carota* L. (Apiales: Apiaceae), *Diplotaxis tenuifolia* (L.) DC. (Brassicales: Brassicaceae), *Fagopyrum esculentum* Moench (Caryophyllales: Polygonaceae), and *Lobularia maritima* (L.) Desv. (Brassicales: Brassicaceae). The presence of predators and parasitoids was evaluated by visual counts. Among predators, Syrphidae adults were evaluated by visual observation of inflorescence visits and/or hovering. The other predators recorded on the insectary plants were collected and divided into six groups: Aeolothripidae, Araneae, Chrysopidae, Coccinellidae, Dicyphini tribe, and *Orius* spp. Parasitoids were also collected and grouped into families. The Syrphidae interacted the most with *D. tenuifolia*, *F. esculentum*, and *L. maritima,* the last one being the plant with higher proportion of visits after hovering on the inflorescence. Parasitoids were recorded the most on *A. millefolium* and *L. maritima*. Finally, significant differences were found in the preference of each group of predators for the six insectary plants. The different natural enemy groups preferences for the insectary plants are discussed in biological control context and of the key influencing factors that should be considered when assessing the relative attractiveness of natural enemies to the insectary plants.

1 | Introduction

One of the main objectives of a biological control programme is to adjust habitat in agroecosystems to provide shelter and food (nectar, alternative hosts/preys, and pollen) to the natural enemies (predators and parasitoids) (González-Chang et al. 2019; Gurr et al. 2004; Heimpel and Jervis 2005). The key to an effective conservation biological control is an early colonisation and establishment of natural enemies in a crop, when pest populations are still at low densities (Ardanuy et al. 2022; Gómez-Marco et al. 2016a; Gómez-Marco et al. 2016b; Symondson et al. 2002). This can be particularly complicated in the case of ephemeral habitats, like annual crops (i.e., horticultural crops), as it requires natural enemies to successively establish and survive on alternative habitats, between crops, following a seasonal cycle (Schellhorn et al. 2015; Wissinger 1997). To conserve and

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attract natural enemies, the use of floral margins and/or plant intercropping (i.e., insectary plants) has been widely used in different agroecosystems (Ardanuy et al. 2022; Gómez-Marco et al. 2016a; Gómez-Marco et al. 2016b; Mockford et al. 2022) including ephemeral agroecosystems such as horticultural crops (Jachowicz and Sigsgaard 2025). Therefore, to study the specific interactions and the preference of these natural enemies with insectary plant species, it is key to improve and establish a successful biological control programme.

Predatory syrphids (Syrphidae) are important natural enemies because of their high reproductive, prey search and consumption rates, and their strong dispersal capabilities (Chambers and Adams 1986; Rodríguez-Gasol et al. 2020; Tenhumberg and Poehling 1995). While some syrphid larvae are predatory, adults always feed on nectar and pollen for energy and egg maturation, respectively (Rodríguez-Gasol et al. 2020). The attraction of syrphids through insectary plants increases biological control and subsequent population suppression of pests (Irvin et al. 2021). Insectary plants that are especially attractive to adult syrphids include *Fagopyrum esculentum* Moench (Caryophyllales: Polygonaceae) and *Lobularia maritima* [L.] Desv. (Brassicales: Brassicaceae) (Arnó et al. 2021; Badenes-Pérez 2018; Gontijo et al. 2013; Irvin et al. 2021; Smith and Chaney 2007). In horticultural areas of the Mediterranean, the presence of Syrphidae has been associated with successful control activity of pest populations such as aphids (Aparicio et al. 2021; Chambers and Adams 1986) and their interactions with insectary plant species have also been investigated (Ambrosino et al. 2006; Irvin et al. 2021). Parasitoids also play an important role in biological pest control due to their ability to regulate the populations of many phytophagous insects. Many of these parasitoids reach their maximum biological potential when they have an adequate food supply (Benelli et al. 2017; Heimpel and Jervis 2005; Jervis et al. 2008). Many studies have related the availability of sugar-rich sources, such as nectar presence from insectary plants, with the improvement of parasitoid fitness and the enhancement of the biological control service provided by the parasitoid (Tena et al. 2015). For example, it has been proved that *L. maritima* is a nutrient-rich food source for four larval parasitoids of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelichiidae) and an aphid parasitoid, *Aphidius ervi* Haliday (Hymenoptera: Braconidae) in laboratory experiments (Aparicio et al. 2018; Arnó et al. 2018b; Urbaneja Bernat et al. 2024). However, to our knowledge, few studies have focused on the attraction of different species (or families) of parasitoids by insectary plant species in the field. Uniquely, to our knowledge, two studies explored the presence of parasitoid families on different insectary plant species, relating the flower structure and parasitoid size and morphology to their presence on each insectary plant species (Jervis et al. 1993; Denis et al. 2021).

In the 1970s, Catalonia region in Spain was a pioneer in the application of biological control management in horticultural crops in the Mediterranean basin (Arnó et al. 2018a). The history of using native parasitoids and predators against key horticultural pests such as aphids, whiteflies, *Liriomyza* sp. (Diptera: Agromyzidae) and *Tuta absoluta* (Lepidoptera: Gelechiidae) is large (Arnó et al. 2018a). As an example, the parasitoids belonging to the Eulophidae and Braconidae families are valuable biocontrol agents against leaf miners (i.e., *Liriomyza* sp.), *T. absoluta* and aphids in horticultural areas of the Mediterranean (Arnó et al. 2018a). Polyphagous predators of the Dicyphini tribe (Heteroptera: Miridae) such as *Macrolophus*, *Dicyphus* and *Nesidiocoris* genera, have proved very successful in controlling whiteflies and other key tomato pests in greenhouses of the Mediterranean, relating the presence of adjacent insectary plants (i.e., *Calendula officinalis* L. [Asterales: Asteraceae]) to adequate and early colonisation of tomato fields by predatory mirids (Dicyphini tribe) (Alomar et al. 2002; Ardanuy et al. 2022; Gabarra et al. 2004).

However, not all flowering resources can function as beneficial insectary plants for all natural enemies. Depending on the natural enemy groups or species, the insectary plant species might benefit or fail to provide the resources that a specific natural enemy species can exploit. Poorly selected insectary plants may act as “sinks” for some species of natural enemies (Landis et al. 2000; MacLeod 1999). As an example, volatiles produced by *L. maritima* attracted two natural enemies, the aphid parasitoid *A. ervi* and the predator *Aphidoletes aphidimyza* (Rondani) (Diptera: Cecidomyiidae). However, only the parasitoid was able to increase its longevity when exposed to *L. maritima* in laboratory experiments (Aparicio et al. 2018). In the same direction, Arnó et al. (2018b) showed that different insectary plant species provided different benefits in terms of survival and egg load for three parasitoid species of *T. absoluta* in laboratory experiments. These differences show that the selection of insectary plant species must be accompanied by the study of the attraction each insectary plant species exerted on each predator or parasitoid targeted to be used in each biological control programme.

In this study, we quantified the natural enemies, predators and parasitoids, that are inhabiting (for food and/or shelter) six insectary plant species that have been used widely in horticultural agroecosystems: *Achillea millefolium* L. (Asterales: Asteraceae), *C. officinalis*, *Daucus carota* L. (Apiales: Apiaceae), *Diplotaxis tenuifolia* (L.) DC. (Capparales: Brassicaceae), *F. esculentum* and *L. maritima*. These plant species were selected as the insectary plants to be investigated since several studies have highlighted their utility to enhance the performance of beneficial fauna (Ambrosino et al. 2006; Aparicio et al. 2018, 2021; Araj et al. 2008; Araj and Wratten 2015; Ardanuy et al. 2022, Arnó et al. 2018; Idris and Grafius 1995; Jado et al. 2019). The objective of this study is to disentangle the interactions between these six insectary plant species with the considered key natural enemy groups, predators and parasitoids, occurring spontaneously in horticultural areas of a Mediterranean agroecosystem. The flowering period and inflorescence density of these plant species were tracked to correlate with the presence of Syrphidae adults, parasitoid families and six groups of predators: Aeolothripidae, Araneae, Chrysopidae, Coccinellidae, the Dicyphini tribe and the *Orius* genus.

2 | Material and Methods

2.1 | Plant Material

Insectary plant species: *A. millefolium*, *C. officinalis*, *D. carota*, *D. tenuifolia*, *F. esculentum* and *L. maritima* (seeds from Semillas Silvestres, S.L., Cordoba, Spain), were sown in two groups (1 m

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separation) with a randomised block design with three different repetitions of 70 × 170 cm for each plant species (five plants per row for each species), with a total amount of six plots per insectary plant species, in an experimental field at IRTA, Cabrils, Catalonia (Spain). Two sown periods were scheduled, first at the end of winter (first week of March) and second at the end of spring (end of May). The water regime was three times per week to enhance the growing of the plants. When flowers decayed, the plants were trimmed to enhance the flower regeneration (Table S1) and to prolong the flowering period. Flowering starting time was recorded for all plant species and to determine the inflorescence density a plastic ring of 8.5 cm diameter ($56.75\,\text{cm}^2$) was placed aleatory on top of the plots. The total number of inflorescences inside the ring were counted weekly from May to October in 2017. In this study, we refer as inflorescences for all flower related structures in all plant species (including the "capitulum" and "umbels" for *C. officinalis* and *D. carota*, respectively).

2.2 | Insect Counts and Identification

The presence of natural enemies on each insectary plant species was recorded weekly from May to October 2017, between 8:00 a.m. and 11:00 a.m. The frappage method was used to count the number of parasitoids and predators. The frappage method involves striking or shaking plant parts (such as branches, foliage, or shrubs) over a collecting surface (like a tray, cloth, or net) so that insects and other arthropods are dislodged and fall onto it. The samples collected can then be examined, counted, or preserved for identification. Each plant was beaten three times on a white tray in three aleatory areas of the plant plot. Parasitoids were collected with an aspirator and identified at the family level under the microscope following taxonomic keys from Pinto and Hanson (2006). Data on insectary plant species preference by parasitoid families were divided into two periods to analyse preference throughout the sampling period (see results). Predators were identified and grouped into five groups: predatory thrips (Aeolothripidae), arthropods from the Araneae order, insects from the Chrysopidae family, beetles from the Coccinellidae family, adults of the Dicyphini tribe, and the *Orius* genus. Aeolothripidae, Araneae, Chrysopidae, and Coccinellidae are generalist predators that have been documented as important natural enemies for numerous crop systems. Similarly, some species of the Dicyphini tribe (Hemiptera: Miridae) described in Spain have shown to be important predators in diverse crops, and all the *Orius* genus (Hemiptera: Anthocoridae) species reported in Spain are important generalist predators (Alomar et al. 2002; Ardanuy et al. 2022; Gabarra et al. 2004), except *Orius pallidicornis* (Reuter), strongly associated with its plant host *Ecballium elaterium* L. (Cucurbitales: Cucurbitaceae) (Ferragut and González-Zamora 1994).

Syrphid adult interactions with insectary plants were recorded with visual observations for 3 min. Two behaviours were recorded separately. Visit was considered when the syrphid lands on the inflorescence and hovering when they flew around the inflorescences. We consider in this study the sum of both events (visit and hovering) as the total interactions of Syrphidae adults with each plant species. The percentage of visits, which represents the landing preference, was calculated by dividing the number of visits by the total number of interactions on each plant species, date, plot and repetition. Although we were careful not to double-count insects as they arrived on inflorescences, it is possible that 3 min was sufficient for some syrphids to leave and return to the inflorescences multiple times and, therefore, some individuals could have been counted multiple times. Thus, our data should be interpreted as an interaction rate rather than as a count of the actual number of syrphids interacting with the insectary plants. From the plant perspective, the interaction rate is likely a more important indicator of attraction than the specific identity of an individual insect. Further, we propose that the high interaction rates are also a reasonable proxy of syrphid inflorescence preference. We observed three peaks of Syrphidae interactions with insectary plants (see results section) corresponding to three different Syrphidae generations and/or different Syrphidae species presence. Data on insectary plant species preference by Syrphidae (insect visits on inflorescence) were divided into these three periods to analyse preference of Syrphidae on insectary plants throughout the sampling period (see results).

2.3 | Statistics

All statistical analyses were conducted in R Statistical Software (version 4.3.3; R Core Team 2024). To assess if there were statistical differences in the interactions performed by Syrphidae and the presence of each parasitoid family on the corresponding periods (SI, SII and SIII for Syrphids and PI and PII for parasitoids) a two-way ANOVA, with number of interactions or presence of syrphids or parasitoids (data from all sampling date on each period was aggregated by repetition), respectively, as the response variable, was performed to compare the average interactions or presence of both groups with insectary plants. Pairwise comparisons of interactions or presence between each period were conducted with a Tukey test. The abundance of each predator group on the six insectary plant species was also analysed with an ANOVA, with insectary plant species as fixed effect and presence of predator group as the response variable (pairwise comparisons also with Tukey post hoc). The landing preference of the Syrphidae adults on the six insectary plants was analysed by the Kruskal Wallis test, with the plant species as the fixed effect and the percentage of interactions that become visits as response variable. Pairwise comparisons of the percentage of interactions that become visits between each plant species were conducted with a Dunn's test. For all statistical tests, the significance level of $\alpha = 0.05$ for the null hypothesis was used.

3 | Results

3.1 | Insectary Plants Inflorescence Density

The six insectary plant species tracked had inflorescences at some point throughout the study, flowering simultaneously and were available for all Syrphidae, parasitoids, and other predators interaction assessments (May 18th to October 12, 2017) (Figure 1). Inflorescence density for each plant species reached the maximum

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at different times. *Achillea millefolium* was the slowest to reach the maximum inflorescence density (4.81 inflorescences/cm^2 at 111 days) and *C. officinalis* was the fastest (0.6 inflorescences/cm^2 at 7 days) (Table 1). On average throughout the study, significant differences were found in the inflorescence density between insectary plant species ($F_{2,598} = 52.06$, $p < 0.001$). *D. carota* had the lowest inflorescence density (0.123 ± 0.018 inflorescence/cm^2 and date) and *L. maritima* had the highest inflorescence density (1.757 ± 0.235 inflorescence/cm^2 and date).

3.2 | Predator and Parasitoid Occurrence on Insectary Plants Species

Among predators, Syrphidae adults were present throughout the study. There were a total of 1471 interactions with insectary plants on 544 sampling events (3 min). After data visualisation, we identified three periods corresponding to three Syrphidae generations and/or Syrphidae species presence: from May 18 to June 28 (period SI), from June 28 to August 11 (period SII)

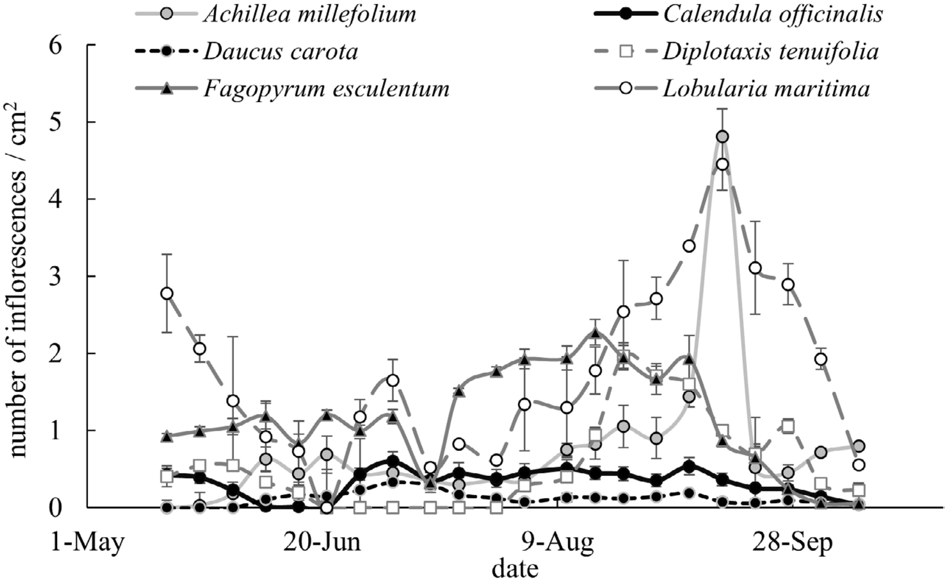

FIGURE 1 | Inflorescence average density (±SE) dynamics throughout the sampling season (from May 18 to October 12 of 2017) of the six insectary plant species tracked: *A. millefolium*, *C. officinalis*, *D. carota*, *D. tenuifolia*, *F. esculentum*, and *L. maritima*.

TABLE 1 | The date that the six insectary plant species (*Achillea millefolium*, *Calendula officinalis*, *Daucus carota*, *Diplotaxis tenuifolia*, *Fagopyrum esculentum* and *Lobularia maritima*) were transplanted, and each plant species' flowering started, maximum inflorescence density, the number of days until plants produced the maximum inflorescence density, and the length of flowering (days). For each insectary plant species, the total number of Syrphidae interactions, total predators and parasitoids recorded are displayed.

	A. millefolium	***C. officinalis***	***D. carota***	***D. tenuifolia***	***F. esculentum***	***L. maritima***
Transplant dates (first)	3-May	3-May	30-Jan	20-Jan	12-Jan	12-Jan
Date flowering started	25-May	18-May	8-June	18-May	18-May	18-May
Maximum inflorescence density (cm^2)/date	4.81/13-Sept	0.6/5-Jul	0.33/5-Jul	1.97/23-Aug	2.27/17-Aug	4.45/13-Sept
Days to maximum inflorescence density	111[a]	7 (from 28-Jun)	27[a]	21 (from 2-Aug)	91[a]	77 (from 28-Jun)
Length of flowering (days)	140	28 + 106	126	28 + 71	147	28 + 106
Total Syrphid interactions	123	105	87	290	532	329
Total parasitoids recorded	921	382	169	99	259	874
Total predators recorded	633	1836	342	467	633	1294

[a] From transplant date.

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and from August 11 to October 12 (period SIII) (Figure 2A). In "period SI", the Syrphidae adults interactions with insectary plants peaked on May 25 (8.7 ± 1.95 interactions per plant species and plot). In "period SII" and "period SIII" Syrphidae adult interactions peaked on July 19 (7.05 ± 1.2) and August 23 (4.14 ± 0.80), respectively (Figure 2A). Comparing the total

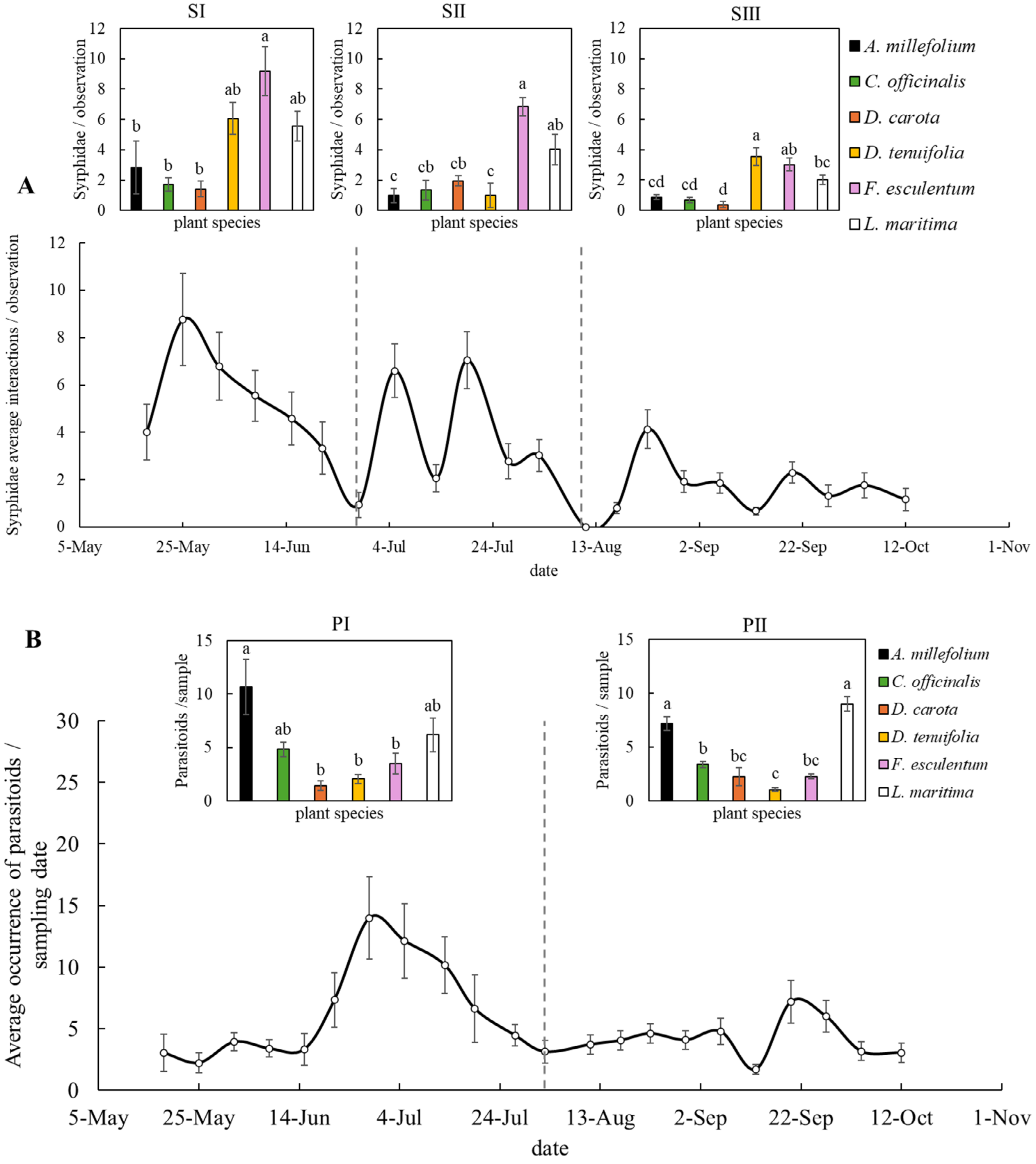

FIGURE 2 | Average (±SE) of Syrphidae interactions (A) and parasitoids occurrence (B) on six insectary plant species (*A. millefolium*, *C. officinalis*, *D. carota*, *D. tenuifolia*, *F. esculentum* and *L. maritima*) throughout the sampling period (May 18 to October 12). Line in (A) and (B) indicates average interactions by Syrphidae and average occurrence of parasitoids, respectively, on each sampling date. Diagram bars figures on top of graph A indicate the average Syrphidae interactions per plant species (±SE) on the three timeframes throughout the sampling period: May 18 to June 28 (SI), June 28 to August 11 (SII) and August 11 to October 12 (SIII). Diagram bars on top of graph B indicate the average parasitoid occurrence per plant species (±SE) on two timeframes throughout the sampling period: May 18 to August 2 (PI) and August 2 to October 12 (PII). Different letters indicate significant differences in the interaction/presence of insects between insectary plant species. [Colour figure can be viewed at wileyonlinelibrary.com]

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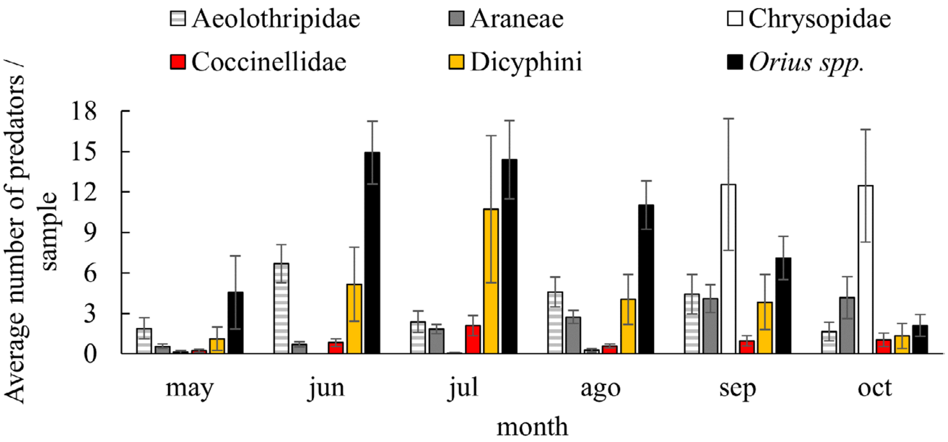

FIGURE 3 | Presence of predators. Average number of predators (±SE) (i.e., Aeolothripidae, Araneae, Chrysopidae, Coccinellidae, Dicyphini and *Orius* spp.) on insectary plants by month (sampling from May 18 to October 12 of 2017, between 8:00 a.m. and 11:00 a.m.). [Colour figure can be viewed at wileyonlinelibrary.com]

average of interactions between the three periods (SI, SII and SIII) and plant species, significant differences were observed between periods ($F_{2,82} = 14.31$, $p < 0.001$) and between insectary plant species ($F_{5,82} = 16.43$, $p < 0.001$). Syrphids had an average of total interactions on period SI, SII and SIII of 4.464 ± 0.78 ($n = 18$), 2.686 ± 0.442 ($n = 36$) and 1.752 ± 0.242 ($n = 36$), respectively. *Fagopyrum esculentum*, *L. maritima* and *D. tenuifolia* were the insectary plant species that Syrphidae visited on the inflorescences the most during the three timeframes delimited in this study for this group (Figure 2A).

Parasitoids were found throughout the study. A total of 2704 parasitoids were reported on 542 frappages on the six insectary plant species. After data visualisation we identified two periods corresponding to two parasitoid generations and/or parasitoid species presence: from May 18 to August 2 "period PI" and from August 2 to October 12 "period PII" (Figure 2B). In "period PI" the parasitoid occurrence on insectary plants peaked on June 28 (14 ± 3.35 parasitoids per plant species and repetition). In the second timeframe, "period PII", parasitoid occurrence peaked on September 20 (7.19 ± 1.72) (Figure 2B). Comparing the total average of parasitoid presence on the six insectary plant species between the two periods (PI and PII), no significant differences were observed between periods ($F_{1,62} = 1.66$, $p = 0.203$) and significant differences were observed between insectary plant species ($F_{5,62} = 15.109$, $p < 0.001$). Parasitoids average presence on periods PI and PII was of 5.027 ± 0.779 ($n = 33$) and 4.193 ± 0.528 ($n = 36$), respectively. *Achillea millefolium* and *L. maritima* were the insectary plants where more parasitoids were recorded in both time frames delimited in this study for this group (Figure 2B).

Other predator groups (apart from Syrphidae) were found on the insectary plants with the frappage sampling method. We subdivided the group of "other predators" as Aeolothripidae, Araneae, Chrysopidae, Coccinellidae, Dicyphini, and *Orius* spp. The most abundant group was the *Orius* spp. (1831 individuals recorded), followed by Chrysopidae (910), Dicyphini (826), Aeolothripidae (763), Araneae (533), and Coccinellidae (176). The Chrysopidae family was the only group that was absent on more than one sampling date; this was from May 25 to July 13 and again from July 27 to August 8 (Figure 3). All the predators tracked in this study were present in all the insectary plant species except the Dicyphini group, which was not found in *D. tenuifolia* and *F. esculentum* (Table 2). Each group of the other predators had significant preferences in the plant species inhabited during the tracking period of this study. Aeolothripidae and Chrysopidae groups preferred *D. tenuifolia* and *L. maritima* (Aeolothripidae; $F_{5,181} = 22.86$, $p < 0.001$; and Chrysopidae; $F_{5,181} = 4.65$, $p < 0.001$) (Table 2). The Araneae group appeared more often on *L. maritima* ($F_{5,181} = 14.77$, $p < 0.001$) (Table 2). Coccinellids were found more often on *D. carota* ($F_{5,181} = 17.19$, $p < 0.001$) and the Dicyphini group on *C. officinalis* ($F_{5,181} = 45.6$, $p < 0.001$) (Table 2). Finally, *Orius* spp. were found in three plant species at the same level: *A. millefolium*, *F. esculentum*, and *L. maritima* ($F_{5,181} = 18.26$, $p < 0.001$) (Table 2).

3.3 | Syrphidae Preference to Land on Insectary Plants

Syrphidae interacted with the insectary plants 1466 times when the density of inflorescences was > 0 inflorescence/cm^2 on each plant species during our sampling period. From those interactions (sum of hovering and visits), 536 (36.56%) became a visit of a Syrphidae adult on an inflorescence. There were significant differences in the percentage of interactions that became visits per insectary plant species (Kruskal–Wallis $\chi^2 = 11.11$, df = 5, $p = 0.049$). Syrphidae adults visited more times *L. maritima* and less *A. millefolium* and *D. carota* (Figure 4).

3.4 | Parasitoid Families and Its Insectary Plant Species Preference

A total of 1728 parasitoids were captured after frappage to be identified in the laboratory. Sixteen different families were identified, in order of abundance: Scelionidae (65.45%), Trichogrammatidae (9.49%), Mymaridae (8.91%), Pteromalidae (3.88%), Encyrtidae (3.76%), Aphelinidae (1.97%), Torymidae (1.39%), Ceraphronidae (1.33%), Figitidae (1.10%), Eulophidae and Braconidae (both 0.81%), Eurytomidae (0.64%), Diapriidae (0.23%), Perilampidae (0.12%), Chalcididae and Ichneumonidae (both 0.06%).

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TABLE 2 | Average presence of other predator groups on the six insectary plant species. For an insect group, different letters indicate significant differences in the presence of predators among the insectary plant species.

Plant species	Aeolothripidae	Araneae	Chrysopidae	Coccinellidae	Dicyphini	*Orius* spp.
Achillea millefolium	0.879 ± 0.278 b	1.909 ± 0.280 b	3.788 ± 1.233 b	0.545 ± 0.18 b	0.061 ± 0.042 b	12.909 ± 1.687 a
Calendula officinalis	0.563 ± 0.185 b	1.781 ± 0.287 b	0.406 ± 0.161 b	0.25 ± 0.11 b	25.68 ± 3.738 a	1 ± 0.266 b
Daucus carota	1.75 ± 0.384 b	1.714 ± 0.377 b	1 ± 0.463 b	3.714 ± 0.764 a	0.036 ± 0.036 b	5.714 ± 1.138 b
Diplotaxis tenuifolia	11.308 ± 1.86 a	1.615 ± 0.441 b	12.615 ± 4.391 a	0.192 ± 0.079 b	0 b	3.115 ± 1.294 b
Fagopyrum esculentum	2.97 ± 0.565 b	1.697 ± 0.280 b	0.939 ± 0.439 b	0.909 ± 0.21 b	0 b	15.636 ± 2.301 a
Lobularia maritima	7.857 ± 1.159 a	7.629 ± 1.274 a	11 ± 4.13 a	0.314 ± 0.121 b	0.029 ± 0.029 b	17.6 ± 1.942 a

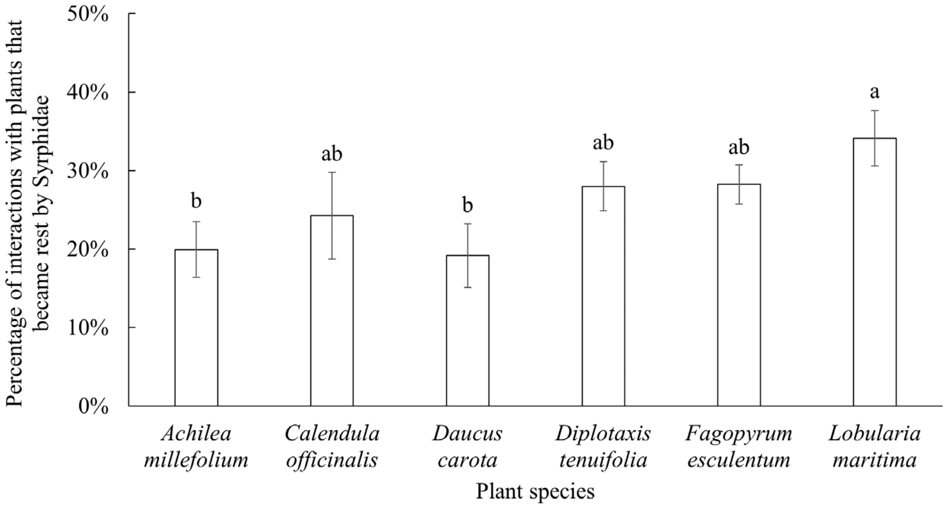

FIGURE 4 | Preference to visit insectary plant species of the Syrphidae group. Percentage of interactions that became a visit on the inflorescences of six plant species by Syrphidae. Different letters indicate significant differences in the percentage of visits by Syrphidae on the six plant species.

Aphelinidae and Ceraphronidae families were not present on *D. tenuifolia*. Braconidae family was present on *C. officinalis*, *F. esculentum*, and *L. maritima* but not in the other three insectary plant species studied. Encyrtidae, Eulophidae, Mymaridae, Scelionidae, and Trichogrammatidae families were present on all six insectary plant species. Finally, Figitidae and Pteromalidae were not present on *A. millefolium* and *F. esculentum*, respectively (Figure 5).

4 | Discussion

Overall, predators and parasitoids interacted with all the six insectary plant species throughout the study. *Diplotaxis tenuifolia*, *F. esculentum*, and *L. maritima* were the insectary plant species more visited by Syrphidae adults. Between these three insectary plant species, there were not significant differences in the ratio of visits per interaction (hovering over the inflorescence + visit) by the Syrphidae adults. Similarly, Ambrosino et al. (2006) found that predatory syrphids interacted with *F. esculentum* and *L. maritima* at the same levels. On the contrary, Arnó et al. (2021) found that syrphids interacted more often with *F. esculentum* than *L. maritima*. On the other hand, overall, parasitoids interacted mostly with *A. millefolium* and *L. maritima*. In both cases, we assume that there was not any interspecific interference and displacement from foraging competition neither territoriality since there was a high interaction rate of both syrphids and parasitoids on *L. maritima* (Wellington and Fitzpatrick 1981). Other predator groups tracked in this study, Aeolothripidae, Araneae, Chrysopidae, Coccinellidae, Dicyphini, and *Orius* spp., had clear preferences for specific insectary plant species (Table 2). Remarkably, 99.52% of the predators belonging to the Dicyphini group were found in *C. officinalis* and ~90% of the Dicyphini mirids counted on the tray during the frappage were *M. pygmaeus* (C. Denis personal observation). This confirms previous studies that also found *C. officinalis* as the best insectary plant species for predators belonging to the Dicyphini and specially for *M. pygmaeus* (Ardanuy et al. 2022). Excluding the Dicyphini group from the total amount of predators found in this study,

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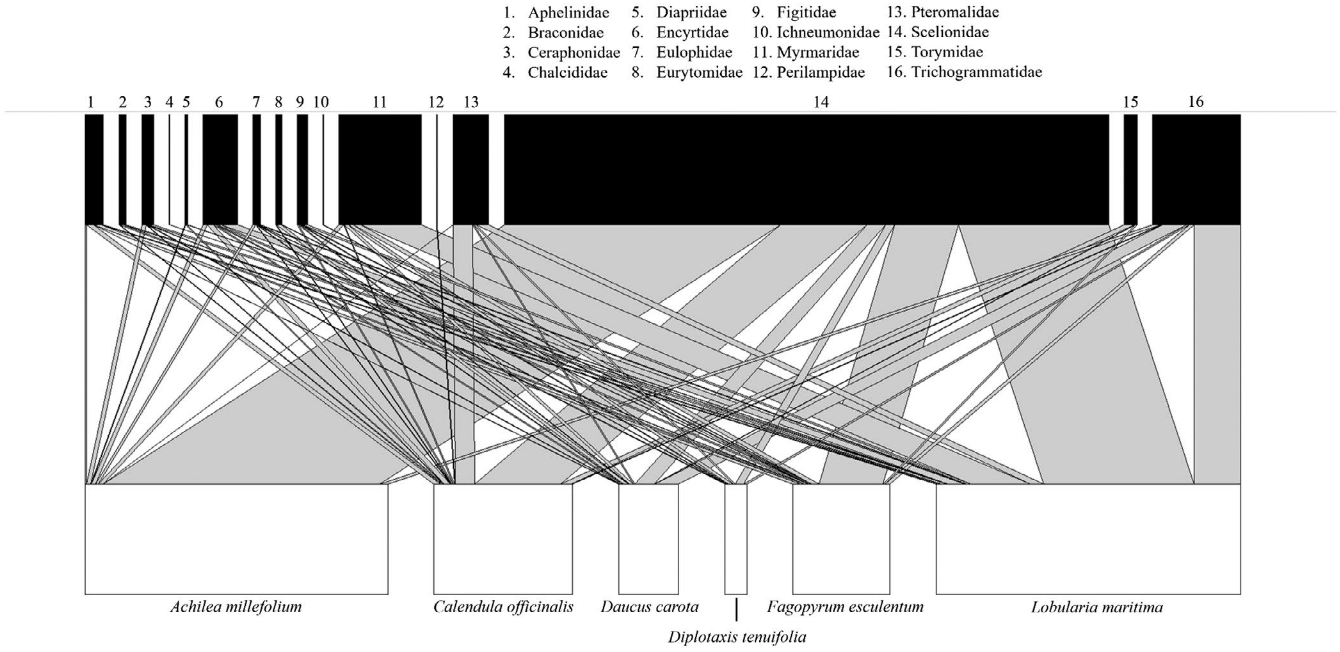

FIGURE 5 | Visualisation of parasitoid families-insectary plant species association showing interactions between plants species (white boxes) and parasitoids (black boxes) in all sampling dates combined. The width of the grey lines connecting plant species and parasitoid families is scaled to the number of interactions.

36.98% of predators was found on *L. maritima*, which remarks the suitability of this insectary plant species to attract natural enemies as indicated in previous studies (Aparicio et al. 2018; Badenes-Pérez 2018; Pease and Zalom 2010; Zuma et al. 2023). In this study, *Orius* spp. showed a natural preference for *L. maritima*, *F. esculentum*, and *A. millefolium* in the field (Table 2). Many previous studies have shown that fitness and performance of *Orius* spp. improved with the presence of insectary plants (Lundgren et al. 2009; Waite et al. 2014; YongSeok et al. 2024; Zhang et al. 2021; Zuma et al. 2023). However, to our knowledge, this is the first study that shows insectary plant species preferences by Dicyphini and *Orius* spp. in the field.

The present study also disentangles the attraction/presence of different parasitoids families to six insectary plant species in the field (Figure 5). As mentioned above, the insectary plants species *A. millefolium* and *L. maritima* were the two plants species with more presence of parasitoids (Figure 5). Specifically, Scelionidae family was the most abundant wasp family found in this study (64% of all parasitoid wasps) and were also recorded more often on these two insectary plant species. Scelionidae family is considered key in biological control programmes since most species are generally idiobiont which attack eggs of different insect orders (i.e., Hemiptera, Lepidoptera) (Orr 1988). The most important Scelionid genera relevant in the field of biocontrol are *Telenomus* Haliday, *Trissolcus* Ashmead and *Gryon* Haliday (Gard et al. 2022; Martel et al. 2019). Several studies highlighted the importance of insectary plants to improve the efficiency of these parasitoids genera in the field (Ardina et al. 2024). Our results confirm which insectary plant species are preferred by Scelionidae family in the field.

The second most abundant parasitoid families found in this study were Mymaridae and Trichogrammatidae. Both families were mostly present in autumn (~period PII, Figure 2B) on *L. maritima* (Figure 5). Most of the species belonging to these two families, Mymaridae and the majority of Trichogrammatidae, are parasitoids of eggs, and they have been used in biological control programmes in horticultural agroecosystems (Fortes et al. 2023; Chailleux et al. 2013; Pinto and Hanson 2006; Huber 1997).

Parasitoids of the Aphelinidae family were mostly found in spring (~ period PI in this study). At the same time, our results showed that this wasp family visited and/or looked for shelter on *C. officinalis* and *F. esculentum*. In our plots, inflorescences from all the insectary plant species were available and abundant in spring (~period PI). Therefore, based on our results, it might be a trend in the preference of the Aphelinidae family for plant species with large inflorescences such as *C. officinalis* and *F. esculentum*, compared with the size of the parasitoids belonging to the Aphelinidae family.

Figitidae wasps were found in all the insectary plant species except *A. millefolium*. These families comprise mainly very small wasps that are likely to have few problems in gaining access to nectar in tubular and narrow corollas (small flowers) (Jervis et al. 1993; Denis et al. 2021). Therefore, the absence of Figitidae on *A. millefolium* might be due to the lack of attraction to this plant species particularly and not by a physical barrier. In the same direction, the low presence of Aphelinidae, Pteromalidae, and Torymidae on *A. millefolium* (also families that are comprised of small wasps) might also be explained because of the lack of attraction to this plant species. The importance of conserving these parasitoid families

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in horticultural agroecosystems is crucial to enhance the biological control of horticultural crop pests. For example, some parasitoid species of the Figitidae family are parasitoids of fruit flies such as *Drosophila suzukii* Matsumura (Diptera: Drosophilae) (Marchiori 2023).

The range of insectary plants exploited by a particular parasitoid species might depend not only on floral morphology but also on other factors (Table 3). Jervis et al. (1993) summarised these factors: (i) temporal and spatial coincidence of parasitoid species flight period and the flowering period of the plant species and (ii) food plant specific attraction to wasps. Wasps may avoid visiting not only those plant species whose nectar is inaccessible but also species whose nectar is accessible but either repellent or nutritionally unsuitable. The nectar may have an unpleasant taste (Prŷs-Jones and Willmer 2008), or it may contain metabolically harmful substances (Stevenson et al. 2017; Wäckers 2001). In the selection process of an insectary plant to be included in a biological control programme other factors have to be considered such as the presence of potential pests for a specific crop, the establishment of the plant under specific climatic conditions, the water requirements that have to be in accordance with the crop where the insectary will be installed and the robustness of the insectary plant to support the management practices of a specific crop.

The results of this study confirm that the insectary plant species, *C. officinalis*, *F. esculentum* and *L. maritima* are recommended

TABLE 3 | Selected references for studies on factors affecting the selection of different floral resources (=insectary plant species) by parasitoid families.

Factors studied	Parasitoid families studied	References
Flower features	Braconidae	Vattala et al. (2006), Sivinski et al. (2011), Hatt et al. (2018)
	Chalcidoidea	Sivinski et al. (2011)
	Ichneumonidae	Idris and Grafius (1995), Sivinski et al. (2011), Hatt et al. (2018)
	Proctotrupidae	Hatt et al. (2018)
	Pteromalidae	Hatt et al. (2018)
Food quality	Braconidae	Damien et al. (2019), Vattala et al. (2006)
Host presence	—	Bianchi and Wäckers (2008)
	Aphelinidae	Rebek et al. (2006)
	Braconidae	Lewis et al. (1998), Souza et al. (2021)
Nectar supply	—	Bianchi and Wäckers (2008)
	Braconidae	Damien et al. (2019), Vollhardt et al. (2010), Araj et al. (2008)
Nectar accessibility	Aphelinidae	Denis et al. (2021)
	Braconidae	Lavandero et al. (2006), Denis et al. (2021)
	Encyrtidae	Lavandero et al. (2006)
	Eulophidae	Patt et al. (1997)
	Ichneumonidae	Lavandero et al. (2006), Denis et al. (2021)
Plant location	Braconidae	Lee and Heimpel (2005) Vollhardt et al. (2010)
Plant phenology (spatial and temporal)	Ichneumonidae	Badenes-Pérez et al. (2017)
	Ichneumonidae	Lee and Heimpel (2005)
Plant species	Aphelinidae	Araj et al. (2019)
	Braconidae	Araj and Wratten (2015), Géneau et al. (2012), Winkler et al. (2009), Jado et al. (2019)
	Encyrtidae	Sigsgaard et al. (2013)
	Ichneumonidae	Winkler et al. (2009), Idris and Grafius 1995
	—	Frank et al. (2008)
Volatiles	Braconidae	Belz et al. (2013), Souza et al. (2022)
	Encyrtidae	Foti et al. (2019)
	Platygastridae	Foti et al. (2019)

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for installation as ecological infrastructures to increase the presence of natural enemies that might enhance the biological control effects in horticultural areas in the Mediterranean. However, considering the abundance of both parasitoids and *Orius* spp. together with the agronomic factors named in the previous paragraph, *A. millefolium* would be also an excellent insectary plant because its robustness, establishment success and water requirements (personal communication by authors). Specifically, in horticultural areas of the mediterranean and based on the results obtained in this study, in order to enhance the presence of Syrphids in late spring and early summer it would be recommendable to plant *F. esculentum* and *L. maritima*, being *D. tenuifolia* an option also for spring but mostly for fall. Similarly, *L. maritima* would be an excellent option to enhance the presence of predatory thrips (Aeolothripidae), spiders (Araneae) and Chrysopidae. To enhance the presence of *Orius* spp., *A. millefolium* and *F. esculentum* would be the choice. However, to enhance the presence of Coccinellidae and predatory mirids (Dicyphini group) it would be recommendable to plant *D. carota* and *C. officinalis*, respectively. These recommendations attempt to 'engineer' agroecosystems to enhance biological control, which require an extensive knowledge of the ecology of the herbivore, its enemies, and their interactions with potential resource subsidies (Lavandero et al. 2006).

Author Contributions

Francesc Gómez Marco: writing – original draft, validation, visualization, writing – review and editing, formal analysis, data curation. **Valmir A. Costa:** data curation, writing – review and editing. **Carmen Denis:** conceptualization, investigation, methodology, visualization, validation, writing – review and editing, data curation. **Paula Molina:** investigation, writing – review and editing,validation. **Rosa Gabarra:** conceptualization, funding acquisition, project administration, resources, supervision. **Jordi Riudavets:** resources, supervision, data curation, project administration, writing – review and editing, visualization, validation, methodology, conceptualization. **Judit Arnó:** conceptualization, investigation, wirting – review and edtiting, project administration, resources, supervision, data curation, methodology, validation.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are openly available in CORA Repositori de dades de recerca at https://doi.org/10.34810/data2915.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Table S1:** Insectary plant species sown, transplants and prune dates.

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