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Short Communication

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Ground-cover vegetation composition shapes the abundance of *Sphaerophoria scripta* (Diptera: Syrphidae) in Mediterranean olive groves

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The ground-cover vegetation, commonly found in olive groves, provides shelter and vital floral resources for syrphids. Such resources can contribute to syrphids' growth, development, reproduction, and survival, allowing them to maximize their function as natural pest enemies, pollinators, and decomposers of organic matter. Therefore, identifying the flowering plant families driving the abundance of *Sphaerophoria scripta* Linnaeus, 1758, is essential to promote its presence and abundance. Here, we described the flowering plants present in the vegetation cover of olive groves and studied how these flowering plant families shape the abundance of *S. scripta*. A total of 90 plant species belonging to 20 families were identified. Asteraceae was the dominant flowering family, followed by Poaceae. The generalized linear model showed that the presence of flowering plants of the families Campanulaceae, Asteraceae, Orobanchaceae, and Plantaginaceae in the ground-cover vegetation promotes the abundance of *S. scripta* in olive groves. Conversely, flowering plants of the families Poaceae and Polygonaceae were associated with the decreased abundance of this syrphid species. Our results suggest that increasing particular plant families and decreasing others in the ground-cover vegetation may favor *S. scripta* abundance in the Mediterranean olive groves.

Key words: Asteraceae, flowering plants, *Olea europaea*, Poaceae, syrphids

Graphical Abstract

Introduction

Olive, *Olea europaea* L. (Oleaceae), an emblematic evergreen tree in the agricultural landscapes of the Mediterranean basin, frequently faces threats from insect pests that can significantly reduce production yields. However, the presence of beneficial insects can be essential to reduce pest populations to acceptable levels and provide other important ecosystem services (Ricarte et al. 2011, Villa et al. 2021).

Syrphids (Diptera: Syrphidae) are beneficial insects found in olive groves. They contribute to natural systems as pollinators, decomposers, and predators of pests present in the crop (Sacchetti 1990, Villa et al. 2021). *Sphaerophoria scripta* L. is a widespread and abundant syrphid in a wide range of crops and habitats (e.g., Ricarte et al. 2011, Wojciechowicz-Żytko and Jankowska 2017, Villa et al. 2021) being previously identified as one of the most abundant syrphids in Mediterranean olive groves (Villa et al. 2021). Moreover, this Dipteran has acquired particular attention as a potential biocontrol agent since it is globally distributed (Raymond et al. 2013) and because there are reports of *S. scripta* larvae feeding on more than 30 genera of aphids (Hemiptera: Aphididae), psyllids (Hemiptera: Psyllidae), and larvae of Lepidoptera (Rojo et al. 2003). As adults, *S. scripta* visit flowers between spring to autumn in open terrain and settle in ground-cover vegetation (Speight 2017). However, *S. scripta* is a partially migratory species, mainly in late spring; in other words, a part of the population remains in summer habitats and hibernates in the larval, pupal, or adult stages while the rest of the population moves south to milder climatic conditions (Raymond et al. 2013).

In general, ground-cover vegetation in perennial crops increases the diversity and abundance of natural enemies (Silva et al. 2010), which contributes to the biological control of crop pests (Wojciechowicz-Żytko and Jankowska 2017). In contrast to tillage, this soil manipulation technique offers natural enemies food resources—pollen, nectar, and honeydew, as well as prey-altered microclimate, habitat, and shelter for estivation (Silva et al. 2010).

Syrphids are considered generalists regarding flower visits; however, despite being generalists, there are reports that they tend to prefer certain plant species (e.g., Klecka et al. 2018). Moreover, flowers attract pollinators through distinct stimuli, such as color, shape, size, and scent (Fenster et al. 2004). Understanding how the vegetation cover influences the abundance of syrphids is essential to implement measures that promote their presence and abundance in agroecosystems and, consequently, maximize their ecosystem services. Here, we described the Syrphidae community in Mediterranean olive groves and determined how the flowering ground-cover vegetation composition shaped the abundance of *S. scripta*.

Materials and Methods

Study Area

We conducted the study in 2 olive groves of the "Cobrançosa" cultivar, each covering an area of 3 ha, located in Cedães (Mirandela, Northeast of Portugal) (41°29′15.77″N, 7°07′52.11″W; 41°29′217.88″N, 7°07′35.21″W). The olive groves were nonirrigated and maintained under integrated production management. Tree spacing varied between 7 and 9 m, and the age of the trees varied between 18 and 80 yr. The olive tree is the dominant crop in the study area.

Sampling Methods

From May to 1 August 2018, we identified the flowering plant family/species of the ground-cover vegetation of the olive groves and recorded the number and species of adult syrphids on a weekly basis. All samplings were performed on days without rain between 8:00 AM and 14:00 PM.

For plant family/species identification, we randomly distributed 30 rectangular sampling units (100 × 25 cm) along a 100-m diagonal transect covering approximately 1.0 ha (Fig. 1). Within each rectangular

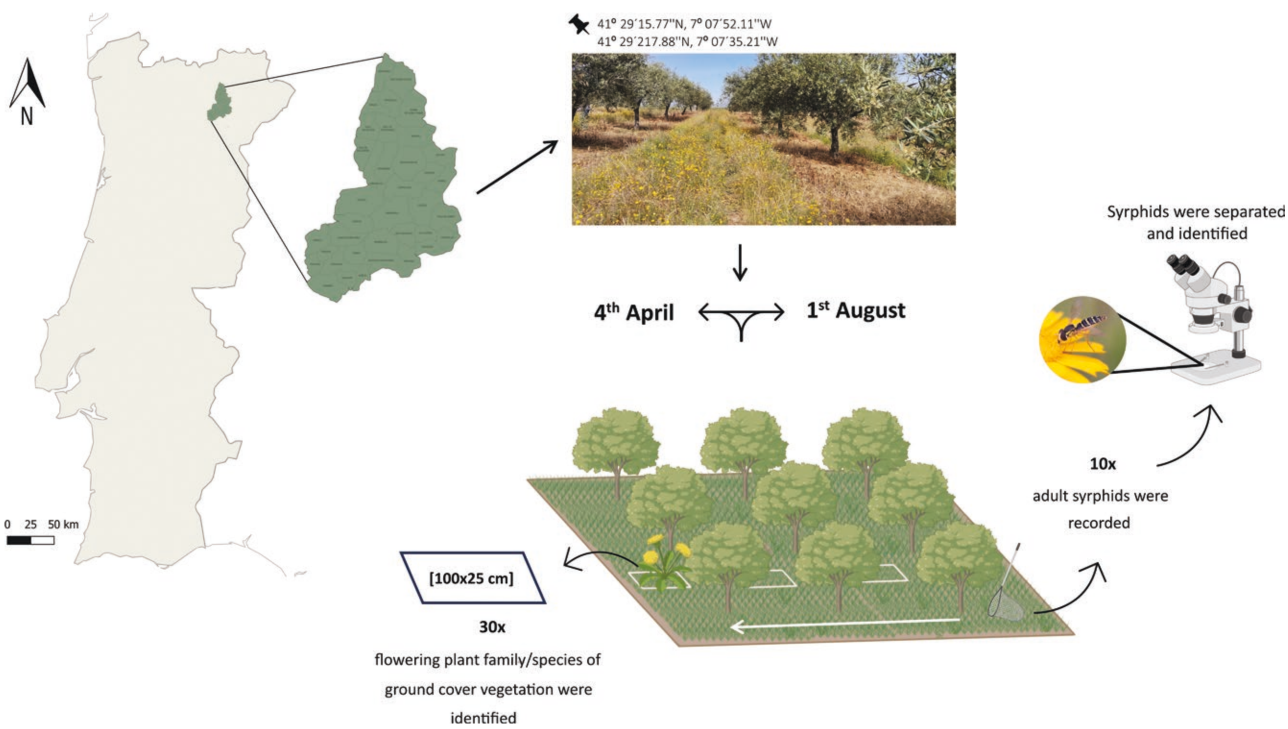

Fig. 1. Schematic drawing of the sampling methods.

sampling unit, we recorded only the plant species with open flowers and their respective percentage of ground cover. We consulted Aizpuru et al. (2007) for plant identification. We constructed a heatmap using the superheat package in R (v4.2.2; R Core Team 2023) following Barter and Yu (2018), to visualize the percentage of ground cover of flowering plants over the sampling dates.

We collected syrphids randomly over 1.0 ha using a standard entomological sweep net (38 cm diameter). We performed 10 samples, each comprising 20 consecutive sweeps on the vegetation cover of each olive grove. Subsequently, we transferred the contents of each sample into plastic bags and introduced 0.3 mL of diethyl ether into each bag to euthanize the arthropods. The samples were then transported to the laboratory and frozen at −20 °C. We used a stereomicroscope (Leica EZ4, Leica Microsystems, GmbH, Wetzlar, Germany) to separate and identify the syrphids (Fig. 1). Identification of adult syrphids was conducted according to appropriate entomological keys (Gilbert 1986, Speight 2020, Speight and Courey Wiliams 2021), and the functional groups of each identified syrphid species were described (Wojciechowicz-Żytko and Jankowska 2017).

Response of *S. scripta* to Flowering Plant Families

Sphaerophoria scripta was one of the most abundant Syrphid species recovered in the Mediterranean olive groves we sampled from. Thus, we assessed the response of *S. scripta* (Villa et al. 2021) to the percentage of ground cover of the flowering plant families with a generalized linear model (GLM) with Poisson distribution. We used the abundance of *S. scripta* as the response variable and the percentage of ground cover of the plant families as explanatory variables. The remaining syrphid species recorded were excluded from further analysis since they showed scarce abundance, thus avoiding overinterpretation of the data. The plant families Apiaceae, Hypericaceae, Lamiaceae, Solanaceae, and Violaceae were not included in the model because they represented a cover percentage lower than 1% across samples.

Before running the model, we checked the plant families for multicollinearity; we calculated principal component analyses (PCA) and Pearson correlations. To visualize the contribution to the variance of the plant families and their relations (Supplementary Fig. S1), we used the PCA function from the "FactoMineR" package (Lê et al. 2008) and the function cor from base R to calculate and visualize the Pearson correlations (Supplementary Fig. S2). To further assess multicollinearity, we calculated the variance inflation factor (VIF): the highest VIF scores were below 4 (the common threshold for VIF is usually >10; Dormann et al. 2013). When multicollinearity was found among plant families, we selected those with which *S. scripta* was reported to interact, as previously presented by Villa et al. (2021).

We selected the model by comparing the Akaike information criterion (ΔAIC) (Akaike 2011) with the null model. Thus, the final model comprises the families: Campanulaceae, Asteraceae, Orobanchaceae, Plantaginaceae, Poaceae, Polygonaceae, and Rosaceae. The model was checked for overdispersion and residual distribution using the "DHARMa" package in R (Hartig 2023).

Results

Syrphids

In total, 212 syrphid adults (Syrphidae: Diptera) were recovered (Table 1). The most abundant species were *S. scripta* (198 specimens), followed by *Melanostoma mellinum* Linnaeus 1578 (7 specimens).

Sphaerophoria scripta showed a peak of abundance in June (112) followed by July (70). In the first 3 wk of sampling and the last 2, the number of *S. scripta* individuals was almost zero (Fig. 1).

Ground-Cover Plants

In total, 90 plant species belonging to 20 families were identified (Supplementary Table S1). During the sampled period, Asteraceae was the dominant flowering family, comprising 50.90% of observations, followed by the families Poaceae (12.81%), Fabaceae (12.71%), and Caryophyllaceae (7.04%). Asteraceae, on June 27th, reached maximum flowering with 21.63% of observations (Fig. 2).

Response of *S. scripta* to Flowering Plant Families

According to our results, increasing the ground coverage percentage of the olive grove with plants of the families Campanulaceae, Asteraceae, Orobanchaceae, and Plantaginaceae promotes the abundance of *S. scripta* (Table 2, Fig. 3). On the opposite side, increasing the ground coverage percentage with plants of the families Poaceae and Polygonaceae was associated with the decreased abundance of *S. scripta* (Table 2 and Fig. 3).

In the 6 families that affect the abundance of *S. scripta*, a total of 43 plant species were identified. Asteraceae, with 21 species of flowering plants, was the family with the highest number of identified plant species, with 15%, including *Cnicus benedictus* L., *Coleostephus myconis* (L.) Rchb.f., and *Logfia gallica* (L.) Coss. & Germ. The plant species *Cynodon dactylon* (L.) Pers. (Poaceae), *Hordeum murinum* subsp. *leporinum* (Link) Arcang. (Poaceae), and *Rumex bucephalophorus* L. (Polygonaceae) covered the ground with percentages greater than 15% on certain dates. Contrary, *Rumex induratus* Boiss. & Reut. (Polygonaceae), *Plantago lanceolata* L. (Plantaginaceae), *Misopates orontium* (L.) Raf. (Plantaginaceae), Orobanche sp. (Orobanchaceae), *Orobanche ramosa* L. (Orobanchaceae), and *Senecio vulgaris* L. (Asteraceae) were the species of plant identified with less abundance (1%).

Table 1. The abundance of Syrphidae in herbaceous vegetation cover across 2 sampled olive groves from May to August of 2018

Syrphid species	FG	May	June	July	August	Total
Eupeodes corollae Fabricius, 1794	Pr/P		1 (0/1)			1 (0/1)
Melanostoma mellinum Linnaeus, 1758	Pr/P			7 (6/1)		7 (6/1)
Melanostoma scalare (Fabricius, 1794)	Pr/P		1 (0/1)			1 (0/1)
Sphaerophoria rueppelli Wiedemann, 1830	Pr/P	1 (0/1)	1 (1/0)			2 (1/1)
Sphaerophoria scripta Linnaeus, 1758	Pr/P	11 (4/7)	112 (60/52)	70 (36/34)	5 (2/3)	198 (102/96)
Syrphidae spp.	NA/P		1	2		3
Total		12 (4/8)	116 (61/54)	79 (42/35)	5 (2/3)	212 (109/100)

The functional group (FG) is indicated (P: pollinator adult; Pr: predatory larva; NA: not identified). The number of females and males is shown between brackets: (number of females/number of males).

Fig. 2. Heatmap plot showing the percentage of ground cover of each plant family in full bloom identified in the ground-cover vegetation of the 2 olive groves under study and the mean and respective standard error of *Sphaerophoria scripta* in the 2 olive groves by sampling date.

Table 2. GLM outputs testing the response of *Sphaerophoria scripta* abundance to the coverage of Campanulaceae, Asteraceae, Orobanchaceae, Plantaginaceae, Poaceae, Polygonaceae, and Rosaceae plants

Variables	Estimate	SE	*z*-value	*P*-value
(Intercept)	0.66	0.3	2.22	0.02
Campanulaceae	0.92	0.1	9.2	<0.001
Asteraceae	0.08	0.03	3.24	0.001
Orobanchaceae	3.38	0.81	4.17	<0.001
Plantaginaceae	2.21	0.43	5.11	<0.001
Poaceae	−0.2	0.05	−3.75	<0.001
Polygonaceae	−2.98	0.76	−3.93	<0.001
Rosaceae	−1.33	0.97	−1.38	0.17

Discussion

Analyzing how flowering plants shape the abundance of *S. scripta*, one of the main syrphids associated with the Mediterranean olive grove, can be helpful information to farmers to promote the abundance of this species in the olive groves since they are essential pollination agents (to both wildflowers and economically important crops) and offer biological pest control (Sacchetti 1990, Villa et al. 2021).

Typically, *S. scripta* begins its flight period in April (Speight 2017). Although we did not have data for that period, our results showed 1 abundance peak in June, starting to decrease in at the end of July, which is in accordance with what was previously reported by Djellab et al. (2019), Rossi et al. (2006), and Villa et al. (2021).

The abundance and diversity of natural enemies, such as syrphids, are affected by the diverse composition of the agricultural landscape (Madureira et al. 2022). The herbaceous vegetation present in the perennial crops represents an essential source of pollen, nectar, and refuge for the syrphids (Speight 2017). Our results indicated that the abundance of *S. scripta* was positively influenced by some plants of the herbaceous vegetation present in the olive groves, namely: Asteraceae, Campanulaceae, Orobanchaceae, and Plantaginaceae.

Studies by Villa et al. (2021), Gibson et al. (2006), and Klecka et al. (2018) consistently reported the attraction of *S. scripta* to plants of the Asteraceae. The dominance of yellow and white colors in Asteraceae flowers is known to elicit feeding in syrphids (Speight 2017, Amy et al. 2018). Plants of the Campanulaceae, particularly *Jasione montana* L., were also identified as common food resources for *S. scripta*, although less consumed compared to Asteraceae (Speight 2017, Villa et al. 2021). Moreover, the flowers of *J. montana* have shades of blue and lilac, colors known to attract pollinators such as *S. scripta* (de Buck 1990).

Additionally, some studies have reported the presence of *S. scripta* on plants of the Orobanchaceae, with *Bartsia trixago* L. showing a notable correlation with the abundance of *S. scripta* (de Buck 1990). Direct observations of feeding preference trials could further validate the significance of this association. Moreover, *S. scripta* has been documented to feed on plants from the Plantaginaceae and

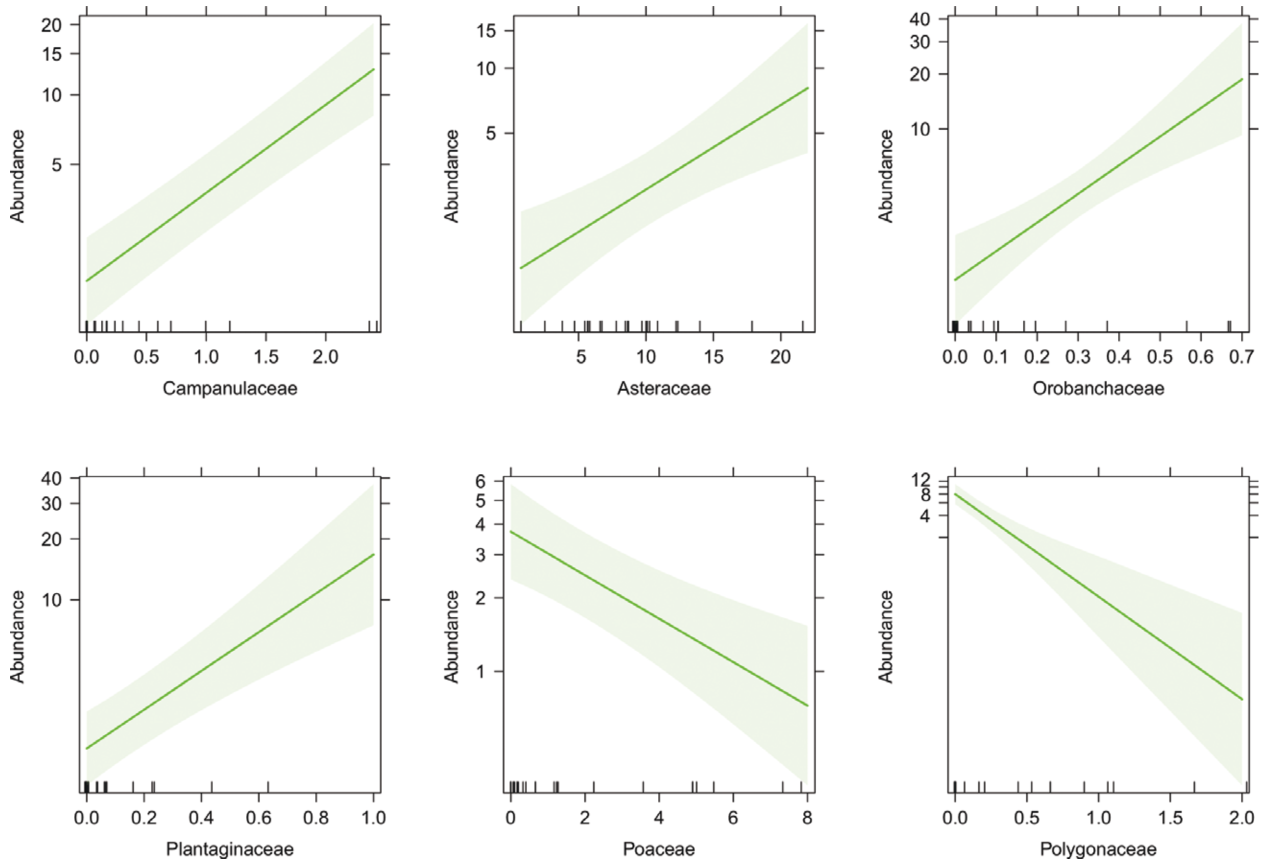

Fig. 3. Response of *Sphaerophoria scripta* to the percentage of ground cover of flowering plants of the families Campanulaceae, Asteraceae, Orobanchaceae, Plantaginaceae, Poaceae, and Polygonaceae. Plots include model estimate and 95% confidence interval of the GLM (response variable—*Sphaerophoria scripta* abundance; explanatory variable—plant family abundance; data distribution—Poisson).

Melanostoma mellinum Linnaeus, 1758, another abundant syrphid that also frequents Plantaginaceae plants (de Buck 1990, Rossi et al. 2006, Klecka et al. 2018, Villa et al. 2021).

Conversely, the families Poaceae and Polygonaceae were associated with the reduced abundance of *S. scripta* in olive groves. These anemophilous plants tended to flower earlier than animal-pollinated species, possibly leading to a mismatch in flowering time with *S. scripta*'s peak abundance. While *S. scripta* males carry pollen from Poaceae and Polygonaceae, their development cycle may not align with the availability of these plants (Gilbert 1986, Saunders 2018). However, further studies are necessary to fully understand this relationship.

The remaining families of flowering plants identified in this study showed no significant effect on the abundance of *S. scripta*. However, reports suggest occasional visits or feeding by *S. scripta* on plants from families such as Apiaceae, Euphorbiaceae, Lamiaceae, and Rosaceae (Speight 2017). This might be attributed to factors like pollen or nectar availability or plant fitness (Speight 2017).

Understanding the influence of different flowering plant families on the abundance of *S. scripta* can inform more sustainable management practices, such as promoting ground-cover plant species that benefit the presence of *S. scripta*. Moreover, enhancing *S. scripta* and other syrphid species can contribute to greater biological control of pests in Mediterranean olive groves.

Author contributions

Marta Madureira (Formal analysis [equal], Investigation [equal], Methodology [equal], Validation [equal], Writing—original draft [equal], Writing—review & editing [equal]), Isabel Rodrigues (Conceptualization [equal], Formal analysis [equal], Investigation [equal], Methodology [equal], Supervision [equal], Writing—review & editing [equal]), and Jose Alberto Pereira (Conceptualization [equal], Funding acquisition [equal], Investigation [equal], Resources [equal], Supervision [equal], Writing—review & editing [equal])

Supplementary data

Supplementary data are available at *Journal of Insect Science* online.

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