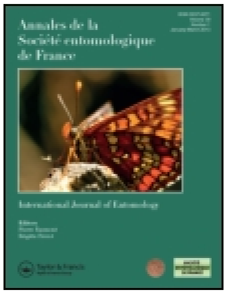

Bees and crops in Spain: an update for melon, watermelon and almond

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	species. Increasing the number of studies across different regions of Spain will likely add further species to these lists, and will help planning conservation actions nearby crop fields to maintain this important diversity of potential pollinators.

Bees and crops in Spain: an update for melon, watermelon and almond

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Abstract

Pollinators of most of the plants cultivated in in the Mediterranean regions of Europe are still unknown. We provide new data and we review previously available information on bees (Apoidea Latreille, 1802) associated with three economically important crops in Spain: melon, watermelon and almond. We found that overall 138 bee species spanning four families visit the studied crop species. The bee assemblages of melon includes 8-35 species, with moderate to high importance of small *Lasioglossum* Curtis, 1833 (Halictidae Thomson, 1869) and honeybee (*Apis mellifera* Linnaeus, 1758: Apidae Latreille, 1802). Watermelon flowers are visited by 14-20 species of bees, with low to moderate abundance of honeybees and predominance of small *Lasioglossum*. Bees collected on almond trees spanned 12-37 species, being the honeybee and medium-size to large *Andrena* Fabricius, 1775 (Andrenidae Latreille, 1802) and *Osmia* Panzer, 1806 (Megachilidae Latreille, 1802) predominant. The new samples expanded the geographical distributions of nearly one-fourth of the collected species. Diversity estimators slightly varied even within fields of the same crop, and a cluster analysis suggests both a certain overlap between melon and watermelon and a role of geographical distance on similarity among bee assemblages. Below ground-nesting and solitary species were more frequent than above ground-nesting and eusocial species, but for melon and watermelon the highest abundances were recorded for eusocial species. Increasing the number of studies across different regions of Spain will likely add further species to these lists, and will help planning conservation actions nearby crop fields to maintain this important diversity of potential pollinators.

Key words: Hymenoptera, Apoidea, *Apis*, *Lasioglossum*, Spain, pollination, agriculture

Running title: Bees on melon, watermelon and almond in Spain

Introduction

Despite bees are reported to be essential in pollinating > 70% of the about 1500 world crops (Klein et al. 2007; Garibaldi 2013), farmers actually mange less than 10 bee species out of the > 20000 occurring worldwide (Michener 2007), with, by far, the honeybee (*Apis mellifera* Linnaeus, 1758) as the main managed pollinator (Klein et al. 2007). However, relying almost exclusively on one single species for maintain pollination service has several important problems. First, the service of the honeybee is nowadays compromised in many areas because of populations decline due to pesticides, parasites and other diseases (Neumann & Carreck 2010; Potts et al. 2010), making important to understand which wild bee species may make a comparably good work on each target crop species (Hoehn et al. 2008; Mallinger & Gratton 2015; Winfree et al. 2007). Second, great hive densities of honeybee managed at crop fields may represent a risk for wild bee populations (Mallinger et al. 2017; Valido et al. 2019), so that a particular attention to not compromise the potential service of wild bee species by inadequately increase honeybee density should be considered, i.e. including by studying wild bee species potentially important for the target crops.

Knowing in detail the bee assemblages visiting crop flowers is thus an essential first step to maintain pollination service in agricultural areas (Kremen et al. 2002; Garibaldi et al. 2014), since with such basic diversity data it is possible to choose, case-by-case, the best plan aimed to increase both flower and nesting resource around crops, and thus ultimately population size, of these species (Roulston & Goodell 2011; Everaars et al. 2018; MacIvor 2017). However, such kind of basic though essential studies was performed on a relatively low number of crop species, particularly in the Mediterranean basin, a key centre of bee speciation (Michener 1979, 2007) where bee assemblages of only about 50 cultivated plants were studied (reviewed in Herrera 2020).

Here, we focused in three economically important crop species largely cultivated in Spain, one of the Mediterranean countries for which information of pollinator guilds in agricultural areas are still scarce and fragmented. These crops are melon (*Cucumis melo*

Linnaeus, 1753 (Cucurbitaceae)) watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai, 1916 (Cucurbitaceae)) and almond (*Prunus dulcis* (Mill.) D.A.Webb, 1967 (Rosaceae)). Melon is an herbaceous, annual crop having monecious flowers with a yellow corolla and large, sticky and heavy pollen grains that cannot be transported by wind (Knapp & Osborne 2019). The "toad skin" variety of melon is abundantly cultivated in Spain and was here studied. Similarly, watermelon is also a self-compatible annual crop, primarily producing yellow monecious flowers, that is dependent upon insect visitation to set seed because of its large and sticky pollen grains (Knapp & Osborne 2019). Both melon and watermelon flowers have a similar phenology in Spain, blooming in June-July. Almond possess whitish pink flowers which bloom from February to March in Spain, most of its varieties are self-incompatible, and its pollen is not windblown and thus also dependent on pollinators (Polito et al. 1996).

The few detailed studies on potential pollinators of melon in the Mediterranean were recently carried out in France (Carrè et al. 2009) and few localities in Spain (Rodrigo Goméz et al. 2016; Azpiazu et al. 2020). The few studies of the assemblage of bee species visiting flowers of watermelon in the Mediterranean were carried out in Israel and Egypt (Taha & Bayoumi 2009; Pisanty & Mandelik 2015; Pisanty et al. 2016). Almond-associated bee fauna was also scarcely studied at community-level in the Mediterranean, in several localities of Spain, Italy, Egypt and Israel (Moleas 1978; Ortiz-Sanchez & Tinaut 1993, 1995; Norfolk et al. 2016; Alomar et al. 2018). These data show an impressive richness of bees that can be found even at single crop fields. Here, we provide novel data to increase the knowledge of the bee fauna associated with melon, watermelon and almond crops in Spain, and review the available literature for the country.

Materials and methods

Study areas

All field work was performed in Central-Eastern Spain. Melon bee assemblages were studied at one locality within the region of Castilla-La Mancha (El Chaparrillo (3.916667°W, 38.983333°N, 640 m a.s.l.), province of Ciudad Real) (1.VII.2013 to 30.VII.2013) and one locality in the region of Valencia (Carcaixent (-0.4333°W, 39.1167°N, 21 m a.s.l.), province of Valencia) (15.VI.2014 to 7.VII.2014) (Fig. 1A,B). Because at El Chaparrillo the same melon crop was previously studied in 2011 (Rodrigo Gómez et al. 2016), we combined the new data collected in 2013 with those collected in 2011 (14.VI.2011 to 18.VII.2011) to have a more complete overview of the bee assemblage at this crop field. Watermelon bee assemblage was studied at two localities within the region of Castilla-La Mancha (El Chaparrillo (11.VII.2013 to 25.VII.2013)) and Villarrobledo (-2.6°W, 39.266667°N, 724 m a.s.l.) (province of Albacete) (12.VII.2014 to 21.VII.2014) (Fig. 1A,C). Almond bee assemblage was studied at one locality within the region of Castilla-La Mancha (Villarrobledo) (21.II.2019 to 24.II.2019) (Fig. 1A,D).

Bee sampling

We used two sampling methods to characterize the bee community associated with the studied crop species (e.g. Roulston et al. 2007; Popic et al. 2013), though practical issues did not allow the use of both methods at each site and year. Net collection within transects was used to sample bees at all sites and years, selecting plants/trees which were coded with unique identification numbers, and sampled at random rotation (different plants/trees in different days, selected randomly). One transect per hour for melon and watermelon (0900 to 1400 h) and three transects per hour for almond (1000 to 1600 h) was performed. While for melon and watermelon each transects included several plant individuals (for a total of 36 plants/year for both crops during the study), for almond each transect corresponded to one tree (for a total of 40 trees during the study). At El Chaparrillo in 2013 (melon), transects were carried out each three days; at Carcaixent in 2014 (melon) and at Villarrobledo in 2014 (watermelon), transects were carried out each day (excluding bad weather days); at El Chaparrillo in 2013 (watermelon) transects were carried out each two day; at Villarrobledo in 2019 (almond) transects were carried out each day. All bees landing on flowers of the crop species and fed on nectar and/or collected pollen were sampled with an entomological net, in each transect, for 10 minutes (melon and watermelon) or 15 minutes (almond).

Pan-trap sampling was used to collect bees at the melon crop in 2014 at Carcaixent and the watermelon crop in 2014 at Villarrobledo (and at El Chaparrillo melon crop in the previously published study (Rodrigo Gómez et al. 2016), whose 2011 data are here incorporated). Because pan-trap colour can affect the collection of different groups of bees (e.g. Leong & Thorp 1999; Gollan et al. 2011) and the combined use of pan-traps of different colours seems important in collecting bees of a wide taxonomic spectrum (Stephen & Rao 2005; Wilson et al. 2008), we used traps of three colours (yellow, white and blue), arranged randomly in proximity of 52 (El Chaparrillo) and 54 (Villarrobledo) plants and with a rotation system (i.e. colour assignment to each sampled plant changed once a week). Traps were placed in the morning, between 0800 and 0900 h, removed in the afternoon of the next day, and substituted with new traps. Plants selected to place the pan traps were different from plants selected for transects.

A total of 797 individuals were collected at the melon field at El Chaparrillo, 334 individuals were collected at the melon field at Carcaixent, 85 individuals were collected at the watermelon field at El Chaparrillo, 266 individuals were collected at the melon field at Villarrobledo and 199 individuals were collected at the almond field at Villarrobledo. The taxonomic identification of each sampled bee individual and its sex was assessed in the laboratory. A proportion of specimens were preserved in the freezer for future morpho-physiological and genetic studies, and the rest were pinned and deposited at the Universidad de Castilla-La Mancha. The nomenclature of the bees follows Michener (2007) and Pauly et al. (2015, 2017). To each species, two main ecological traits were assigned based on previous information (Settele et al. 2005; Michener 2007; Bommarco et al. 2010; Fortel et al. 2014; Forrest et al. 2015; Danforth et al. 1999, 2003; Packer 1998; Carrié et al. 2017): nesting type (above ground (i.e. tunnel in woods, aerial combs) or below ground (i.e. in the soil) and sociality (solitary (including communal), eusocial, socially polymorphic (i.e. species that have populations either solitary or eusocial) or non-nesting cleptoparasite). Some species lack information on sociality and were excluded from some analyses. The head width of the collected bees (except particularly damaged individuals) was measured with a digital calliper to the nearest 0.02 mm and was used as an indicator of bee body size (e.g. Cane 1987).

To complete our overview of the bee species associated with the three studied crop species, we reviewed all previously available data for Spain. A part from the aforementioned study by Rodrigo Gómez et al. (2016) whose data, having been performed at the same melon crop field studied in 2013 at El Chaparrillo, were incorporated to the new ones for this crop field, species lists were found for melon at Corral de Almaguer, Toledo (Castilla-La Macha, -3.166667W, °39.76°N, 724 m a.s.l.) and at La Poveda, Arganda del Rey, Madrid (Comunidad de Madrid, -3.47747°W, 40.319°N, 613 m a.s.l.) (Azpiazu et al. 2020), and for almond at 18 locations in Mallorca Island (Balearic Islands) (Alomar et al. 2018) and 24 locations in Granada province (Ortiz-Sanchez and Tinaut 1993, 1995). In Alomar et al. (2018) and Ortiz-Sanchez and Tinaut (1993), species lists were available as pooled samples from the different locations; hence, in these cases an assignation to a single locality for each species was not possible. In addition, while the species list in Ortiz-Sanchez and Tinaut (1995) could be assigned to a specific locality in the Granada province, we noted that all species therein sampled were also sampled across the many localities over the province explored in Ortiz-Sanchez and Tinaut (1993), so that we considered a single species list for Granada province. No previous data on bee assemblages on watermelon in Spain were found by inspecting the literature. The data available in these published studies consist in presence data, not in abundance data for each sampled bee species. Thus, the complete data set included five bee assemblages with abundance data and other four bee assemblages with presence data.

Data analysis

Each of the bee assemblages were described using a number of parameters.

Chao 1 is a non-parametric estimator (distribution-free) of total species richness (Chao 1984). Chao-1 estimates the number of species that are represented only by a single individual (singletons) or by two individuals (doubletons) in that sample based on abundances, thus operating by using the number of rare species that are found in a sample as a way of calculating how likely it is there are more undiscovered species (i.e. suggesting how much complete were the samples). As the Chao 1 values are estimates and thus have a degree of uncertainty, they are accompanied by their variances, calculated following Chao (1987).

The Shannon diversity index (H) and the Dominance index (D, i.e. 1-Simpson index) were used to characterize species diversity in a community by accounting for both abundance and evenness of the species present (Shannon & Weaver 1949; Simpson 1949). Furthermore, taxonomic diversity (Δ) and taxonomic distinctness (Δ*), two univariate measures which use information derived from a hierarchical taxonomic tree to estimate biodiversity, were calculated following Clarke & Warwick (1998). Δ is the expected path length between any two randomly picked individuals from the sample (thus it includes aspects of taxonomic relatedness and evenness), while Δ* is the average path length between two randomly chosen but taxonomically different individuals, thus being a measure of pure taxonomic relatedness (Clarke & Warwick 1998). Both Δ* and Δ were calculated twice, once using species abundances and once using species occurrences (in the latter case, Δ* = Δ so we refer in this case only to Δ*). We entered the taxonomic information on four levels: species, genus, subfamily and family.

To evaluate whether bee species assemblages cluster according to either crop species or locality, two cluster analyses were performed using paired group algorithm (UPGMA) (Legendre & Legendre 1998): one based on the abundance data from the five bee assemblages for which abundance data were available (using Cosine similarity), and one based on occurrence data from all nine bee assemblages (using Jaccard similarity) (Jongman et al. 1995).

All data analyses were carried out in the software PAST (Hammer et al. 2001).

Results

Melon

The new samplings performed on melon gave a total of 33 (Carcaixent) and 35 (El Chaparrillo) species of bees (Tables 1-2), with an estimation (Chao 1) of around 40 species present at both site (Table 2). The two bee assemblages included species spanning 3 (Carcaixent) and 4 (El Chaparrillo) families, and both were dominated by Halictidae Thomson, 1869 in terms of number of species (45%-57%) (Table 1). In terms of abundance, Halictidae dominated at El Chaparrillo (84.7% of all individuals, with 72% belonging to the genus *Lasioglossum* Curtis, 1833) but Apidae Latreille, 1802 were most abundant (56%) at Carcaixent, which had 36% abundance of Halictidae (with 27% belonging to *Lasioglossum*) (Fig. 2A-B, Table 1). Honeybee summed up 10% at El Chaparrillo and 23% at Carcaixent (Fig. 2A-B, Table 1). This different distribution of taxa in the two sites, despite giving similar values of Shannon Index and Dominance index, gave taxonomic diversity and distinctness (based on abundance) both slightly higher at Carcaixent (Table 2). At both melon fields, most of bee species were ground-nesting species (24) with a solitary behaviour (20) (Fig. 3A, Table 1). However, the contribution to flower visits seemed to be higher for social species. Indeed, the most abundant species at El Chaparrillo, in the genus *Lasioglossum*, are eusocial, and the most abundant species at Carcaixent (honeybee) is also eusocial (Table 1). The collected species had a generally small body size (El Chaparrillo: mean head width per species: 2.30 mm, Standard Deviation: 0.72 mm, range: 1.1-3.9 mm; Carcaixent: mean head width per species: 2.60 mm, Standard Deviation: 0.93 mm, range: 1.09-4.7 mm) (Fig. 3B, Table 1).

The information retrieved from the literature on two further sites (within the provinces of Toledo and Madrid) (Azpiazu et al. 2020) adds nine bee species to the visitors of melon in Spain (Table 1), summing up the total number of species known to be associated with this crop to 67. These studies reported a substantially lower number of species visiting melon (8-13), though taxonomic distinctness based on occurrence data was comparable to that in the newly reported samples (Table 2). In these previously published samples, below ground-nesting species also dominate; however, solitary species were more numerous at La Poveda, but not at Corral de Almaguer (Fig. 3A). Despite abundance data *per* species are not available in Azpiazu et al. (2020), the authors state that the visits of small short-tongue bees (e.g. most of Halictidae) were the most abundant in melon crops, in agreement with our new observations. They also reported a variable (between and within years) but always low to moderate (4%-36%) abundance of long-tongue bees (i.e. including the honeybee), also agreeing with our new observations.

Watermelon

The new samplings performed on watermelon gave a total of 20 (Villarrobledo) and 14 (El Chaparrillo) species of bees (Tables 1-2), with an estimation (Chao 1) of around 25-28 occurring species respectively (Table 2). The two bee assemblages included species spanning 3 families at both sites, dominated by Halictidae in terms of number of species (78%-80%) (Table 1). In terms of abundance, Halictidae dominated at both sites (El Chaparrillo: 92.9% of all individuals, with 88% belonging to the genus *Lasioglossum*; Villarrobledo: 69.2%, with 67.3% belonging to *Lasioglossum*) (Fig. 2A-B, Table 1). Honeybee had 29.3% abundance at Villarrobledo but only 4.7% at El Chaparrillo (Fig. 2A-B, Table 1). The abundance-based indices show a greater diversity at Villarrobledo (H, Δ, Δ*) but a greater dominance (D) at El Chaparrillo (Table 2). At both watermelon fields, most of bee species were ground-nesting species (11-14), while the proportion of solitary over social species was 1 or close to 1 (Fig. 3A, Table 1). As for melon, the contribution to flower visits seemed to be however higher for social species, since several eusocial *Lasioglossum* (and honeybee at one site) were the most abundant species (Table 1). The collected species had a generally small body size and with a generally small body size (El Chaparrillo: mean head width per species: 1.98 mm, Standard Deviation: 0.97 mm, range: 1.00-3.92 mm; Villarrobledo: mean head width per species: 2.05 mm, Standard Deviation: 0.80 mm, range: 1.12-3.96 mm) (Fig. 3B, Table 1). No previous data were available for watermelon-associated bee fauna for Spain.

Almond

The new samplings performed on almond (Villarrobledo) gave a total of 18 species of bees (Table 2, Table 1), with an estimation (Chao 1) of around 19 occurring species at this site (Table 2). The assemblage included species spanning 4 families, with Andrenidae Latreille, 1802 including the highest % of species (38.8%) (Tables 1-2) (Fig. 2E, Table 1). Apidae was, however, the most abundant family in term of number of individuals (52.2%, of which 39.7% of honeybee), followed by Andrenidae (27.6%) (Fig. 2E, Table 1). The indices H, D, Δ and Δ* reached moderate values at this crop field (Table 2). Most of bee species were ground-nesting species (14) with a solitary behaviour (13) (Fig. 3A), with a generally medium-sized body (mean head width per species: 3.11 mm, Standard Deviation: 0.93 mm, range: 1.48-5.33 mm) (Fig. 3B).

The information retrieved from three further studies (within the province of Granada and Majorca) (Ortiz-Sanchez & Tinaut 1993, 1995; Alomar et al. 2018) adds 31 bee species to the visitors of almond in Spain (Table 1), summing up the total number of species known to be associated with this crop to 47. These studies reported either a lower (12: Majorca) or higher (37: Granada) number of species visiting almond, though taxonomic distinctness based on occurrence data was comparable to that in our newly reported sample (Table 2). Also in these previously published samples, below ground-nesting and solitary species dominate; however, while figures were similar between our sample and the sample from Majorca, the sample from Granada reported a much greater dominance of both below ground-and solitary species over above ground-nesting and social species (Fig. 3A). Despite abundance data *per* species are not available in Ortiz-Sanchez & Tinaut (1993) and Alomar et al. (2018), some calculations therein presented gave some tips on the relative proportion of honeybees over wild bees. Ortiz-Sanchez & Tinaut (1993) showed a great variation among study sites, with honeybee having from almost null % abundance to over 80% abundance, but high abundances were more common. In a second study performed at a single locality of Granada province, for which abundance data were presented *per* species, Ortiz-Sanchez & Tinaut (1995) reported >90% abundance of honeybee, with the second and third bee species not reaching the 3%. Similarly, Alomar et al. (2018) reported in Majorca that 89.69% of flower visits were performed by honeybees and only 4.51% by wild bees.

Cluster analyses

The UPGMA cluster analyses reasonably suggested that bee assemblage composition is at least partially driven by both the crop species and the geographical distances among crop fields. This was visible both using abundance data (five crop fields) (Fig. 4A) and occurrence data (nine crop fields) (Fig. 4A). Using occurrence data, almond bee assemblages were similar among the studied crop fields and more distant to the bee assemblages recorded for melon and watermelon, which seem to overlap to some degree their bee assemblages (Fig. 4B). However, while watermelon crop fields clustered closely together, melon crop fields fall either in the watermelon cluster or together in a melon cluster, and this pattern seems to be affected by geographical distances. In the dendrogram based on occurrences, the close melon crop fields (<100 km) of La Poveda and Corral de Almaguer appeared to cluster together and more distant from melon crop fields of farer localities (Fig.4B). Furthermore, abundance data show a strict similarity only between watermelon fields, while almond and melon seem more distributed in the dendrogram according to distance among fields (Fig. 4A).

New distributional records

We found novel information which expands the distribution of 20 of the species collected in the five newly studied field crops (23.8% of species). *Andrena dorsata* (Kirby,1802), collected at Villarrobledo, is a rare species in the Iberian Peninsula and it was only known to date from Portugal, Cantabrian mountains, Southern Andalusia and Balearic Islands (Rasmont et al., 2013). The also infrequently collected *Halictus sexcinctus* (Fabricius, 1775), sampled at Carcaixent, was known to date only in the Iberian Peninsula in its Northern half part and in two localities of Almeria province (Andalusia) (Blügten 1924; Ornosa et al. 2013; Ortiz-Sánchez & Pauly 2017). *Lasioglossum brevicorne* (Schenck, 1869) and *Lasioglossum callizonium* (Pérez, 1895), both collected at El Chaparillo, were known to date in the Iberian Peninsula mostly in its Central-Western part and were rarely sampled in Castilla-La Mancha (Cuenca and Albacete provinces) (Blügten 1924; Ornosa et al. 2013; Ortiz-Sánchez & Pauly 2017). *Lasioglossum euboeense* (Strand, 1909), collected in Villarrobledo, has previously only reported two times in the Iberian Peninsula, both from Sierra de Guadarrama (Madrid) (Ornosa et al. 2013). *Lasioglossum politum* (Schenck, 1853), collected in El Chaparillo and Villarobledo, was previously known in the Northern part of the Iberian Peninsula to date, with the exception of two records in Southern Andalusia (Blügten 1924; Ortiz-Sánchez & Pauly 2017). *Lasioglossum pauxillum* (Schenck, 1853), collected in El Chaparillo and Villarobledo, was largely known to date from the Northern half of the Iberian Peninsula but from only three records in its Central-Southern part (Central Portugal and Andalusia) (Blügten 1924; Ornosa et al. 2013; Ortiz-Sánchez & Pauly 2017). *Lasioglossum puncticolle* (Morawitz, 1872), collected in El Chaparillo and Villarobledo, has a dispersed and scarce distribution in the Iberian Peninsula, and to date it was only known from few records in Asturias (2), Palencia (1), Teruel (1), Madrid (3) y Andalucía (3) and Lisboa (1) (Blügten 1924; Ornosa et al. 2013; Ortiz-Sánchez & Pauly 2017). *Lasioglossum semilucens* (Alfken, 1914), collected in El Chaparillo and Villarobledo, was only known to date for a single record in Madrid province and four records in Northern Portugal (Blüthgen 1924; Ornosa et al. 2013; Ortiz-Sánchez & Pauly 2017). *Lasioglossum subaenescens* (Pérez, 1895), collected in Villarrobledo, is rare in the Iberian Penisnula, where only seven records were available to date (Madrid, Segovia, Teruel, Jaén and Almería provinces (Blügten 1924; Ortiz-Sánchez & Pauly 2017)). *Nomioides facilis* Smith 1853, collected in El Chaparillo, was previously known in Northern-Eastern localities of the Iberian Peninsula (Cataluña, Valencia, Almeria) and in Southern Portugal (Pauly 2011). *Nomioides minutissimus* (Rossi, 1790), collected in El Chaparillo, was previously known, in the Iberian Peninsula, from Balearic Islands and Cataluña, Zaragoza, Salamanca, Valladolid, Segovia, Valencia, Murcia, Almería and El Algarve in Portugal (Pauly 2011). The Western-Mediterranean *Megachile albohirta* (Brullé, 1839) (Ornosa et al. 2007), collected in El Chaparillo, was previously recorded only two times in the Iberian Peninsula, in Cataluña and Madrid areas. The Central-Southern species *Megachile apicalis* Spinola, 1808 (Ornosa et al. 2007), collected in Carcaixent, was rarely reported to date in the Iberian Peninsula, except in Cantabrian mountains and the Eastern coast North to Valencia. *Megachile centuncularis* (Linnaeus, 1758), collected in Carcaixent, was cited in many Spanish regions (Ornosa et al. 2007) but it was previously not recorded in the Valencia territory. *Megachile versicolor* Smith, 1844, collected in Carcaixent, was previously reported in Northern-Central areas of the Iberian Peninsula (Cataluña, Huesca, central regions) (Ornosa et al. 2007). *Ceratina nigrolabiata* Friese, 1896, collected in El Chaparillo, was previously known through scarce records in the Northern and Western-Southern parts of the Ibe~~a~~rian Peninsula (Ortiz-Sánchez & Terzo 2004). *Ceratina parvula* Smith, 1854, collected in Carcaixent, was already known from Eastern Spain coasts (Le Goff & Terzo 1999; Ortiz-Sánchez & Terzo 2004) but not from Valencia region. *Epeolus variegatus* (Linnaeus, 1758) and *Epeolus fallax* Morawitz, 1872, both collected in Carcaixent, were known to date from few dispersed records in the Iberian Peninsula and Balearic Islands (Bogusch & Hadrava 2018), but never from Valencia region (*E. fallax*), nor from Levante (Spanish South-Eastern coast) (*E. variegatus*).

Discussion

Previous studies on melon, watermelon and almond in the Mediterranean regions of Europe are scarce but provide some comparisons with our results for Spain.

The data for bees associated with melon crops in Spain seem to be not very dissimilar with what is known for other Mediterranean countries. For example, Carrè et al. (2009), in southern France, also recorded a great diversity of bee species, spanning 37 subgenera and including also various species of *Lasioglossum*. Concerning the importance of honeybee over wild bees, in terms of abundance, the low to moderate values of honeybee abundance found in

Spain stays in line with the study of Carrè et al. (2009) in France, which reported 29% honeybee abundance, though much higher values were reported in Southern Italy by Pinzauti (1981) (almost 80%).

The studies carried out on watermelon in other areas of the Mediterranean, showing similar assemblages and similarly great diversity to those here reported. For example, Pisanty et al. (2016) reported in Israel a total of 52 bee species, with almost 50% belonging to Halictidae (and over one third belonging to *Lasioglossum*). Also in Israel, Pisanty & Mandelik (2015) found that Halictidae covered > 60% of abundance, with two species of *Lasioglossum* (including *Lasioglossum malachurum* (Kirby, 1802), also frequently collected in Spain) as the most abundant species on watermelon, within a rich and diverse assemblage also including other Halictidae, *Hylaeus* Fabricius, 1793 (Colletidae Lepeletier, 1841, a family not collected in Spain) and *Ceratina* Latreille, 1802 as further prominent species. Previous studies found higher honeybee abundances in watermelon fields compared with our observations. Pisanty et al. (2016) in Israel observed that 85% of watermelon flower visits in Israel were performed by honeybees, while Taha & Bayoumi (2009) in Egypt found only two bee species on watermelon, with honeybee multiply for ten the abundance recorded for the other species (an *Andrena* Fabricius, 1775 species) (61% vs. 6%).

Few studies on bee assemblages of almond were performed in other Mediterranean countries. Norfolk et al. (2016) in Egypt and Moleas (1978) in Italy reported bee assemblages with roughly similar compositions to our studied one, with honeybee and below ground-nesting Andrenidae (particularly *Andrena*) and Apidae being predominant. Furthermore, Halictidae (Mandelik & Roll 2009) or both Halictidae and Megachilidae Latreille, 1802 (particularly *Osmia* Panzer, 1806) (Pisanty & Mandelik 2015) were also predominant in Israel. Honeybee seems variably important in these studies; for example, 77%-95% of flower visitors were honeybees in Norfolk et al. (2016) and Mandelik & Roll (2009), while the % proportion of wild bees over honeybees surpassed 50% in many of the years studied by Moleas (1978) at a Southern Italy locality.

We have found a certain degree of overlap between the bee assemblages of melon and watermelon. While from one side a certain similarity between the bee assemblages of these two crops is likely due to their similar flower morphology and blooming phenology, which are different from almond, on the other side climatic variation among sites and even among years may affect bee assemblages. Though sometimes honeybee could be more abundant than wild bees at certain years or locations, melon and watermelon seem to share the great dominance of ground-nesting Halictidae and particularly by several species of social *Lasioglossum*. Halictidae were claimed to be very important pollinators for both these crops species. For example, in Greece, Garantonakis et al. (2016) found that *Lasioglossum* species needed a significantly lower mean number of visits to effect pollination than honeybees. Njoroge et al. (2010) showed in Kenya that, despite honeybee to be abundant, three also abundant species of *Lasioglossum* had a significantly higher pollen deposition on watermelon stigmas than honeybees. In Florida, Campbell et al. (2019) showed that, despite honeybees being the most common visitor of watermelon, one halictid bee (as well as a wasp) carried as much watermelon pollen as honeybees. Similarly, in the only previous study on melon in Spain, Rodrigo Gómez et al. (2016) suggested, based on observations on the frequency of pollen and nectar foraging, flower visit duration and seasonal and daily activity, that *Lasioglossum* spp. could effectively be the key pollinators of melon in the Mediterranean. Pisanty & Mandelik (2015), after having studied the bee assemblages associated with watermelon, almond and sunflower crop fields in Israel, concluded that crop and non-crop pollinators are distinguished by behavioural and morphological traits. For example, these authors showed that watermelon crop-associated bee assemblages are dominated by relatively small, ground-nesting, social and polylectic species (i.e. essentially Halictidae). Our results largely show a similar pattern for Spain and suggests that it could be common across the whole Mediterranean Region.

With our new data and review on the bee assemblages of three economically important crops in Spain, and thus on their potentially important pollinators, we give the following conclusive remarks. First, our study overall supports the hypothesis that, besides honeybees, local pollinators can be very important in the pollination of melon, watermelon and almond (Mallinger & Gratton 2015; Winfree et al. 2007; Garibaldi et al. 2014). Second, an increased sampling both within the studied sites and across new sites in Spain will certainly add further bee species to the lists here compiled for melon, watermelon and almond. Third, the differences in honeybee abundances across sites of a same crop species do not seem to be due to presence of hives in the vicinity of the crop fields, since in all studied localities honeybee was routinely managed; nevertheless, we cannot exclude that these differences could be at least partially due to abundance differences of hives around the crop fields (Agüero et al. 2018).

Because high densities of honeybee hives can negatively affect wild bee populations (Mallinger et al. 2017; Valido et al. 2019), famers should pay attention to this point in case of crop species, such those here studied, abundantly visited by a rich wild bee fauna with high pollination potential. Fourth, the analysis of bee life-history traits, such as body mass, nesting and sociality can help assessing the pollination services that the different bee species are likely to provide, since bee assemblages associated with crops have characteristics not necessarily shared by bee assemblages nearby, but outside, the crop fields (Mandelik et al. 2012; Garratt et al. 2014; Pisanty & Mandelik 2015). Five, knowing in detail the life-history of potential key pollinators of crops can be used as a useful instrument to properly manage practices that encourage pollinators to live and nest, and not only forage, within crop fields, i.e. by creating bare soil areas for ground-nesting bee species and by placing trap-nests with an appropriate architecture for aerial-nesting wild bee species (Bosch 1994; Roulston & Goodell 2011; Knapp & Osborne 2019; Everaars et al. 2018; MacIvor 2017).

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Figure legends

Figure 1. A, Spanish locations where bee communities on melon (*M*), watermelon (*W*) and almond (*A*) crop fields were studied. In red, the locations sampled in this study. CH: El Chaparrillo (Ciudad Real, Castilla-La Mancha) (new data + Rodrigo Gómez et al. (2016)), CX: Carcaixent (Valencia, Comunidad Valenciana), VR: Villarrobledo (Albacete, Castilla-La Mancha), LP: La Poveda (Madrid, Comunidad de Madrid) (Azpiazu et al. 2020), CA: Corral de Almaguer (Toledo, Castilla-La Mancha) (Azpiazu et al. 2020), GR (Granada province) (Ortiz-Sanchez and Tinaut 1993), MA (Majorca island) (Alomar et al. 2018). Note that GR and MA locations are represented by circles instead of points, to evidence that data obtained from different localities within the provinces were presented as pooled in the published articles (circles roughly cover the sampled areas). B, The melon crop field at CH. C, The watermelon crop field at VR. D, The almond crop field at VR.

Figure 2. Abundance (% of individuals) of the bee genera collected on melon (A-B), watermelon (C-D) and almond (E) flowers. A, El Chaparrillo (melon); B, Carcaixent (melon); C, El Chaparrillo (watermelon); D, Vollarrobledo (watermelon); E, Villarrobledo (almond). The inset pictures show individuals of *Ceratina* sp. (A), *Halictus scabiosae* (B), *Megachile leachella* (C), *Apis mellifera* (D) and *Osmia cornuta* (E).

Figure 3. A, The ratio of below ground-nesting over above ground-nesting species plotted against the ratio of solitary over social species for the nine field crops. B, Box-and-whisker plots showing jitter dots (observed values), medians (horizontal lines within boxes), 1° and 3° quartile (horizontal lines closing the boxes), and maximum and minimum values (ends of the whiskers) of head width (mm) across the collected bee species (mean values across individuals *per* species) for the five crop fields with abundance data. M: melon, W: watermelon, A: almond. CH: El Chaparrillo (Ciudad Real, Castilla-La Mancha) (new data + Rodrigo Gómez et al.

(2016)), CX: Carcaixent (Valencia, Comunidad Valenciana), VR: Villarrobledo (Albacete, Castilla-La Mancha), LP: La Poveda (Madrid, Comunidad de Madrid) (Azpiazu et al. 2020), CA: Corral de Almaguer (Toledo, Castilla-La Mancha) (Azpiazu et al. 2020), GR (Granada province) (Ortiz-Sanchez and Tinaut 1993, 1995), MA (Majorca island) (Alomar et al. 2018).

Figure 4. Similarity in bee community composition, obtained from a UPGMA cluster based on the Jaccard similarity of abundance or presence data of species. A, dendrogram using abundance data from five crop fields. B, dendrogram using presence data from nine crop field. M: melon, W: watermelon, A: almond. CH: El Chaparrillo (Ciudad Real, Castilla-La Mancha) (new data + Rodrigo Gómez et al. (2016)), CX: Carcaixent (Valencia, Comunidad Valenciana), VR: Villarrobledo (Albacete, Castilla-La Mancha), LP: La Poveda (Madrid, Comunidad de Madrid) (Azpiazu et al. 2020), CA: Corral de Almaguer (Toledo, Castilla-La Mancha) (Azpiazu et al. 2020), GR (Granada province) (Ortiz-Sanchez and Tinaut 1993, 1995), MA (Majorca island) (Alomar et al. 2018). Points in the blank maps indicate the position of the crop field (note that for Granada and Mallorca data are pooled from the whole respective provinces and thus are indicated by circles, see text for details).

Tables

Table 1. Total list of bee species collected on flowers of melon, watermelon and almond in Spain, with locality and morpho-ecological traits. [a] Ortiz-Sanchez and Tinaut (1993) († also listed in Ortiz-Sanchez and Tinaut (1995)), [b] Alomar et al. (2018), [c] Rodrigo Gómez et al. (2016), [+ c] also listed in Rodrigo Gómez et al. (2016), [d] Azpiazu et al. (2020). In [a] and [b] the provided bee species list combined the results of multiple sampling localities across the provinces. "-" indicates that data are not reported in the published sources. Codes for Spanish administrative regions (Comunidades Autónomas): CH = El Chaparrillo (Ciudad Real, Castilla-La Mancha), CX = Carcaixent (Valencia, Comunidad Valenciana), VR = Villarrobledo (Albacete, Castilla-La Mancha), LP = La Poveda (Madrid, Comunidad de Madrid), CA = Corral de Almaguer (Toledo, Castilla-La Mancha), GR = Granada province, MA = Majorca island. Codes for nesting: BG = below ground, AG = above ground. Codes for sociality: SOL = solitary, SOC = eusocial.

Crop	Locality	Familia	Especies	*N* females	*N* males	Head width (mm) ± SE	Nesting	Sociality
Melon	CX	Apidae	*Amegilla albigena* (Lepeletier, 1841)	2	0	3.98 ± 0.06	BG	SOL
			Apis mellifera Linnaeus, 1758	78	0	4.00 ± 0.19	AG	SOC
			Ceratina cucurbitina (Rossi, 1792)	19	0	3.11 ± 0.12	AG	SOL
			Ceratina cyanea (Kirby, 1802)	15	0	3.33 ± 0.00	AG	SOL
			Ceratina dallatorreana Friese, 1896	25	0	2.07 ± 0.03	AG	SOL
			Ceratina parvula Smith, 1854	45	0	1.96 ± 0.03	AG	SOL
			Epeolus fallax Morawitz, 1872	1	0	3.76 ± 0.00	-	CLP
			Epeolus variegatus (Linnaeus, 1758)	2	0	2.95 ± 0.04	-	CLP
		Halictidae	*Halictus scabiosae* (Rossi, 1790)	16	0	1.84 ± 0.06	BG	SOC

			Halictus sexcinctus (Fabricius, 1775)	3	0	3.46 ± 0.04	BG	POL
			Seladonia cfr. *smaragdula* (Vachal 1895)	4	0	2.97 ± 0.13	BG	SOC
			Seladonia subaurata (Rossi 1792)	1	0	1.53 ± 0.03	BG	SOC
			Lasioglossum albocinctum (Lucas, 1846)	1	0	2.99 ± 0.00	BG	SOL
			Lasioglossum elegans (Lepeletier, 1841)	3	0	1.24 ± 0.01	BG	?
			Lasioglossum lativentre (Schenck, 1853)	9	0	1.20 ± 0.02	BG	SOL
			Lasioglossum leucozonium (Schrank, 1781)	57	0	2.12 ± 0.02	BG	SOL
			Lasioglossum malachurum (Kirby, 1802)	3	0	2.07 ± 0.10	BG	SOC
			Lasioglossum marginatum (Brullé, 1832)	3	0	2.27 ± 0.06	BG	SOC
			Lasioglossum morio (Fabricius, 1793)	2	0	1.92 ± 0.05	BG	SOC
			Lasioglossum punctatissimum (Schenck, 1853)	12	0	1.55 ± 0.04	BG	?
			Nomiapis bispinosa (Brullé, 1832)	4	0	3.15 ± 0.10	BG	SOL
			Nomiapis diversipes (Latreille, 1806)	1	0	2.79 ± 0.00	BG	SOL
			Sphecodes sp.	1	0	1.38 ± 0.00	-	CLP
		Megachilidae	*Anthidium florentinum* (Fabricius, 1775)	1	0	4.70 ± 0.00	AG	SOL
			Coelioxys afra Lepeletier, 1841	2	0	1.71 ± 0.03	-	CLP
			Coelioxys argentea Lepeletier, 1841	1	0	1.09 ± 0.01	-	CLP
			Dioxys sp.	1	0	2.49 ± 0.00	-	CLP
			Heriades crenulata Nylander, 1856	3	0	1.86 ± 0.00	AG	SOL
			Megachile apicalis Spinola, 1808	9	0	3.40 ± 0.05	AG	SOL
			Megachile leachella Curtis, 1828	4	0	3.45 ± 0.00	AG	SOL
			Megachile centuncularis (Linnaeus, 1758)	1	0	3.57 ± 0.05	AG	SOL
			Megachile versicolor Smith, 1844	4	0	3.16 ± 0.10	AG	SOL
			Osmia caerulescens (Linnaeus, 1758)	1	0	2.80 ± 0.00	AG	SOL
Melon	CH	Andrenidae	*Andrena* sp. [c]	1	2	3.21 ± 0.00	BG	SOL
			Panurgus calcaratus (Scopoli, 1763) [c]	1	0	2.85 ± 0.00	BG	SOL
			Panurgus cephalotes Latreille, 1811 [c]	4	0	3.25 ± 0.40	BG	SOL
		Apidae	*Apis mellifera* Linnaeus, 1758 [+ c]	82	0	3.91 ± 0.014	AG	SOC

	Ceratina cucurbitina (Rossi, 1792) [c]	1	0	1.80 ± 0.00	AG	SOL
	Ceratina dentiventris Gerstäcker, 1869 [c]	1	0	1.93 ± 0.00	AG	SOL
	Ceratina nigrolabiata Friese, 1896 [+c]	5	0	1.89 ± 0.05	AG	SOL
	Ceratina saundersi Daly, 1983	2	0	1.76 ± 0.00	AG	SOL
	Eucera seminuda Brullé, 1832 [c]	3	0	3.46 ± 0.01	BG	SOL
	Nomada sp. [c]	0	1	2.68 ± 0.00	-	CLP
Halictidae	*Halictus fulvipes* (Klug, 1817) [c]	20	3	2.74 ± 0.06	BG	SOC
	Vestitohalictus pollinosus (Sichel 1860) [c]	5	0	2.47 ± 0.02	BG	POL
	Seladonia cfr. *smaragdula* (Vachal 1895) [c]	2	1	1.69 ± 0.20	BG	SOC
	Halictus sp. [c]	1	5	1.88 ± 0.03	BG	?
	Vestitohalictus vestitus (Lepeletier 1841) [c]	21	17	2.96 ± 0.00	BG	POL
	Lasioglossum albocinctum (Lucas, 1846)	1	0	2.75 ± 0.00	BG	SOL
	Lasioglossum brevicorne (Schenck, 1869) [c]	2	0	1.47 ± 0.20	BG	SOL
	Lasioglossum callizonium (Pérez, 1895) [c]	3	11	1.93 ± 0.08	BG	SOL
	Lasioglossum discum (Smith, 1853) [c]	38	5	2.41 ± 0.04	BG	?
	Lasioglossum griseolum (Morawitz, 1872) [c]	18	1	1.24 ± 0.03	BG	?
	Lasioglossum leucozonium (Schrank, 1781) [+c]	16	9	2.42 ± 0.04	BG	SOL
	Lasioglossum malachurum (Kirby, 1802) [+c]	206	104	2.13 ± 0.02	BG	SOC
	Lasioglossum marginatum (Brullé, 1832) [c]	110	17	2.19 ± 0.02	BG	SOC
	Lasioglossum pauperatum (Brullé, 1832) [c]	4	0	1.57 ± 0.05	BG	?
	Lasioglossum pauxillum (Schenck 1853) [c]	2	0	1.37 ± 0.02	BG	SOC
	Lasioglossum puncticolle (Morawitz, 1872) [c]	3	0	1.98 ± 0.00	BG	SOL
	Lasioglossum semilucens (Alfken, 1914)	8	0	1.26 ± 0.02	BG	?
	Lasioglossum sp. [c]	2	0	1.48 ± 0.00	BG	?
	Lasioglossum villosulum (Kirby, 1802) [c]	7	5	1.96 ± 0.07	BG	SOL
	Nomioides minutissimus (Rossi, 1790) [c]	27	0	1.09 ± 0.02	BG	SOL
Megachilidae	*Anthidium taeniatum* Latreille, 1809 [c]	1	0	3.10 ± 0.00	AG	SOL
	Megachile albohirta (Brullé, 1839) [c]	3	9	3.144 ± 0.11	AG	SOL

			Megachile dorsalis Pérez, 1879[c]	0	1	2.80 ± 0.00	AG	SOL
			Megachile leachella Curtis, 1828	5	0	3.15 ± 0.05	AG	SOL
			Megachile sp.[c]	1	0	2.60 ± 0.00	AG	SOL
Melon	CA	Andrenidae	*Andrena bicolor* Fabricius, 1775[d]	-	-	-	BG	SOL
		Apidae	*Apis mellifera* Linnaeus, 1758[d]	-	-	-	AG	SOC
			Ceratina cucurbitina (Rossi, 1792)[d]	-	-	-	AG	SOL
		Halictidae	*Halictus fulvipes* (Klug, 1817)[d]	-	-	-	BG	SOC
			Halictus scabiosae (Rossi, 1790)[d]	-	-	-	BG	SOC
			Lasioglossum malachurum (Kirby, 1802)[d]	-	-	-	BG	SOC
			Lasioglossum minutulum (Schenck 1853)[d]	-	-	-	BG	SOL
			Lasioglossum pygmaeum (Schenck, 1853)[d]	-	-	-	BG	?
Melon	LP	Andrenidae	*Andrena flavipes* Panzer, 1799[d]	-	-	-	BG	SOL
		Apidae	*Apis mellifera* Linnaeus, 1758[d]	-	-	-	AG	SOC
			Ceratina chalcites Germar, 1839[d]	-	-	-	AG	SOL
			Ceratina cucurbitina (Rossi, 1792)[d]	-	-	-	AG	SOL
		Halictidae	*Halictus fulvipes* (Klug, 1817)[d]	-	-	-	BG	SOC
			Halictus maculatus Smith, 1848[d]	-	-	-	BG	SOC
			Halictus rubicundus (Christ, 1791)[d]	-	-	-	BG	POL
			Halictus scabiosae (Rossi, 1790)[d]	-	-	-	BG	SOC
			Lasioglossum albocinctum (Lucas, 1846)[d]	-	-	-	BG	SOL
			Lasioglossum malachurum (Kirby, 1802)[d]	-	-	-	BG	SOC
			Lasioglossum minutulum (Schenck 1853)[d]	-	-	-	BG	SOL
			Lasioglossum pygmaeum (Schenck, 1853)[d]	-	-	-	BG	?
		Megachilidae	*Anthidium florentinum* (Fabricius, 1775)[d]	-	-	-	AG	SOL
Watermelon	CH	Apidae	*Apis mellifera* Linnaeus, 1758	4	0	3.92 ± 0.07	AG	SOC
		Halictidae	*Seladonia* cfr. *smaragdula* (Vachal 1895)	1	0	1.57 ± 0.00	BG	SOC
			Vestitohalictus vestitus (Lepeletier 1841)	1	0	1.78 ± 0.00	BG	POL
			Lasioglossum albocinctum (Lucas, 1846)	1	0	2.89 ± 0.00	BG	SOL

			Lasioglossum cfr. *intermedium* (Schenck, 1868)	3	0	1.23 ± 0.019	BG	?
			Lasioglossum leucozonium (Schrank, 1781)	1	0	2.26 ± 0.00	BG	SOL
			Lasioglossum malachurum (Kirby, 1802)	2	0	2.09 ± 0.04	BG	SOC
			Lasioglossum pauperatum (Brullé, 1832)	1	2	1.19 ± 0.01	BG	?
			Lasioglossum politum (Schenck, 1853)	23	3	1.22 ± 0.01	BG	SOC
			Lasioglossum semilucens (Alfken, 1914)	37	2	1.20 ± 0.01	BG	?
			Nomioides facilis (Smith, 1853)	0	1	0.99 ± 0.00	BG	SOL
			Nomioides minutissimus (Rossi, 1790)	0	1	1.00 ± 0.00	BG	SOL
		Megachilidae	*Megachile apicalis* Spinola, 1808	1	0	3.11 ± 0.00	AG	SOL
			Megachile leachella Curtis, 1828	1	0	3.27 ± 0.00	AG	SOL
Watermelon	VR	Apidae	*Apis mellifera* Linnaeus, 1758	78	0	3.96 ± 0.02	AG	SOC
			Ceratina cyanea (Kirby, 1802)	0	1	1.78 ± 0.00	AG	SOL
			Ceratina saundersi Daly, 1983	1	0	2.15 ± 0.00	AG	SOL
		Halictidae	*Halictus fulvipes* (Klug, 1817)	1	0	2.38 ± 0.00	BG	SOC
			Seladonia cfr. *smaragdula* (Vachal 1895)	1	0	1.44 ± 0.00	BG	SOC
			Vestitohalictus vestitus (Lepeletier 1841)	2	0	2.02 ± 0.14	BG	POL
			Lasioglossum albocinctum (Lucas, 1846)	4	0	2.92 ± 0.06	BG	SOL
			Lasioglossum euboeense (Strand, 1909)	1	0	2.44 ± 0.00	BG	?
			Lasioglossum interruptum (Panzer, 1798)	8	0	1.81 ± 0.05	BG	SOC
			Lasioglossum leucozonium (Schrank, 1781)	5	0	2.47 ± 0.07	BG	SOL
			Lasioglossum malachurum (Kirby, 1802)	23	0	2.07 ± 0.06	BG	SOC
			Lasioglossum pauperatum (Brullé, 1832)	17	0	1.30 ± 0.03	BG	?
			Lasioglossum politum (Schenck, 1853)	63	0	1.22 ± 0.01	BG	SOC
			Lasioglossum puncticolle (Morawitz, 1872)	0	1	1.30 ± 0.00	BG	SOL
			Lasioglossum semilucens (Alfken, 1914)	44	1	1.22 ± 0.01	BG	?
			Lasioglossum sp.	2	1	1.12 ± 0.07	BG	?
			Lasioglossum subaenescens (Pérez, 1895)	7	0	1.57 ± 0.03	BG	?
			Sphecodes gibbus (Linnaeus, 1758)	1	0	2.92 ± 0.00	-	CLP

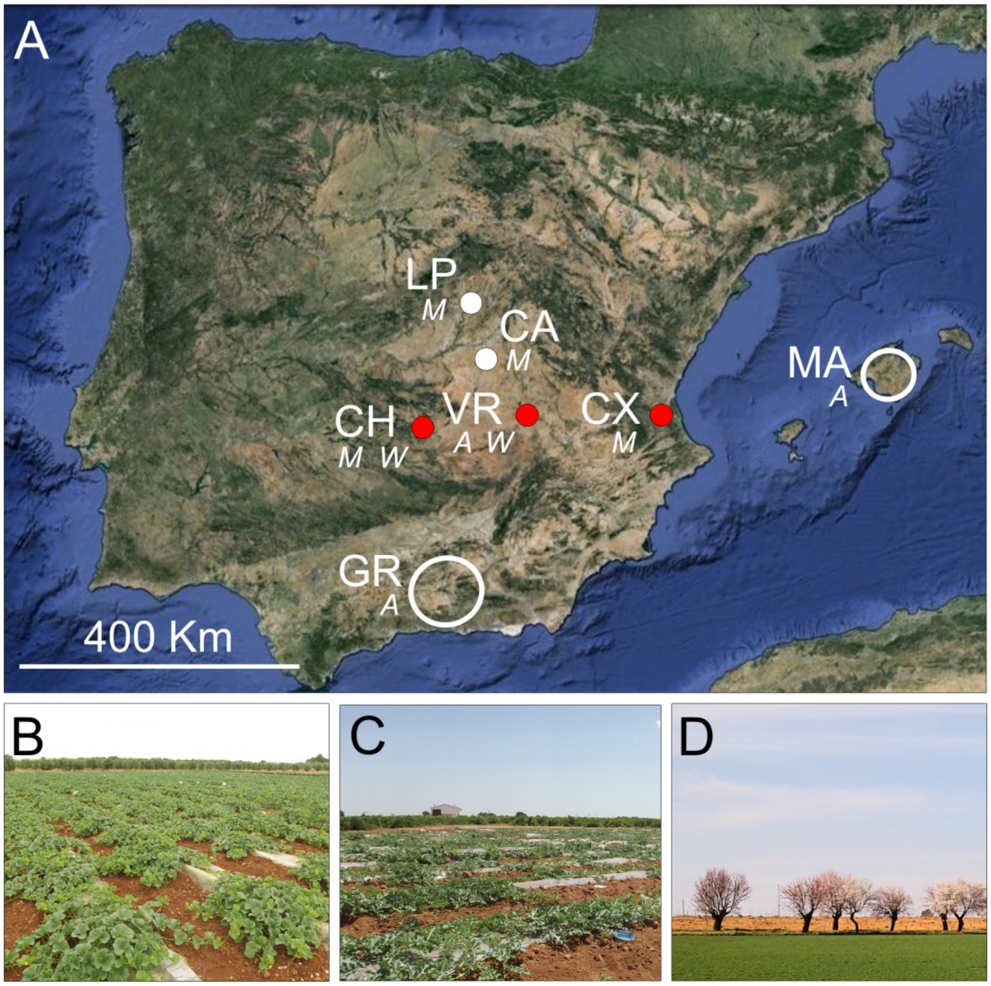
			Sphecodes puncticeps Thomson, 1870	2	0	1.38 ± 0.18	-	CLP
		Megachilidae	*Megachile apicalis Spinola, 1808*	2	0	3.52 ± 0.23	AG	SOL
Almond	VR	Andrenidae	*Andrena bicolor* Fabricius, 1775	5	5	3.00 ± 0.03	BG	SOL
			Andrena sp.	0	4	3.20 ± 0.09	BG	SOL
			Andrena dorsata (Kirby, 1802)	1	2	2.76 ± 0.06	BG	SOL
			Andrena florentina Magretti, 1883	2	1	2.38 ± 0.09	BG	SOL
			Andrena pilipes Fabricius, 1781	2	7	3.12 ± 0.09	BG	SOL
			Andrena tenuistriata Pérez, 1895	0	6	1.83 ± 0.05	BG	SOL
			Andrena thoracica (Fabricius, 1775)	10	10	4.05 ± 0.03	BG	SOL
		Apidae	*Anthophora dispar* Lepeletier, 1841	0	2	3.17 ± 0.03	BG	SOL
			Anthophora romandii Lepeletier, 1841	0	3	3.30 ± 0.02	BG	SOL
			Apis mellifera Linnaeus, 1758	79	0	3.90 ± 0.02	AG	SOC
			Bombus terrestris (Linnaeus, 1758)	2	0	3.87 ± 0.23	BG	SOC
			Eucera notata Lepeletier, 1841	0	2	3.32 ± 0.15	BG	SOL
			Xylocopa violacea Linnaeus, 1758	1	15	5.33 ± 0.06	AG	SOL
		Halictidae	*Lasioglossum malachurum* (Kirby, 1802)	1	0	2.24 ± 0.00	BG	SOC
			Lasioglossum pallens (Brullé 1832)	1	0	2.15 ± 0.00	BG	SOC
			Lasioglossum pauxillum (Schenck 1853)	4	0	1.48 ± 0.06	BG	SOC
			Sphecodes sp.	0	1	2.70 ± 0.00	-	CLP
		Megachilidae	*Osmia cornuta* (Latreille, 1805)	14	19	4.10 ± 0.05	AG	SOL
Almond	GR	Andrenidae	*Andrena aerinifrons* Dours, 1873 [a]	-	-	-	BG	SOL
			Andrena angustior (Kirby, 1802) [a†]	-	-	-	BG	SOL
			Andrena bicolor Fabricius, 1775 [a]	-	-	-	BG	SOL
			Andrena ferrugineicrus Dours, 1872 [a]	-	-	-	BG	SOL
			Andrena flavipes Panzer, 1799 [a]	-	-	-	BG	SOL
			Andrena florentina Magretti, 1883 [a]	-	-	-	BG	SOL
			Andrena minutula (Kirby, 1802) [a†]	-	-	-	BG	SOL
			Andrena mucida Kriechbaumer, 1873 [a]	-	-	-	BG	SOL

	Andrena nana (Kirby, 1802) [a]	-	-	-	BG	SOL
	Andrena nigroaenea (Kirby, 1802) [a†]	-	-	-	BG	SOL
	Andrena ovatula (Kirby, 1802) [a]	-	-	-	BG	SOL
	Andrena tenuistriata Pérez, 1895 [a†]	-	-	-	BG	SOL
	Andrena thoracica (Fabricius, 1775) [a]	-	-	-	BG	SOL
	Andrena trimmerana (Kirby, 1802) [a]	-	-	-	BG	SOL
	Andrena sp. [a]	-	-	-	BG	SOL
Apidae	*Anthophora atroalba* Lepeletier, 1841 [a]	-	-	-	BG	SOL
	Anthophora dispar Lepeletier, 1841 [a†]	-	-	-	BG	SOL
	Anthophora hispanica (Fabricius, 1787) [a]	-	-	-	BG	SOL
	Anthophora leucophaea Pérez, 1879 [a]	-	-	-	BG	SOL
	Anthophora plumipes Pallas, 1772 [a†]	-	-	-	BG	SOL
	Anthophora romandii Lepeletier, 1841 [a]	-	-	-	BG	SOL
	Anthophora subterranea Germar, 1826 [a]	-	-	-	BG	SOL
	Anthophora sp. [a]	-	-	-	BG	SOL
	Apis mellifera Linnaeus, 1758 [a†]	-	-	-	AG	SOC
	Bombus terrestris (Linnaeus, 1758) [a]	-	-	-	BG	SOC
	Eucera caspica Morawitz, 1873 [a]	-	-	-	BG	SOL
	Eucera nigrilabris Lepeletier, 1841 [a]	-	-	-	BG	SOL
	Nomada agrestis Fabricius, 1787 [a]	-	-	-	-	CLP
	Nomada sp. [a]	-	-	-	-	CLP
	Xylocopa valga Gerstäcker, 1872 [a]	-	-	-	AG	SOL
	Xylocopa violacea Linnaeus, 1758 [a†]	-	-	-	AG	SOL
Halictidae	*Lasioglossum capitale* (Pérez, 1903) [a]	-	-	-	BG	?
	Lasioglossum malachurum (Kirby, 1802) [a†]	-	-	-	BG	SOC
	Lasioglossum mediterraneum (Blüthgen, 1926) [a]	-	-	-	BG	SOC
	Lasioglossum mesosclerum (Pérez, 1903) [a†]	-	-	-	BG	?
	Lasioglossum transitorium (Schenck, 1868) [a]	-	-	-	BG	?

		Megachilidae	*Osmia cornuta* (Latreille, 1805) [a]	-	-	-	AG	SOL
Almond	MA	Andrenidae	*Andrena flavipes* Panzer, 1799 [b]	-	-	-	BG	SOL
			Andrena minutula (Kirby, 1802) [b]	-	-	-	BG	SOL
		Apidae	*Anthophora canescens* Brullé, 1832 [b]	-	-	-	BG	SOL
			Anthophora plumipes Pallas, 1772 [b]	-	-	-	BG	SOL
			Anthophora subterranea Germar, 1826 [b]	-	-	-	BG	SOL
			Apis mellifera Linnaeus, 1758 [b]	-	-	-	AG	SOC
			Bombus terrestris (Linnaeus, 1758) [b]	-	-	-	BG	SOC
			Eucera nigrilabris Lepeletier, 1841 [b]	-	-	-	BG	SOL
			Eucera oraniensis Lepeletier, 1841 [b]	-	-	-	BG	SOL
			Nomada concolor Schmiedeknecht, 1882 [b]	-	-	-	-	CLP
			Xylocopa violacea Linnaeus, 1758 [b]	-	-	-	AG	SOL
		Halictidae	*Lasioglossum malachurum* (Kirby, 1802) [b]	-	-	-	BG	SOC

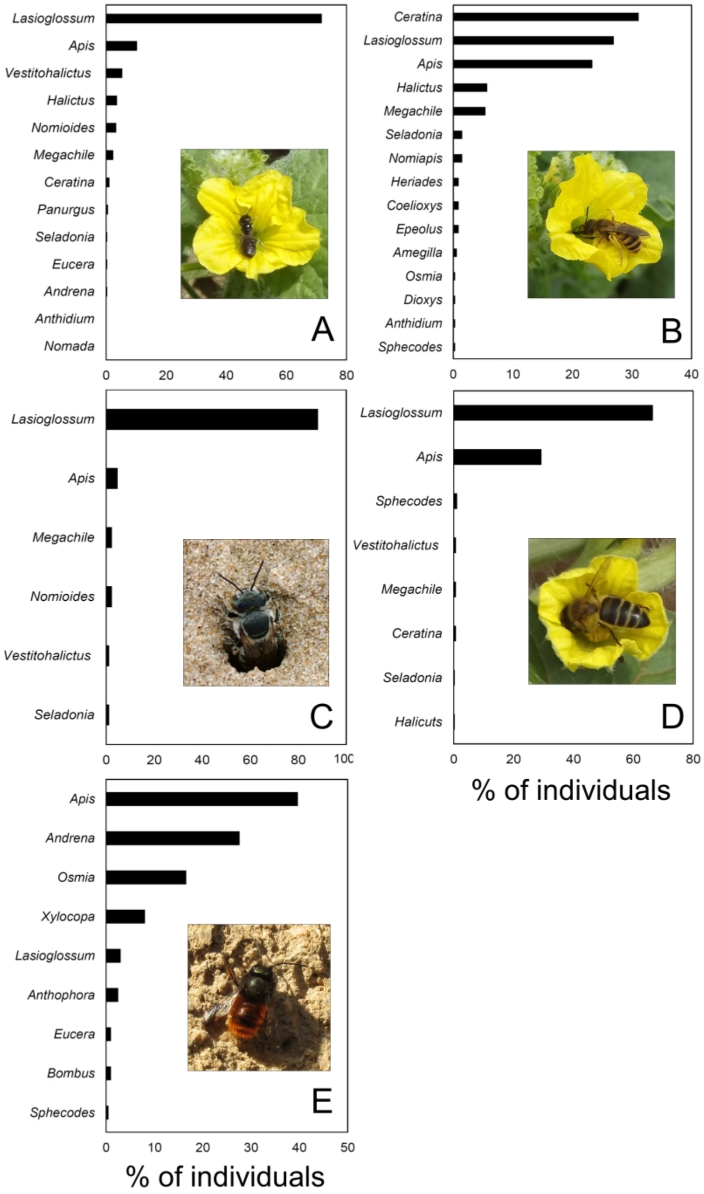
Table 2. Quantitative description of diversity for all nine crop fields. Some parameters could be calculated only for crop fields with abundance data *per* species (- denotes they were not calculated). M: melon, W: watermelon, A: almond. CH: El Chaparrillo (Ciudad Real, Castilla-La Mancha) (new data + Rodrigo Gómez et al. (2016)), CX: Carcaixent (Valencia, Comunidad Valenciana), VR: Villarrobledo (Albacete, Castilla-La Mancha), LP: La Poveda (Madrid, Comunidad de Madrid) (Azpiazu et al. 2020), CA: Corral de Almaguer (Toledo, Castilla-La Mancha) (Azpiazu et al. 2020), GR (Granada province) (Ortiz-Sanchez and Tinaut 1993, 1995), MA (Majorca island) (Alomar et al. 2018).

Parameter	**M (CH)**	**M (CX)**	**M (LP)**	**M (CA)**	**W (CH)**	**W (VR)**	**A (VR)**	**A (GR)**	**A (MA)**
N species	35	33	13	8	14	20	18	37	12
Chao 1	39.7 (35-52)	40.5 (32.7-51.5)	-	-	28 (11.7-32)	25.2 (19.2-37)	18.7 (18-28)	-	-
Shannon index (H)	2.25	2.58	-	-	1.61	2.04	2.06	-	-
Dominance index (D)	0.20	0.12	-	-	0.31	0.18	0.21	-	-
Taxonomic diversity (based on abundance) (Δ)	2.669	3.814	-	-	1.929	2.979	2.85	-	-
Taxonomic distinctness (based on abundance) (Δ*)	3.32	4.316	-	-	2.765	3.641	3.59	-	-
Taxonomic distinctness (based on occurrence) (Δ* = Δ)	4.128	4.33	4.06	4.11	3.714	3.416	4.32	4.03	4.15



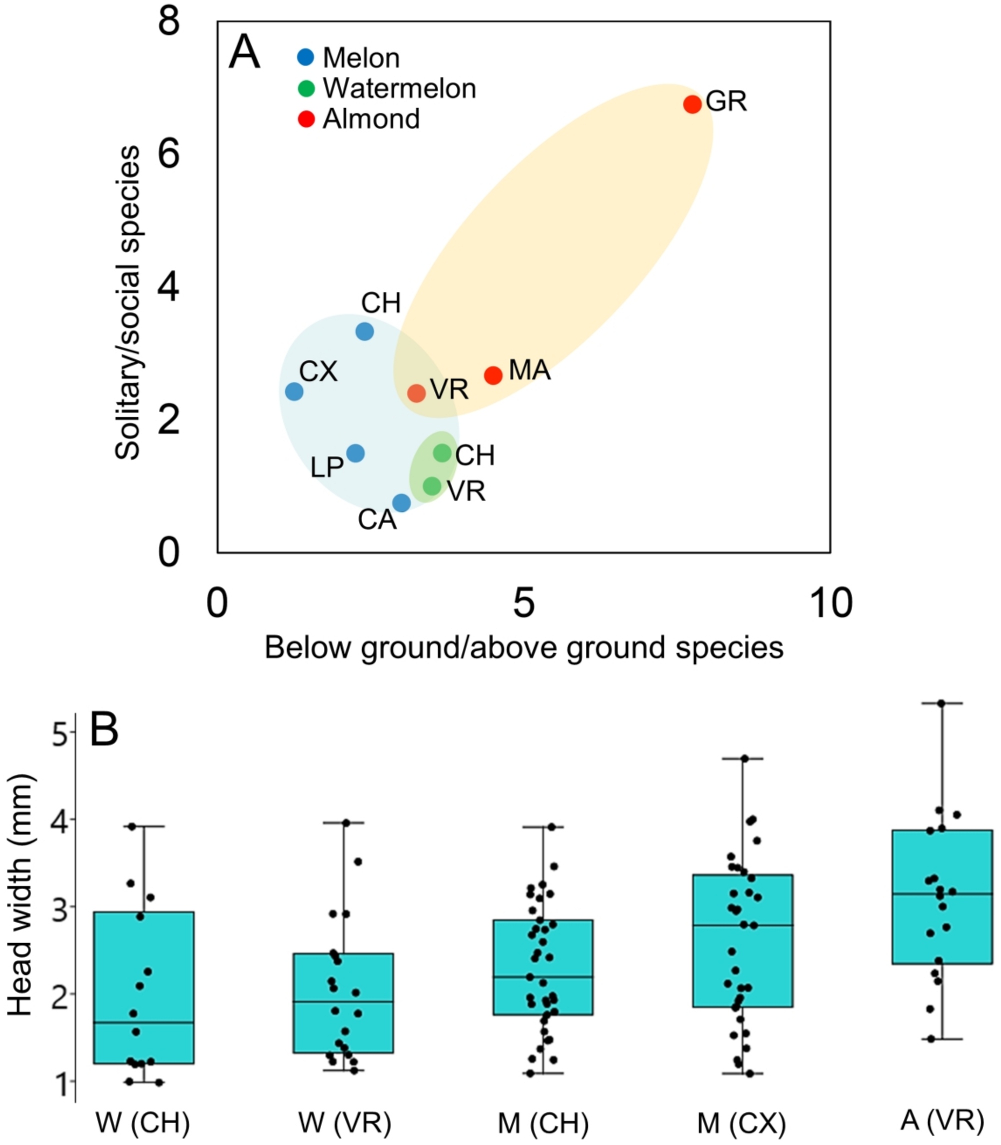
A, Spanish locations where bee communities on melon (M), watermelon (W) and almond (A) crop fields were studied. In red, the locations sampled in this study. CH: El Chaparrillo (Ciudad Real, Castilla-La Mancha) (new data + Rodrigo Gómez et al. (2016)), CX: Carcaixent (Valencia, Comunidad Valenciana), VR: Villarrobledo (Albacete, Castilla-La Mancha), LP: La Poveda (Madrid, Comunidad de Madrid) (Azpiazu et al. 2020), CA: Corral de Almaguer (Toledo, Castilla-La Mancha) (Azpiazu et al. 2020), GR (Granada province) (Ortiz-Sanchez and Tinaut 1993), MA (Majorca island) (Alomar et al. 2018). Note that GR and MA locations are represented by circles instead of points, to evidence that data obtained from different localities within the provinces were presented as pooled in the published articles (circles roughly cover the sampled areas). B, The melon crop field at CH. C, The watermelon crop field at VR. D, The almond crop field at VR.

535x532mm (96 x 96 DPI)



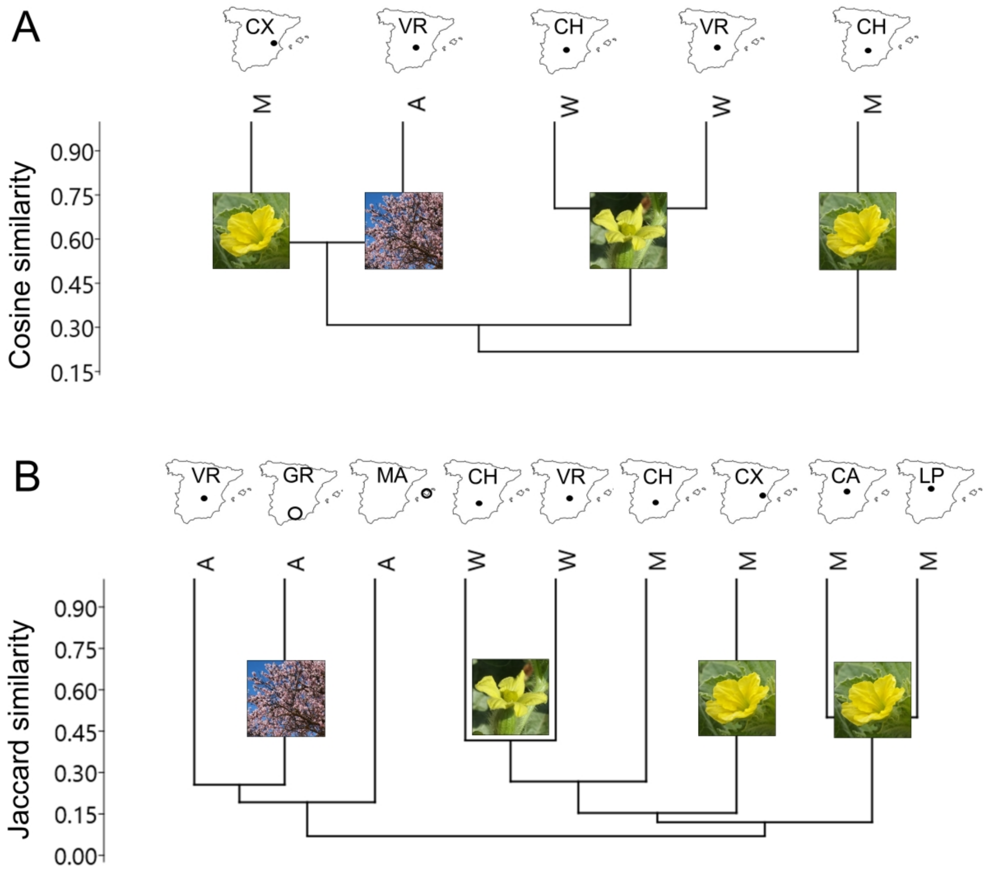
Abundance (% of individuals) of the bee genera collected on melon (A-B), watermelon (C-D) and almond (E) flowers. A, El Chaparrillo (melon); B, Carcaixent (melon); C, El Chaparrillo (watermelon); D, Vollarrobledo (watermelon); E, Villarrobledo (almond). The inset pictures show individuals of Ceratina sp. (A), Halictus scabiosae (B), Megachile leachella (C), Apis mellifera (D) and Osmia cornuta (E).

699x1179mm (96 x 96 DPI)



A, The ratio of below ground-nesting over above ground-nesting species plotted against the ratio of solitary over social species for the nine field crops. B, Box-and-whisker plots showing jitter dots (observed values), medians (horizontal lines within boxes), 1° and 3° quartile (horizontal lines closing the boxes), and maximum and minimum values (ends of the whiskers) of head width (mm) across the collected bee species (mean values across individuals per species) for the five crop fields with abundance data. M: melon, W: watermelon, A: almond. CH: El Chaparrillo (Ciudad Real, Castilla-La Mancha) (new data + Rodrigo Gómez et al. (2016)), CX: Carcaixent (Valencia, Comunidad Valenciana), VR: Villarrobledo (Albacete, Castilla-La Mancha), LP: La Poveda (Madrid, Comunidad de Madrid) (Azpiazu et al. 2020), CA: Corral de Almaguer (Toledo, Castilla-La Mancha) (Azpiazu et al. 2020), GR (Granada province) (Ortiz-Sanchez and Tinaut 1993, 1995), MA (Majorca island) (Alomar et al. 2018).

591x675mm (96 x 96 DPI)



Similarity in bee community composition, obtained from a UPGMA cluster based on the Jaccard similarity of abundance or presence data of species. A, dendrogram using abundance data from five crop fields. B, dendrogram using presence data from nine crop field. M: melon, W: watermelon, A: almond. CH: El Chaparrillo (Ciudad Real, Castilla-La Mancha) (new data + Rodrigo Gómez et al. (2016)), CX: Carcaixent (Valencia, Comunidad Valenciana), VR: Villarrobledo (Albacete, Castilla-La Mancha), LP: La Poveda (Madrid, Comunidad de Madrid) (Azpiazu et al. 2020), CA: Corral de Almaguer (Toledo, Castilla-La Mancha) (Azpiazu et al. 2020), GR (Granada province) (Ortiz-Sanchez and Tinaut 1993, 1995), MA (Majorca island) (Alomar et al. 2018). Points in the blank maps indicate the position of the crop field (note that for Granada and Mallorca data are pooled from the whole respective provinces and thus are indicated by circles, see text for details).

661x584mm (96 x 96 DPI)