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RESEARCH ARTICLE

Flower strips and remnant semi-natural vegetation have different impacts on pollination and productivity of sunflower crops

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Abstract

1. Intensification of agricultural landscapes to fulfil increased global food demands has dramatically impacted biodiversity and ecosystem services. Several pollinator groups, which are vital for the maintenance of pollinator-dependent crops, have been severely affected by this intensification process. Management tools, such as the implementation of agri-environmental schemes, have been widely proposed to improve pollinator's communities and pollination services, although the effectiveness of wildflower strips in comparison to existing natural or semi-natural habitats and the impact on yield has not been fully demonstrated.
2. Here, we aimed to assess the effect of flower strips implementation near sunflower fields in two intensive agricultural regions and to quantify their impact on visitation rates and sunflower productivity. Data were obtained in two regions in Spain (Burgos and Cuenca) in sunflower fields with associated semi-natural vegetation (SNVs), with implemented wildflower strips (WFSs) and without vegetation structures (NonVs). Visitation rates were monitored over 2 years by direct observations, and both sunflower seed production and weight were assessed in 52 fields per year.
3. Our results revealed regional and inter-annual variation in visitation rates, likely driven by structural differences in the landscapes studied. In Cuenca, characterized by more heterogeneous and floral resources-richer landscapes, the effects of WFSs were significant in the second year of implementation, with higher visitation rates and productivity values in fields with implemented wildflower strips compared to those without. In contrast, in Burgos, no consistent effects among field treatments between years were observed.

4. *Synthesis and applications*. The implementation of flower strips or maintenance of remnant semi-natural habitats adjacent to sunflower fields showed context-dependent effects on pollinator visitation rates and crop yield. In highly simplified agroecosystems, these interventions may be insufficient or may need longer times to produce significant effects. Yet, in regions where natural and semi-natural patches were already present, the implementation of flower strips was a successful strategy to promote pollinators and sunflower productivity.

KEYWORDS
Agri-environmental schemes, agroecosystems, flower strips, pollinators, semi-natural vegetation, sunflower, visitation rates, wild bees

1 | INTRODUCTION

Habitat destruction, mainly caused by urbanization, agricultural intensification and pesticide use, is among the most important causes of biodiversity loss of insect pollinators (Powney et al., 2019; Purvis et al., 2019; Raven & Wagner, 2021; Wagner, 2020). Agri-environmental actions within modified landscapes, such as the implementation of field margins or restoration of hedgerows (Albrecht et al., 2020; Blaauw & Isaacs, 2014; Kleijn et al., 2019; Sutter et al., 2018) can offer abundant forage resources (Mandelik et al., 2012; Nicholls & Altieri, 2012) and nesting sites for insect pollinators (Blaauw & Isaacs, 2014; Marshall & Moonen, 2002; Morandin & Kremen, 2013; Purvis et al., 2019), supporting biodiversity conservation. Additionally, natural or implemented field margins seem to work as ecological corridors, linking isolated habitat patches and reducing landscape fragmentation (Purvis et al., 2019). For example, insect pollinators with less mobility benefit from the close proximity of crop fields to these flower margins (Garibaldi et al., 2011, 2014; Morandin et al., 2007; Purvis et al., 2019). Restoration of fields with improved floral resources and nesting sites now has a relevant scientific basis for improving densities of pollinators (Balzan et al., 2014; Blaauw & Isaacs, 2012, 2014; Bommarco et al., 2012; Garibaldi et al., 2014; Schmied et al., 2022). Yet, we still lack field information on how different restoration strategies can mitigate wild pollinator's loss to ensure high crop yields.

In Europe, a biodiversity strategy has been adopted within the member state countries that includes specific goals to enhance green infrastructures, defined as '*a strategically planned network of natural and semi-natural areas (…) designed and managed to deliver a wide range of ecosystem services*' (European Commission, 2020). Thus, current agri-environmental schemes offer incentives to farmers for the implementation of environmentally friendly farm practices. Measures proposed to promote pollinator communities and pollination services within intensive agricultural landscapes include the management of uncultivated field boundaries and less-managed natural habitats near crop fields (Blaauw & Isaacs, 2014; Mandelik et al., 2012; Söderman et al., 2016) or the establishment of floral strips using seed mixtures of melliferous plants that are attractive to bees (Scheper et al., 2015). Yet, the usefulness of implemented wildflower strips versus conserving patches of semi-natural vegetation is still debated by the European Union (European Commission, 2020). A recent study showed that both agri-environmental strategies in highly patched landscapes dominated by sunflower fields might contribute to maintaining taxonomic and functional traits of wild bees (Hevia et al., 2021), although lacking the link with crop productivity. Thus, it remains essential to test the effectiveness of different types of agri-environmental measures on intensively managed agroecosystems to promote pollinator communities, pollination services and final crop yield.

Hedgerows and flower margins have been associated with an increase in the richness and density of pollinator species and, thus, they have been recommended as a conservation action for pollinators (Garibaldi et al., 2014; Kremen et al., 2019; M'Gonigle et al., 2015; Schmied et al., 2022; Sutter et al., 2017). However, the effect of these landscape features on crop yield remains controversial, with positive effects in some case studies (e.g. Balzan, 2017; Blaauw & Isaacs, 2014; Campbell et al., 2017; Tschumi et al., 2016), but without significant effects in others (as reviewed in Albrecht et al., 2020; Kremen et al., 2019; Zamorano et al., 2020). This might be because, on the one hand, hedgerows and flower margins can work as reservoirs of pollinators that may spill over to crop fields and provide pollination services to targeted crops ('exporter' hypothesis; Kremen et al., 2019; Morandin & Kremen, 2013); while, on the other hand, they may have a sink effect on the crop edge, hindering the dispersal of pollinators to the field ('Circe principle', Lander et al., 2011; 'aggregation' hypothesis, Venturini et al., 2017; or 'concentrator' hypothesis, Kremen et al., 2019). Indeed, while recent reviews have found that pollinators and pollination services increase in sites with enhanced flower margins, these effects have been mainly observed at the flower margin or adjacent edge with no spillover effects inside the field and with no clear impacts on final crop yield (Albrecht et al., 2020; Kremen et al., 2019; Zamorano et al., 2020). Additionally, the success of flower margins is also influenced by crop type, landscape structure, flower margin size, age and composition, and for studies targeting specific crops, it would be desirable to disentangle the individual effects of these factors (Albrecht et al., 2020; Blaauw & Isaacs, 2014; Morandin et al., 2016; Nicholson et al., 2018; Sardiñas & Kremen, 2015; Sutter et al., 2018; Zamorano et al., 2020).

The aim of this study was to assess the effectiveness of establishing temporary floral patches in association with a pollination-dependent crop, sunflower *Helianthus annuus* L., to protect pollinator communities and increase crop productivity as a ground-testing strategy to promote better adoption of agri-environmental schemes. In particular, we tested the effectiveness of wildflower strips established by farmers in comparison with the effectiveness of already existing patches of semi-natural vegetation and with the lack of vegetation features defined as a control situation. This was tested in sunflower fields in two intensive agricultural regions in southern Europe (Burgos and Cuenca, Spain) during two consecutive years (2017 and 2018) to address the following questions: (a) how does different field margin management impact visitation rates by honeybees and wild bees to sunflower crops?; (b) how does different field margin management impact sunflower yield measured as seed number and weight?; and (c) how does visitation rates and sunflower productivity vary with the distance to different field margin management? We expected that the presence and lower distance to vegetation-rich field margins, in particular to wildflower strips, would improve the pollination services on sunflower fields with subsequent positive impacts on sunflower productivity.

2 | MATERIALS AND METHODS

2.1 | Study sites and experimental design

The experiment was carried out in 104 sunflower fields (52 fields in each year, see Table S1) from two distinct regions, Burgos and Cuenca (northern and central Spain, respectively, Figure 1), from February to September 2017 and 2018. Data were only collected in areas where explicit permission was provided by land managers. Our study did not require ethical approval to sample pollinators in those areas. Sunflower is an allogamic plant, and thus, it depends on pollination services for producing seeds (Chambó et al., 2011).

In Burgos, the experiment involved contrasting three different landscape structures in the immediate vicinity of sunflower fields (30 in total): 10 fields with patches of semi-natural vegetation (SNVs) adjacent to the sunflower field; 10 fields with implemented wildflower strips (WFSs) adjacent to the sunflower field; and 10 fields without vegetation (NonVs) in the margin of the sunflower field (Figure S1). Regional details about landscape characterization and climatic conditions are provided in Table S2.

In Cuenca, although the landscape is intensively used for agriculture (Table S2), it is also marked by the presence of frequent

FIGURE 1 Aerial images of the sampling regions: (a) location of Burgos and Cuenca regions; (b) municipalities sampled in Burgos and (c) municipalities sampled in Cuenca.

patches of natural vegetation, hindering the possibility to find sunflower fields without adjacent vegetation. Thus, only the following two treatments were considered: 11 fields with semi-natural vegetation (SNVs) and 11 fields with implemented wildflower strips (WFSs), totalling 22 fields. Details on field selection criteria and sunflower varieties are provided in Tables S1 and S3, respectively.

On each field, a total of 32 sunflowers were marked at four different distances from the field margin with the treatment: 0, 15, 30 and 60 m, with eight sunflowers per distance separated by 15 m each (Figure S1A). This design enabled us to explore the effect of the distance to field margins with different management treatments on the studied parameters. The pollinator's observations and productivity were evaluated at these distances. We focused on both managed and wild bees as they represent the key pollinator guilds in sunflower (Greenleaf & Kremen, 2006; Mallinger & Prasifka, 2017).

2.2 | Implementation of wildflower strips

Wildflower strips were implemented in the fields assigned for the WFS treatment, following the same procedure in both regions. The seed mixture used was based on the 'Operation Pollinator' program of Syngenta, modified in terms of species composition and abundance according to expert opinion. Thus, the mixture comprised plant species that successfully germinate and grow in both regions, have morphologically and phenologically distinct flowers and provide diverse food resources for pollinators throughout an extended period of flowering (Table S4). The floral mixture was sown in the WFS plots in March 2017 and resown in February 2018. In 2018, the floral composition of the mixture and the relative abundance of each species was adjusted based on germination success and growth patterns observed in 2017 to obtain similar abundances among plant species. In both regions, WFSs flowered already in the first year, that is, late Spring and Summer of 2017.

In Burgos, the WFSs were designed as a rectangle of 0.23 ha (approximately 100 m long and 25 m wide; Table S5), although in some cases, the WFS had to be adjusted to the shape of the field. In Cuenca, all WFSs had 0.12 ha (100 m long and 12 m wide).

2.3 | Pollinator observations

During the peak of the sunflower flowering period (July–August 2017 and 2018), pollinators were monitored through direct observations to assess visitation rates on sunflower fields. Due to time constraints imposed by the short flowering period of this crop (approximately 10 days within each region), in Burgos, this task was performed in 20 fields (all WFS fields, five SNV fields and five NonV fields), while in Cuenca, it was possible to monitor all the 22 fields. The observation plots were centred in the marked sunflower, thus including observations at all distances from the field margin. The observer walked slowly along a row perpendicular to the field margin and was positioned at approximately 2 m from the marked sunflower, being able to register every plant–pollinator interaction without disturbing the pollinator's activity. Visits were recorded in 1 min census from 9 to 20 hr (GMT) (observation efforts are provided in Table S6). During each census, the following variables were registered: visiting bee species, the total number of sunflowers monitored, the total number of sunflowers effectively visited and the number of interactions, defined as a shift between sunflower plants. Whenever possible, wild bees were photographed and captured for further identification in the laboratory.

2.4 | Sunflower productivity

In mid-September 2017 and 2018 (when seeds were already mature), all marked sunflower flower heads were collected, air-dried and stored. Productivity was quantified in a quarter of the flower head and subsequently extrapolated for the entire head. The total number of florets (not fertilized), empty seeds and full seeds were counted. Finally, full seeds were dried at 68°C for 48 hr and weighed in a precision scale (up to milligrams).

2.5 | Data analyses

To understand the effect of different field margin management associated with sunflower crops on visitation rates and sunflower productivity, generalized linear mixed models (GLMMs) were used. Field ID was used as a random factor for all analyses performed. Because it was not possible to obtain information about the varieties cultivated in some fields in Cuenca, this factor was only included as a random factor in the analyses from the Burgos region. The explanatory variables were as follows: year (2017 and 2018), region (Burgos and Cuenca), field treatment (Burgos: SNV, WFS and NONV; Cuenca: SNV and WFS) and distance to the field margin (0, 15, 30 and 60 m). First, we explored differences between regions and years, including them as the only factors (Figure S2; Table S7). Then, we explored differences among field treatments and distances for each region separately due to the inexistence of NonV fields in Cuenca; for that, a nested design was employed, with field treatment being nested within year and distance being nested within field treatment. The response variables used to describe visitation rates (direct observations data) were as follows: total visitation rate, honeybee visitation rate and wild bees' visitation rate; a square root transformation was applied to these variables [SQRT($x+0.5$)] and a Gamma distribution with an identity link function was used to model the response variables. The response variables to describe sunflower productivity were as follows: the total number of seeds and the weight of 100 seeds. The total number of seeds was analysed using a Poisson distribution with a log link function, including the total number of reproductive units (sum of the total number of non-fertilized florets, empty seeds and full seeds per sunflower flower heads) defined as an offset variable. The weight of 100 seeds was analysed using a Gaussian distribution with an identity link function. Finally, regression analyses using

honeybee visitation rate and wild bees' visitation rate as predictors were used to explain sunflower productivity (response variables fitted as described above) for each region, including field ID as a random factor. Model validation was performed by visual inspection of the residuals for checking heteroscedasticity and normality (Zuur et al., 2009). Statistical analyses were performed in R version 4.0.2 (R Core Team, 2014) using the packages 'car' with Type-III analysis of variance (Fox et al., 2015), 'nlme' for linear and nonlinear mixed models (Pinheiro et al., 2020), 'multcomp' for multiple comparisons after Type-III analysis of variance (Hothorn et al., 2017) and 'emmeans' for obtaining estimated marginal means (R Core Team, 2014).

3 | RESULTS

3.1 | Effect of field margin treatments on pollinator visitation rates

The management of field margins produced different results in each of the studied regions (Burgos: Figure 2 and Table 1; Cuenca: Figure 3 and Table 2). In Burgos, we observed significant differences only for wild bee visitation rates between field treatments within years (Table 1). However, these differences were not consistent across years (Figure 2). Significant differences in wild bee's visitation rates were only observed in 2018: SNV fields presented significantly lower wild bees visitation rates than WFS fields ($p < 0.05$), and NonV fields had intermediate values (Figure 2c).

In Cuenca, we observed a weak effect of WFS implementation in the first year, but differences emerged in the second year. Significant differences between field treatments within a year were observed for all visitation rate's variables (Table 2). However, different patterns were observed between years (Figure 3): in 2017, differences were only observed for total visitation rate, with SNV fields having significantly higher total visitation rates than WFS fields (Figure 3a); in 2018, the WFS fields presented significantly higher values than SNV fields for all visitation rate's variables analysed (Figure 3).

3.2 | Effect of field margin treatments on yield

The management of field margins produced different results in each of the studied regions (Burgos: Figure 2 and Table 1; Cuenca: Figure 3 and Table 2). In Burgos, significant differences between field treatments within years were observed only for the total number of seeds (Table 1). However, these differences were not consistent across years (Figure 2). Total number of seeds revealed significant differences only in 2017, with SNV fields having significantly higher values than WFS fields ($p < 0.05$), and NonV fields having intermediate values (Figure 2d). Additionally, the total number of seeds was significantly and positively impacted by honeybee visitation rates, while no impacts of honeybee visitation rates were detected in sunflower yield (Table 3).

In Cuenca, we observed a weak effect of WFS implementation in the first year, but differences emerged in the second year. Significant differences between field treatments within a year were observed for both total number of seeds and weight (Table 2). However, the WFS fields presented significantly higher values than SNV fields for both productivity variables analysed only in 2018 (Figure 3). Additionally, wild bee's visitation rates impacted significantly and positively both the total number of seeds and the weight of 100 seeds, while honeybee visitation rates impacted significantly and positively the total number of seeds (Table 3).

3.3 | Effect of distance to the field margin treatments

In Burgos, differences among distances within field treatment were observed only for productivity variables (Table 1; Figure S3). Sunflowers in the field margin (distance 0) tended to have higher productivities than the remaining points within the field (Figures S3D,E).

In Cuenca, significant differences among distances within field treatment were observed for all variables studied, except for the total number of seeds (Table 2; Figure S4D). Overall, the visitation rates tended to decrease with increasing distance to the field margin. Significant differences were observed for all variables in the SNV fields, whereas in WFS fields, this was only observed for wild bee visitation rates (Figure S4C). The weight of 100 seeds revealed an opposite pattern in SNV fields, with a slight increase in seed weight with the increase in the distance to the field margin (Figure S4E).

4 | DISCUSSION

4.1 | How does different field margin management impact pollinator visitation rates and yield of sunflower crops?

The implementation of wildflower strips impacted differently the visitation rates by pollinators and the sunflower yield in each study region. In Burgos, there were no consistent effects of field treatments across years. In contrast, in Cuenca, no significant effects were detected in the first year, but such effects became statistically significant in the second year, with sunflower fields adjacent to wildflower strips having higher visitation rates and yields compared to fields only with remnants of semi-natural vegetation. The results from Cuenca support the importance of wild floral strips implementation as an agri-environmental action to improve pollination services in adjacent crop fields. However, given the inconsistency of results from Burgos, and the fact that positive results in Cuenca were only observable in the second year, our results also suggest that the effects of these management actions might be context dependent, either needing different timings to generate evident benefits or even being insufficient to produce consistent improvements (discussed below).

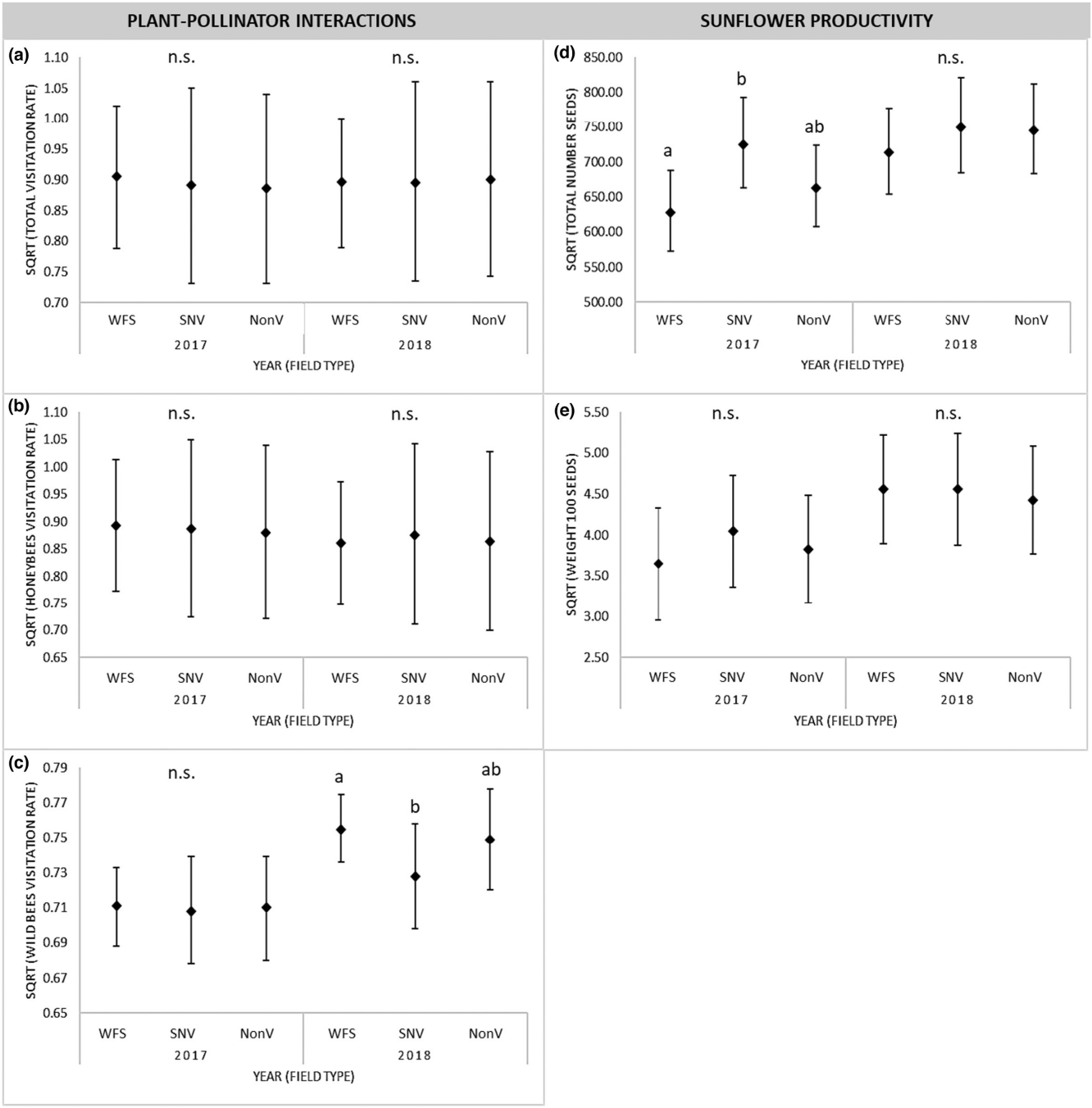

FIGURE 2 Effect of the field treatment (SNV, WFS and NonV) within years (2017 and 2018), in Burgos region, on visitation rates and sunflower productivity: (a) total visitation rate, (b) honeybees visitation rate, (c) wild bees visitation rate; and on sunflower productivity: (d) total number of seeds, (e) weight of 100 seeds. Values are given as estimated marginal means and 95% confidence intervals. Lowercase letters represent significant statistical differences between treatments at $p < 0.05$, n.s.—non-significant at $p < 0.05$.

In Burgos, we observed that honeybee visitation rates positively impacted sunflower productivity (in particular, seed production), as observed by Perrot et al. (2019), regardless of the lack of differences in total and honeybee visitation rates between years. Although no significant direct effects of wild bees on productivity were observed, the increase in yield observed in the second year was accompanied by significantly higher visitation rates by wild bees. Thus, as observed in other sunflower studies (DeGrandi-Hoffman & Watkins, 2000; Greenleaf & Kremen, 2006), the increased visitation by wild bees might have an indirect impact on sunflower yield by increasing the efficiency of honeybees. Wild bees were shown to increase the frequency of pollen transfer by honeybees through behavioural interactions, demonstrating that combined pollination by honeybees and wild bees might result in better productivity than the pollination of each 'group' alone (DeGrandi-Hoffman & Watkins, 2000). The combined importance of honeybees and wild bees' visitation rates was observed in Cuenca, with both contributing significantly to sunflower productivity. Thus, although wild pollinators are important in crop

TABLE 1 Effect of field treatment (SNV, WFS and NonV), year (2017 and 2018) and distance to field margin on visitation rates and sunflower productivity, in Burgos region. Significant differences at $p < 0.05$ are highlighted in bold

Region: BURGOS	Year (field treatment)			Field treatment (distance)		
Effect response variables	***df***	X^2	***p***	***df***	X^2	***p***
Visitation rates						
Total visitation rate	5	0.053	1.000	9	13.579	0.138
Honeybees visitation rate	5	0.178	0.999	9	12.802	0.172
Wild bees visitation rate	5	**14.676**	**0.012**	9	9.140	0.424
Productivity						
Total number seeds	5	**18.542**	**<0.001**	9	**2.691**	**0.004**
Weight 100 seeds	5	7.701	0.174	9	**50.490**	**<0.001**

pollination, honeybees still represent an important component of sunflower pollination, as observed also in Morgado et al. (2002).

Our results support a spillover of pollination services within the field, with increased visitation rates and yields in fields with wildflower strips. Although positive effects of agri-environmental actions on pollination services provisioning are generally detectable (Blaauw & Isaacs, 2014; Feltham et al., 2015), its impacts on crop yield can be variable. For example, the flower strips may be resource richer than crops, removing pollinators from crop patches (Circe principle; Jonsson et al., 2015; Nicholson et al., 2018) and having no impact in seed set of adjacent sunflower fields (Sardiñas & Kremen, 2015). Interestingly, our results indicate increases in productivity linked with higher visitation rates within the fields adjacent to wildflower strips in Cuenca, suggesting a pollinator's 'exporter' effect ('exporter' hypothesis; Morandin & Kremen, 2013; Kremen et al., 2019) from these implemented areas to sunflower fields.

4.2 | How does visitation rates and productivity vary with the distance to the field margin?

The results obtained in Burgos did not show a consistent pattern between within-field distances to the field margin, but in Cuenca, where the wildflower strips implementation revealed to have an effect in all studied variables, some patterns were observed: visitation rates tended to decrease with increased distances to SNV, although, no clear effect was observed in sunflower's productivity. Overall, our results suggest that the proximity to the field margin may effectively be important to promote visitation rates, and thus, it is very relevant to enhance pollination services on fields, with expected positive impacts on sunflower productivity. Few studies have demonstrated the efficiency of WFSs in providing ecosystem services within the field (Zamorano et al., 2020). However, recent reviews have shown that pollination services increase on fields adjacent to enhanced floral patches, decreasing exponentially with the increase in distance to the field margin, but without significant effects on yield (Albrecht et al., 2020), which is consistent with our results. Previous experiments on sunflower fields in Cuenca (Hevia et al., 2016) found that visitation rates were higher at field edges. We obtained similar results for this region, with decreasing visitation rates as the distance to the wildflower strip increased.

4.3 | Can landscape context impact the effectiveness of Agri-environmental actions?

Based on our results, one can hypothesize that the implementation of wildflower strips itself may be insufficient to improve pollinator visitation rates. Landscape homogenization reduces the amount and diversity of habitats that can act as sources of vital resources for the maintenance of pollinator's populations (Montero-Castaño & Vilà, 2012; Purvis et al., 2019; Tscharntke et al., 2005) and lead to phenological gaps during which few or no flower resources are available (Duelli & Obrist, 2003; Goulson et al., 2015; Williams & Kremen, 2007). Additionally, if pollinator-friendly habitats are scarce and scattered in the landscape, wild pollinators will have difficulties moving through the landscape (Garibaldi et al., 2011, 2014; Morandin et al., 2007; Purvis et al., 2019). The landscape of Burgos has become a highly homogeneous agricultural landscape (characterized by annual crops in a rotation scheme between cereal, sunflower and fallow) with few natural and semi-natural habitats capable of promoting ecological connectivity. The lack of effects of the wildflower strips implementation in this region might reflect a depauperated area that compromises the re-naturalization of small areas (such as the WFSs) and hinder pollinator communities' build-up and associated service (Morandin & Kremen, 2013). Thus, the implementation of WFSs in Burgos might need more time to become effective or even need a deeper transformation of the landscape. Indeed, depending on the landscape context, more intensive and specific management structures and practices may be needed (Dainese et al., 2019; Heard et al., 2007; Holzschuh et al., 2007) to improve overwintering and nesting resources for pollinators (Albrecht et al., 2020; Ganser et al., 2019; Kremen et al., 2019; Purvis et al., 2019).

Maintaining a network of semi-natural habitats is crucial for preserving diverse wild pollinator communities (e.g. Bartual et al., 2019; Hevia et al., 2021) and may act as biodiversity reservoirs and as a source of pollinators for implemented floral patches. In Cuenca, although it also harbours rotation crop systems, sunflower fields are always surrounded by semi-natural vegetation, and the landscape is more heterogenous and presents higher connectivity between patches. Landscapes with these characteristics are expected to promote the mobility of pollinators searching for food resources (M'Gonigle et al., 2017; Schellhorn et al., 2015). The results (already significant in the second year after the implementation of WFSs)

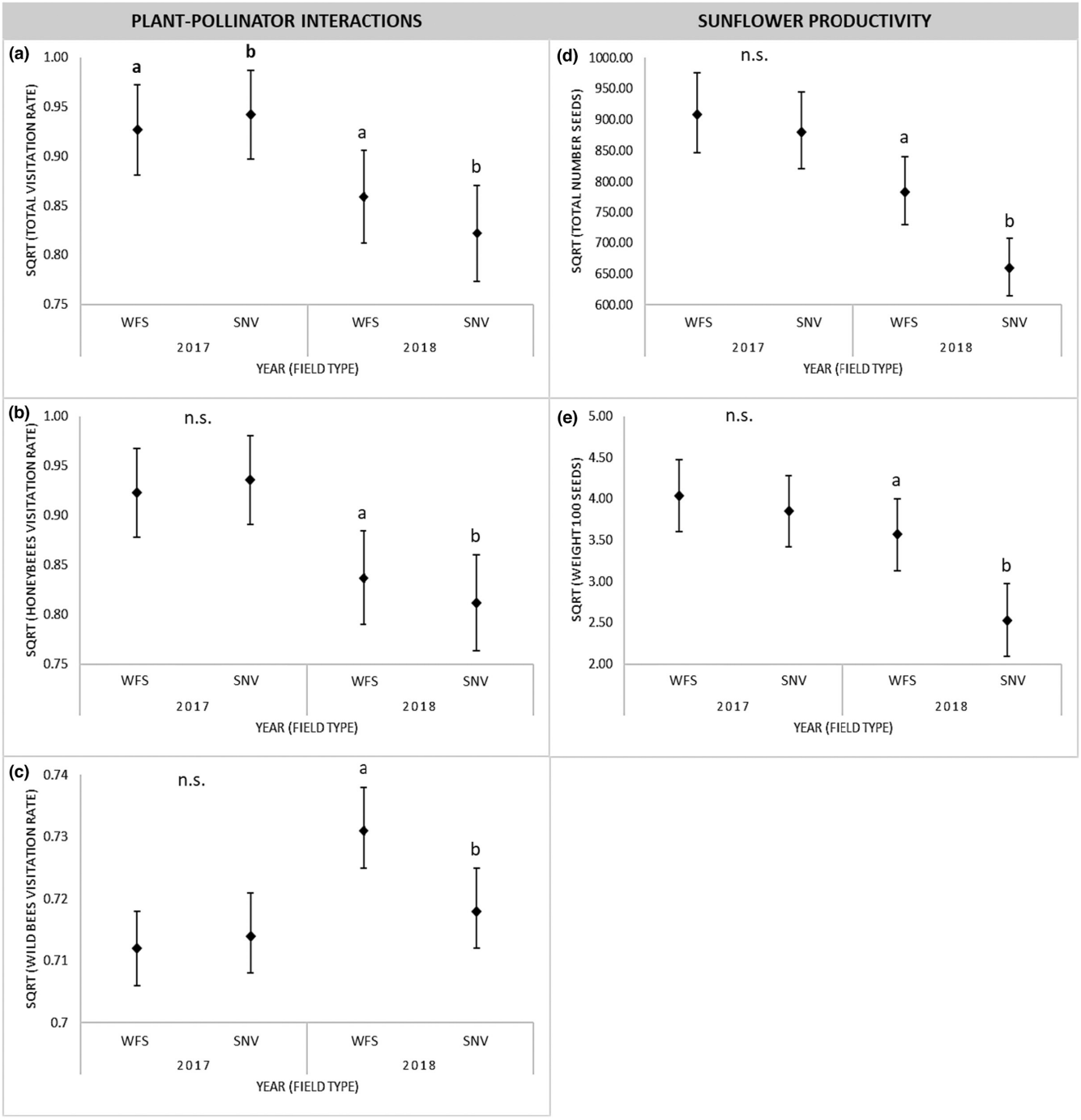

FIGURE 3 Effect of the field treatment (SNV and WFS) within years (2017 and 2018), in Cuenca region, on visitation rates and sunflower productivity: (a) total visitation rate, (b) honeybees visitation rate, (c) wild bees visitation rate; and on sunflower productivity: (d) total number of seeds, (e) Weight of 100 seeds. Values are given as estimated marginal means and 95% confidence intervals. Lowercase letters represent significant statistical differences between treatments at $p < 0.05$, n.s.—non-significant at $p < 0.05$.

obtained in Cuenca suggest that more semi-natural habitats could accelerate the rate of colonization of WFSs by wild bees, which were most probably attracted by the flower-richer diversity present on these structures, increasing visitation rates to adjacent sunflower fields. This finding agrees with the recent meta-analysis of Albrecht et al. (2020), in which several studies demonstrated that the effects of improved WFSs are detectable after 2 years. These results suggest that, in contrast to the Burgos region, pollination services in the Cuenca region might be easier to restore and promote with simple agri-environmental schemes.

4.4 | Caveats and limitations

It is also important to acknowledge that many other factors may have influenced the final yield in the studied sunflower fields

TABLE 2 Effect of field treatment (SNV and WFS), year (2017 and 2018) and distance to GI on visitation rates and sunflower productivity, in Cuenca region. Significant differences at $p < 0.05$ are highlighted in bold

Region: CUENCA	Year (field treatment)			Field treatment (distance)		
Effect response variables	***df***	X^2	***p***	***df***	X^2	***p***
Visitation rates						
Total visitation rate	3	**16.804**	**0.001**	6	**35.542**	**<0.001**
Honeybees visitation rate	3	**20.809**	**0.001**	6	**32.232**	**<0.001**
Wild bees visitation rate	3	**21.884**	**<0.001**	6	**13.587**	**0.035**
Productivity						
Total number seeds	3	**160.688**	**<0.001**	6	1.954	0.070
Weight 100 seeds	3	**28.443**	**<0.001**	6	**25.627**	**0.001**

TABLE 3 Regression analysis of the effect of pollinator visitation rates (honeybee visitation rate and wild bee visitation rate) on sunflower productivity (total number of seeds and weight of 100 seeds) in Burgos and Cuenca. Significant differences at $p < 0.05$ are highlighted in bold

	Total number seeds			Weight 100 seeds		
Region	**Estimate**	***t* value**	***p***	**Estimate**	***t* value**	***p***
Variables						
Burgos						
Honeybees visitation rate	**0.275**	**13.420**	**<0.001**	0.548	0.832	0.411
Wild bees visitation rate	0.054	0.381	0.704	−1.468	−0.376	0.710
Cuenca						
Honeybees visitation rate	**0.159**	**3.048**	**0.002**	0.902	0.875	0.387
Wild bees visitation rate	**2.820**	**7.286**	**<0.001**	**17.458**	**2.092**	**0.043**

(Albrecht et al., 2020; Bartomeus et al., 2015; Mercau et al., 2001; Sezen et al., 2011), and might be a limitation of the present work, especially without a pollinator exclusion treatment. Factors linked with management practices, crop variety and environmental conditions have the potential to drive local- and small-scale differences that may hinder the detection of patterns. For example, fertilization (and nutrient availability), soil properties, water availability and climatic conditions (e.g. temperature, radiation) may impact developmental stages and determine the final number of florets and seeds that can be produced, as well as the whole plant physiology, indirectly influencing crop yield (e.g. Alkio et al., 2003; Bartomeus et al., 2015; Chimenti & Hall, 2001; Dosio et al., 2000; Mercau et al., 2001; Sezen et al., 2011). Future studies should control as many variables as possible and include a pollinator exclusion treatment as a baseline for local productivity values.

5 | CONCLUSIONS

The establishment of wildflower strips adjacent to sunflower fields in agricultural landscapes showed context-dependent effects on visitation rates and crop yield. In simplified agroecosystems, such as in the Burgos region, the WFS implementation alone was insufficient (within a 2-year period) to effectively promote pollination services and enhance crop yield. In these landscapes, pollinator communities might be severely impoverished, and either be unable to build up around the WFS or need longer times to establish. However, in agroecosystems where natural and semi-natural patches were already present in the landscape, such as in the Cuenca region, the effect of WFSs on pollination and crop yield became positive and significant in the second year of its implementation. The distance to vegetation-rich field margins impacted visitation rates, despite no significant effects being obtained on yield. Considering these results, long-term studies, including the analyses of spatial landscape configuration, are needed for better assessing the effective contribution of flower strips and remnant semi-natural vegetation patches to promote pollinator communities and deliver sustainable pollination services to pollinator-dependent crops.

AUTHORS' CONTRIBUTIONS

All authors were involved in the definition of the experimental design and discussion of the results obtained; J.A. and A.S. developed spatial data configurations; L.M., S.C., J.L., C.S., O.A., E.A.N.M., C.R., V.H., J.A.G., J.O.-M., L.C., C.A.L., P.A. and F.M.A. were involved in field data collection and laboratory sample processing; S.C. and L.M., after discussions with V.H., J.A.G. and J.P.S., performed data analyses; L.M. and S.C. with the help of all the co-authors led manuscript writing; E.A.N.M. and C.R. led funding acquisition. Our study brings together authors from the two countries of the Iberian

Peninsula and six different research centres, most of them in the country where the study was carried out. All authors were engaged early on with the research and study design, and, whenever possible, literature published by scientists from Iberian Peninsula was cited.

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CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

DATA AVAILABILITY STATEMENT

Data available via the Dryad Digital Repository https://doi.org/10.5061/dryad.h18931zpg (Mota et al., 2022).

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