Check for updates

Journal of Applied Entomology

WILEY

JOURNAL OF APPLIED ENTOMOLOGY

ORIGINAL ARTICLE

Dominant Wild Pollinators of Moroccan Crops Are Soil Nesting and Pollen Generalist Bees

Insafe El Abdouni[1,2] | Denis Michez[1] | Patrick Lhomme[1,2] | Ahlam Sentil[1,2] | Laila Hamroud[1,2] | Oumayma Ihssane[1,2] | Youssef Bencharki[1,2] | Ayyoub Skaou[3] | Pierre Rasmont[1] | Stefanie Christmann[2]

[1]Research Institute for Biosciences, Laboratory of Zoology, University of Mons, Mons, Belgium | [2]International Center for Agricultural Research in the Dry Areas, Avenue Hafiane Cherkaoui, Rabat, Morocco | [3]Laboratory of Water Science, Microbial Biotechnology, and Sustainability of Natural Resources, Faculty of Science, Cadi Ayyad University, Semlalia, Marrakech, Morocco

Correspondence: Insafe El Abdouni (elabdouni.insafe@gmail.com)

Received: 15 January 2025 | **Revised:** 16 April 2026 | **Accepted:** 24 April 2026

Keywords: agroecosystem | crop flower-visitation | functional traits | ground-nesting bees | pollen generalist

ABSTRACT

Crop pollination by animals is a crucial ecosystem service that enhances the yield and the quality of 75% of major food crops worldwide. Wild bees play a significant role in this process as they are diverse and abundant visitors to crops and are known for their efficiency. However, in many parts of the world, including Morocco, there is no available commented list of wild bee species visiting crops (crop-associated species). Here, we investigated the presence of wild bees associated with agricultural landscapes and described key trait characteristics of these bee species. Pollinator communities were sampled by sweep net and pan trapping across a total of 263 fields containing nine flowering main crops in 2018–2019. Key crop-visiting species were identified as those species which made up 5% or more of the individuals visiting the flowers of each crop. Out of the 359 pollinator species occurring in agroecosystems, 156 were crop-associated bee species and only 26 bee species were classified as key crop-pollinating species. The bee communities observed in the crops were predominantly composed of widespread, solitary, pollen generalist, ground-nesting bees with an extended flight season. Our findings provide essential baseline data on crop flower visitors which can contribute to the enhancement of the regional understanding of wild bee diversity and functional traits associated with crop pollination. Moreover, this information can facilitate the implementation of conservation strategies to improve wild-bee habitats within agricultural landscapes.

1 | Introduction

Animal-mediated crop pollination is an essential ecosystem service that significantly enhances both the yield and the quality of 75% of major crops (IPBES 2016; Klein et al. 2007). Wild bees, known for their diversity and abundance as well as their adapted morphology and behaviour, serve as crucial pollinators worldwide (Rader et al. 2016; Reilly et al. 2020), including Morocco (El Abdouni et al. 2022). Numerous studies have demonstrated the remarkable efficiency of wild bees in pollination (Kleijn et al. 2015; Rauf et al. 2021; Winfree et al. 2008).

At community level, several studies have demonstrated the correlation of bee species diversity and both pollination efficiency and yield (Garibaldi et al. 2013; Mallinger and Gratton 2015). This correlation was generally found to be positive between bee abundance and these same factors. (Blitzer et al. 2016; Winfree et al. 2015; Woodcock et al. 2019). Despite the presence of diverse bee fauna in various agroecosystems (El Abdouni et al. 2022), the crop pollination service seems to remain largely dependent on a few dominant and common bee species (Kleijn et al. 2015). For example, in Europe, a small number of bee species, each accounting for over 5% of the community's abundance, are

© 2026 Wiley-VCH GmbH. Published by John Wiley & Sons Ltd.

responsible for 80% of crop pollination (Kleijn et al. 2015). It is also worth noting the findings of MacLeod et al. (2020) in the USA, who discovered that many dominant wild crop pollinators are classified as rare at the regional scale. Nevertheless, there is still a significant knowledge gap regarding the trait characteristics of these abundant species, particularly in Africa.

Bee morphology and behaviours (i.e., life-history traits) play a significant role in how bee species interact with their environment (Schleuning et al. 2015). These traits also partly explain species resilience facing environmental changes such as habitat fragmentation, agricultural intensification and climate change (Duchenne et al. 2020; Pardee et al. 2022; Scheper et al. 2014). On the other hand, bee functional traits influence crop pollination services (Aguirre-Gutiérrez et al. 2016; Maas et al. 2021). These traits affect the amount of pollen that is foraged on the anthers and deposited on the stigma of a flower during visitation, thereby influencing fruit and seeds production (Blitzer et al. 2016). In Europe and Northern America, several studies have focused on describing the traits of bee species present in agroecosystems and visiting crops. For instance, it was found that generalist, solitary and ground-nesting bees tend to dominate in orchards, blueberry and sunflower fields (Forrest et al. 2015; Nooten et al. 2020).

The limited number of species that ensure most of crop pollination may be susceptible to environmental stressors, necessitating their conservation efforts to maintain pollination services (Potts et al. 2016). To develop effective conservation strategies, it is essential to identify bee species visiting crop flowers and study their life-history traits (Garratt et al. 2014; Nieto et al. 2014).

Morocco stands out as one of the most biodiverse countries for bees in the Mediterranean region (Lhomme et al. 2020), particularly in agroecosystems (El Abdouni et al. 2022). The country is also renowned for its diverse crop production, which contributes significantly to the economy, accounting for 13% of Morocco's Gross Domestic Product (GDP) (Direction des Études et des Prévisions Financières 2019). Approximately 10% of the country's total cropland is dedicated to pollinator-dependent crops, which contribute around 27% of the total value of crop yield (Sabbahi 2022). The economic value of crop pollination in Morocco is estimated at ~1235 M USD$ equivalent to 8.5% of the country's agricultural GDP (Sabbahi 2022). Additionally, pollinator-dependent crops serve as a major source of essential vitamins and nutrients for the human diet (Chaplin-Kramer et al. 2014; Eilers et al. 2011; Ghosh and Jung 2018).

There is a significant and pressing need for further investigations on crop pollinators and wild bee diversity in Morocco. In this context, this study aimed to (1) identify key crop-visiting bee species (KCVBS) occurring in Moroccan agroecosystems, based on their visitation to the flowers of the studied crops, (2) investigate the diversity of KCVBS compared to bee diversity in agroecosystems and (3) describe the spatial patterns and trait characteristics of KCVBS.

These inquiries will help deepen our understanding of the dynamics between wild bees and crop pollination in Morocco, contributing to the development of effective conservation and management strategies.

2 | Material and Methods

2.1 | Study Areas and Sampling Methods

Our study is based on the dataset described in El Abdouni et al. (2022). In 2018 and 2019, we sampled a total of 263 fields encompassing nine different main crops (i.e., faba bean, zucchini, pumpkin, tomato, eggplant, melon, apple, cherry, and okra) in four regions of Morocco. (i.e., Casablanca-Settat, Rabat-Sale-Kenitra, Draa-Tafilalet and Fes-Meknes) (Figure 1). The sampling methodology involved walking transects within the main crop areas and the surrounding fields. Within the crop, we carried out two walking transects of five minutes while two additional transects were performed outside the main crop (total of 10 min of sampling in 2018 and 15 min in 2019). In addition to transects, we used three sets of three coloured pan traps (yellow, white and blue), consisting of a total of nine pan traps. Two sets of pan traps were placed within the main crops and the third set was placed outside the field (for further details, see the supplementary methods). However, as a complementary sampling method, pan traps may favour certain bee groups (e.g., small ground-nesting species) and may therefore influence the taxonomic composition of the dataset. The data set used in this study comprises a total of 17,676 wild bee individuals sampled from all transects and pan traps across all agroecosystems. It includes 2338 bee individuals that visited at least one of the nine main crops within the four regions.

2.2 | Key Crop-Visiting Bee Species and Their Relative Dominance in Agroecosystems

In this study, we classified wild bee species into three categories. (1) All bees: including those collected and identified to species level within agroecosystems. (i.e., inside and outside the crops); (2) Bee visiting crops (crop-associated species): encompassing bee species that were associated to crop flowers; (3) KCVBS: including dominant bee species observed visiting crops the flowers of the studied. To identify the KCVBS, we considered only individuals collected from crop flowers during the flowering period. Following Kleijn et al. (2015), we defined KCVBS as the most abundant species, representing ≥ 5% of the total abundance of individuals collected per crop in each region (Figure 2). This threshold ensures that only the most frequent visitors are included, thereby reducing the influence of rare or accidental species (MacLeod et al. 2020; Vázquez et al. 2005).

In order to compare bee diversity among the aforementioned bee communities (i.e: all bees, Bee visiting crops and KCVBS), we used the iNEXT package (Chao et al. 2014) to calculate the rarefied species richness and Shannon index. This allowed us to compute the Hill numbers (diversity estimates) for each bee community. The rarefaction process was based on the smallest number of bee individuals (1304 bee individuals) collected in our trials ensuring meaningful standardization across the bee communities.

We assessed the total dominance of KCVBS (Dt) in each agroecosystem by calculating the ratio between the total number of KCVBS individuals collected in each crop and the total number of bee species collected within this crop in each region. We also

14390418, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/jen.70019 by Denis Michez - Universitaet De Mons (Umons) , Wiley Online Library on [13/05/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

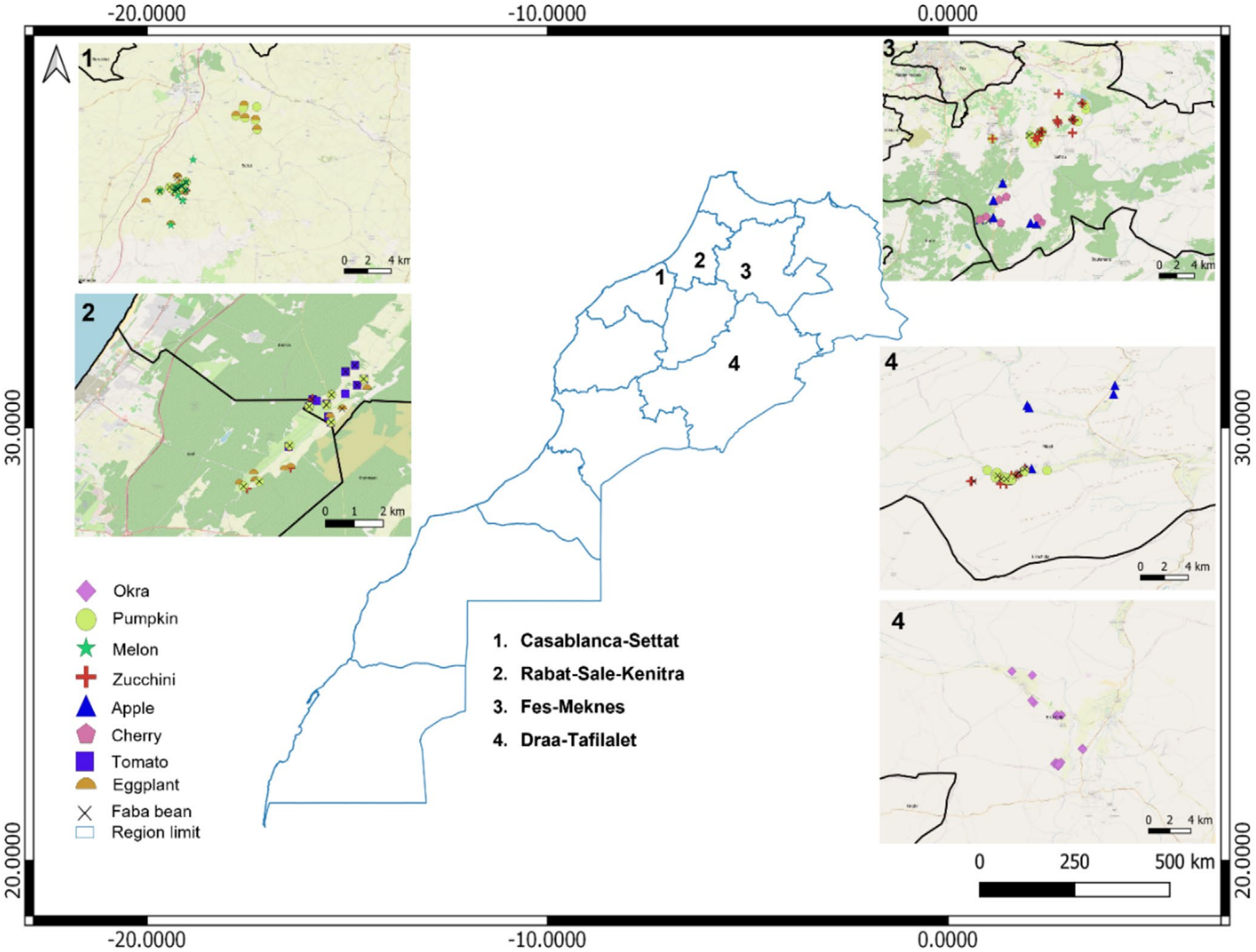

FIGURE 1 | Map of Morocco illustrating the locations of crop trials (from El Abdouni et al. 2022). [Colour figure can be viewed at wileyonlinelibrary.com]

assessed the dominance (Ds) of each KCVBS species by dividing the total abundance of each KCVBS by the total abundance of all bees collected in all agroecosystems.

To compare crops based on the relative abundance of their KCVBS inside and outside the crop, we calculated the ratio between the relative abundance of each KCVBS found on the crop and the relative abundance of this species outside the crop. We obtained the ratio (R) for each species in each crop in each region (Table S2). Then we calculated the average of this ratio per crop.

2.3 | Field Occurrence and Life-History Traits of the Key Crop-Visiting Bee Species

In order to generate the field occupancy value for each KCVBS, we used the full data collected in the four regions studied (i.e., 17,676 specimens). We calculated values based on the presence/absence of the species in each sampled field (263 fields). We classified species into three categories: widespread bee species where field occupancy $\geq 50\%$, bee species with medium distribution where $5\% <$ field occupancy $< 50\%$, bee species with restricted range where field occupancy $\leq 5\%$ (Mouillot et al. 2013).

The relationship between field occupancy for each KCVBS ($n = 26$ species) and their dominance Ds (described above) was assessed using Spearman's rank correlation implemented in the "stats" R package.

We focused on a small set of bee functional traits representing the most common traits used in previous research: nesting behaviour, sociality, host-plant specialization, and seasonality (Graham et al. 2024). We characterized nesting (above vs. underground) and sociality (social or eusocial and primitively eusocial vs. solitary) based on relevant literature (Michener 2007). We also categorized the bee floral choices into two categories: oligolectic vs. polylectic species (i.e., pollen specialist vs. pollen generalist). To assign flight season, we assembled a database of specimen sampling dates from our field data. We then scored each species as being present or absent in each season (i.e., Spring: March–April–May; Summer: June–July–August; Autumn: September–October–November) and assigning a seasonal category: occurring in spring, spring–summer, and spring-autumn.

All analyses in this study were conducted using statistical software R 3.6.1 (R Core Team).

14390418, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/jen.70119 by Denis Michez - Universitaet De Mons (Umons), Wiley Online Library on [13/05/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

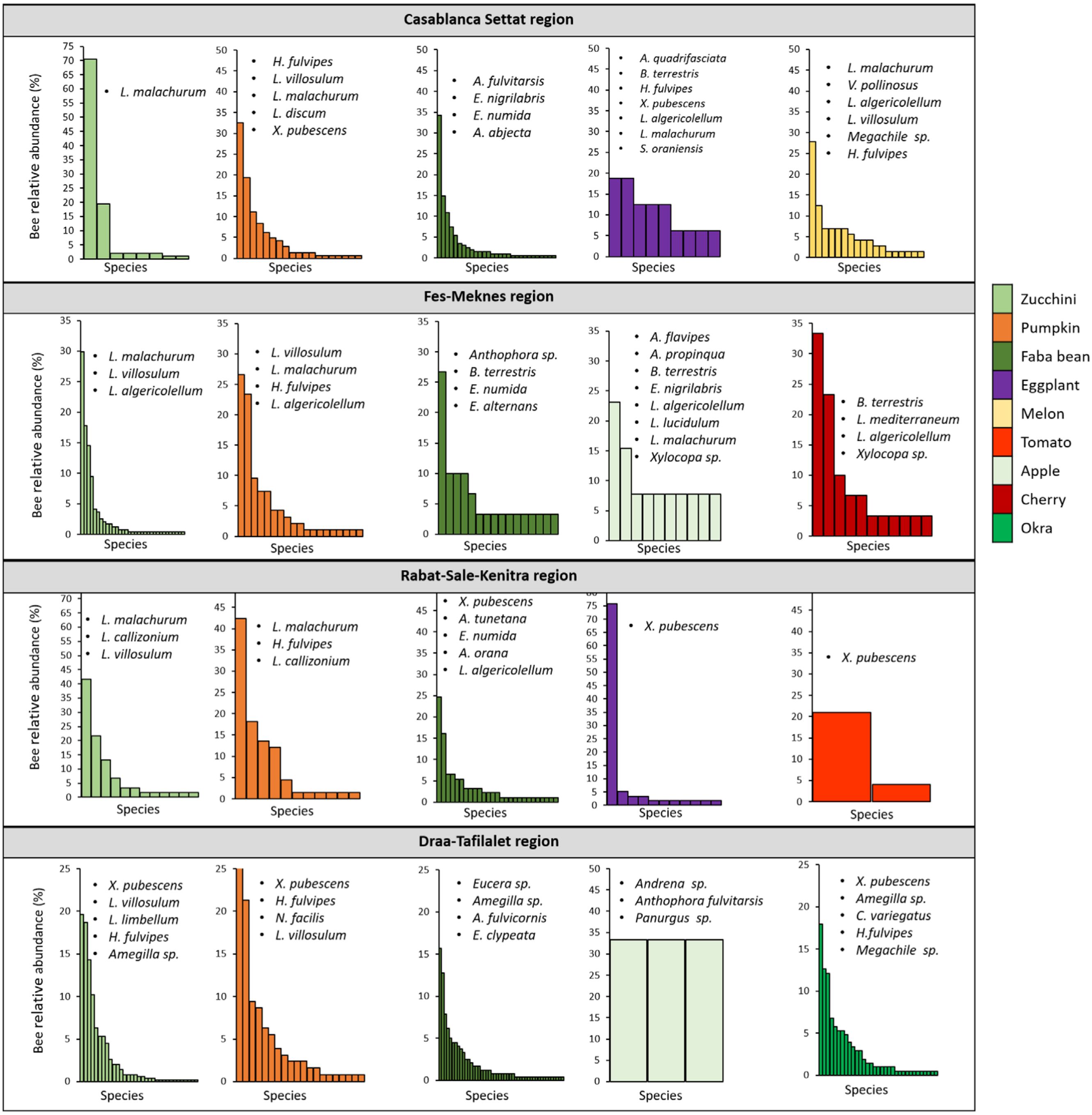

FIGURE 2 | The relative abundance of bee species visiting each crop in four regions in Morocco. The list per figure represents key crop-visiting bee species with 5% or more of the total bee individuals collected by each crop for 2 years (2018 and 2019): Zucchini, pumpkin, faba bean, eggplant, melon, tomato, apple, cherry and okra. The *X*-axis rufers to identified species, Y labels refers to bee relative abundance (%). Bars without species names represent unidentified species. [Colour figure can be viewed at wileyonlinelibrary.com]

3 | Results

3.1 | Diversity and Abundance of Bee Species in Moroccan Crops and Agroecosystems

A total of 359 bee species were collected and identified across the studied agroecosystems; among these, 156 are crop-associated bee species and 26 species are defined as KCVBS. These species belong to three families (Andrenidae, Apidae, and Halictidae) and 11 genera. The number of KCVBS varied across crops and regions. For example, we found only one wild bee species as dominant on zucchini in the Casablanca-Settat region, while in Draa-Tafilalet, we identified five species (Figure 2).

When assessing species richness based on the rarefied number of specimens, we observed variations among the three groups (i.e., all bees, bee visiting crops, KCVBS). Agroecosystems demonstrated a high level of diversity compared to crops. Moreover, only a small number of species were found to be

14390418, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/jen.70119 by Denis Michez - Universitat De Mons (Umons) , Wiley Online Library on [13/05/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

dominant on crops, accounting 14% of the total rarified species richness for all bees, 20% of rarified species richness for bees visiting crops and 2.7% of the national richness. The same pattern was observed when considering the Shannon diversity index (Sall bees = 70.57; Scv = 35.91 and Scp = 12.69) (Table 1).

Taking into account the dominance of KCVBS within agroecosystems, they represent 28% ± 16% on average. Notably, pumpkin in the Casablanca-Settat region exhibited the highest dominance with 57% while tomato and eggplant in the Rabat-Sale-Kenitra region had the lowest dominance with 3% (Table S1).

3.2 | Spatial Distribution and Traits of Bee Species in Moroccan Crops and Agroecosystems

For field occupancy, three species were classified as widespread with occupancy exceeding 50%. These species are all from the genus *Lasioglossum*: *L. algericolellum*, *L. malachurum*, and *L. villosulum*. Twenty species had medium occupancy, and three species had restricted occupancy. Relating field occupancy of each KCVBS and their dominance, we found a positive relationship between the two variables ($n = 26$, p value $< 0.001 = 2.964e^{-08}$; ρ (rho) = 0.854) (Figure 3).

TABLE 1 | Observed and rarified species richness, Shannon diversity for the three bee communities.

	Diversity Index	Observed diversity	Rarefied diversity	LCL	UCL
All Bees	Species richness	359	182.55	179.67	185.43
	Shannon diversity	79.04	70.57	69.02	72.12
Bee visiting crops	Species richness	156	128.58	121.96	135.21
	Shannon diversity	37.14	35.91	33.69	38.14
Key crop-visiting bee species	Species richness	26	26	25.30	26.70
	Shannon diversity	12.69	12.69	11.96	13.42

Note: The rarefaction was obtained basing on the minimum number of collected individuals (1304 bee individuals).

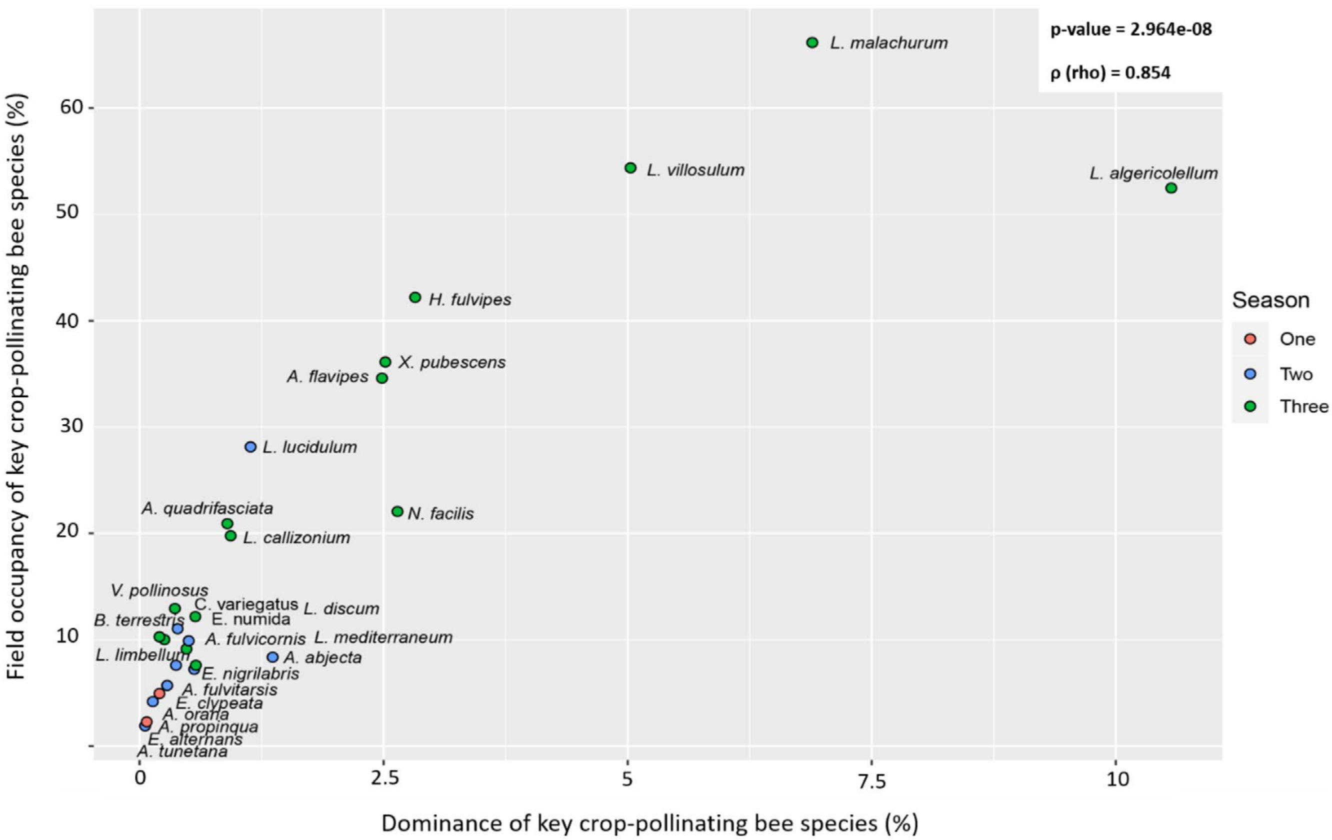

FIGURE 3 | Relationship between field occupancy of key crop-visiting bee species and their field dominance and seasonality in Moroccan agroecosystems. Coloured cercles refer to each key crop-visiting bee species and colours to each seasonal category (one: Key crop-visiting bee species flying during one season, two: Key crop-visiting bee species flying during two seasons and key crop-visiting bee species flying during three seasons). [Colour figure can be viewed at wileyonlinelibrary.com]

14390418, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/jen.70119 by Denis Michez - Universitaet De Mons (Umons), Wiley Online Library on [13/05/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

The species assemblage of the KCVBS was dominated by solitary, polylectic, and ground-nesting bees with a long flight season (Figure 4). Comparing traits between the three communities, we found that bee species with a long flight season (occurring in two or three seasons) represent 92% of KCVBS, 66% of bee species visiting crops, and 41% of all bees. While ground-nesting bees dominate all communities with 96% for KCVBS, 89% for bee species visiting crops, and 81% for all bees (Figure 4).

The comparison of the mean ratio R (described above) showed differences between crops. KCVBS were found to be more abundant on crops like tomato, apple, and eggplant than outside the crops. While other crops like pumpkin, zucchini, and okra were visited by KCVBS, which are common and abundant also outside the crops (Figure 5).

4 | Discussion

4.1 | Diversity and Abundance of Bee Species in Moroccan Crops and Agroecosystems

Our study represents the first attempt to characterize the wild bee community associated with multiple crops in Morocco.

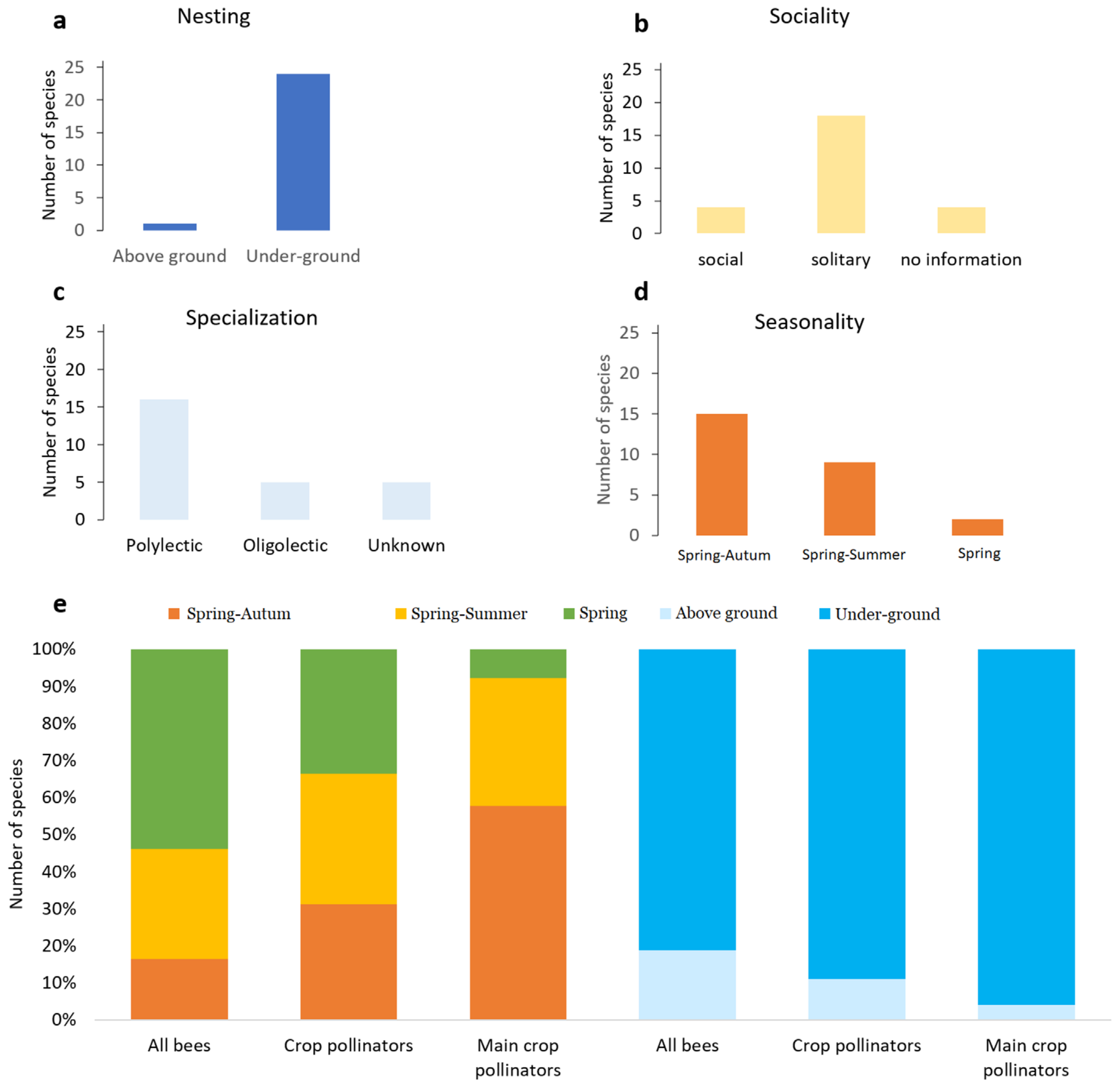

FIGURE 4 | Life-history traits of key crop-visiting bee species in Moroccan agroecosystems: (a) nesting behaviour, (b) sociality, (c) pollen specialization group and (d) flight season duration. The total number of key crop-visiting bee species is 26 species collected in four regions and on nine crops (zucchini, pumpkin, tomato, eggplant, faba bean, apple, cherry, melon and okra). (e) represents the percentage of bee species richness comparison between three categories of bee communities collected in Moroccan agroecosystems considering nesting behaviour and seasonality. [Colour figure can be viewed at wileyonlinelibrary.com]

14390418, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/jen.70119 by Denis Michez - Universitat De Mons (Umons) , Wiley Online Library on [13/05/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

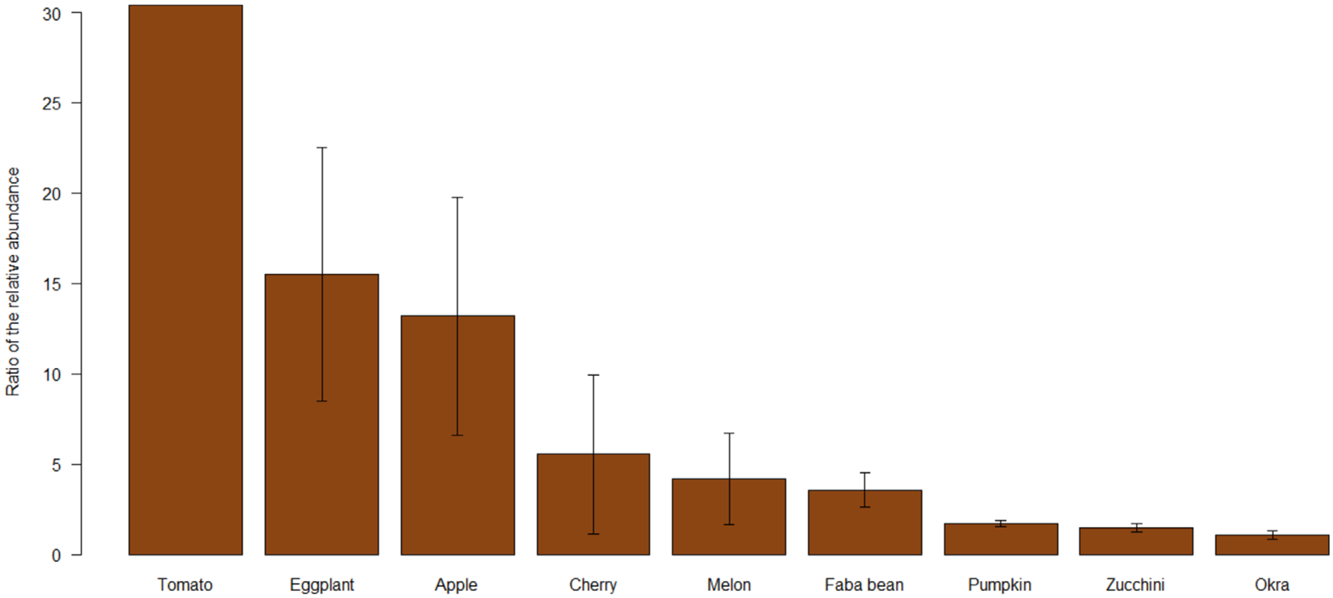

FIGURE 5 | Bar graph showing the average ratio of the relative abundance of key crop-visiting bee species collected on crops and outside the crops. Error bars indicate mean ± SE between crops. [Colour figure can be viewed at wileyonlinelibrary.com]

Our findings demonstrate that Moroccan agricultural landscapes harbour diverse communities in terms of species diversity and functional traits. However, we discovered that a small group of bee species dominates crop flower visitation (i.e., accounting for more than 5% of the total abundance). KCVBS make up 20% of the bee visiting crops richness, 14% of the total rarified species richness in studied agroecosystems. Concerning the national richness (Lhomme et al. 2020), KCVBS represent around 3%. These results are consistent with studies conducted in different regions worldwide (Hutchinson et al. 2021; Kleijn et al. 2015; MacLeod et al. 2020; Pisanty and Mandelik 2015). For instance, Kleijn et al. (2015) found that only 2% of regional bee community provides significant pollination services worldwide. Similarly, MacLeod et al. (2020) observed that 18% of crop visitors were classified as dominant bees visiting crops. This marked discrepancy may reflect differences in biogeographic history between regions, cropping systems and landscape complexity. Furthermore, variation in methodological approaches, sampling intensity and taxonomic resolution could also contribute to the observed contrast (Bonfanti et al. 2025; Bottero et al. 2023).

At the agroecosystem level, key crop-visiting bee species tend also to dominate bee communities, accounting for an average of 28%. However, this proportion is higher in European and north American agricultural landscapes, with values of 75% and 59% respectively (Kleijn et al. 2015).

4.2 | Spatial Distribution and Traits of Bee Species in Moroccan Crops and Agroecosystems

In terms of occurrence, our study revealed that KCVBS are generally associated with large and medium occupancy, occurring in the majority of surveyed fields (i.e., in various regions). In addition, a strong positive correlation between field occupancy and species dominance was observed and confirmed by Spearman's rank correlation ($n = 26$, $p < 0.001$), indicating that bee species occurring in a higher proportion of sampled fields also tended to be dominant. The three species *Lasioglossum algericolellum*, *L. malachurum* and *L. villosulum* that we found to be widespread are also known to be well represented and broadly distributed across agricultural, natural, and semi-natural landscapes (Polidori et al. 2010; Wood et al. 2016). The latter two species are moderately polylectic, visiting a wide range of wild and cultivated plant species, with a marked preference for members of the Asteraceae family (Polidori et al. 2010; Wood et al. 2016). Furthermore, their underground nesting behaviour and long activity period make them stable components of pollinator communities (Polidori et al. 2010; Wood et al. 2016). In contrast, *L. algericolellum* remains poorly studied compared to the other two species. However, we also observed that species with restricted field occupancy contribute to crop flower visitation. These species account for 12% of key crop-pollinating bees (i.e., *Andrena tunetana*, *A. propinqua*, *Eucera alternans*). This finding aligns closely with the results found by (MacLeod et al. 2020) in the USA, who reported that 19% of dominant bees are classified as regionally rare species. Moreover, it has been found that rare species play a crucial role in the pollination services of both wildflowers and crops (Genung et al. 2022). Among the species with restricted field occupancy, we observed that two species have a short flight season, mainly occurring in spring. This flight duration factor has been identified as the most important trait influencing the occurrence and abundance of European bees in croplands (De Palma et al. 2015).

In the studied agroecosystems, we observed the dominance of ground-nesting bees, accounting for 81% of the total bee population and 96% of the KCVBS. This result aligns with previous knowledge that wild bee species nesting in the soil dominate the overall wild bee fauna (Michener 2007), and they are also more abundant as crop pollinators (Christmann 2022; Everaars 2012).

14390418, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/jen.70119 by Denis Michez - Universitat De Mons (Umons) , Wiley Online Library on [13/05/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Moreover, several studies demonstrated that landscape simplification (transitioning from semi-natural to agricultural landscape) restricts the presence of above-ground nesting bees due to the scarcity of suitable nesting materials (St. Clair et al. 2022).

Within the agroecosystems and among the main crop flower visitors, we found that most species exhibit a long flight season, occurring in at least two seasons. This result is in line with an European study that demonstrated a positive relationship between the flight season duration and the probability of occurrence and abundance in croplands (De Palma et al. 2015). Similarly, we found that social and specialist bee species were less prominent among the main crop flower visitors in our fields. This finding aligns with the explanation provided by (Williams et al. 2010) who attributed this pattern to the detrimental impact of agricultural intensification on social and specialist bees.

The average ratio of the relative abundance of key crop-visiting bee species on crops and outside the crop was found different between studied crops. For instance, pumpkin, zucchini, and apple for example demonstrated high KCVBS dominance, likely due to their abundant, easily accessible nectar and pollen, which attract a wide range of pollinators. In contrast, Tomato and eggplant crops, in particular, displayed higher selectivity (low KCBS dominance ~3%), being specifically pollinated by a single species, *Xylocopa pubescens*, in the Kenitra region (Figure 1). This outcome can be attributed to the unique pollination process of these crops known as 'buzz pollination' (Jayasinghe et al. 2017; Toni et al. 2020). In buzz-pollinated flowers, pollen is less accessible to most bees, resulting in lower rewards for non-sonicating visitors (Cooley and Vallejo-Marín 2021). Despite the presence of other species that can ensure this type of pollination, such as *Bombus terestress* no visits were observed on tomato crops, and only a single visit on eggplant, which can be attributed to its generally low abundance in the study area. Relying on a single species to ensure pollination of such of crops can present several risks, including vulnerability to species decline, temporal or spatial mismatches, limited resilience of pollination service, as well as pollination deficits and reduced yields (Marshall et al. 2023; Rahimi and Jung 2025; Vasiliev and Greenwood 2020). However, managed *Bumbus* species are widely used to pollinate crops requiring buzz pollination such as tomato, particularly under greenhouse conditions (Cooley and Vallejo-Marín 2021). In addition, *Xylocopa pubescens* in the Kenitra region could represent a viable alternative pollinator, as it has also been demonstrated to be effective on various crops, including sunflower, squash, tomato, and eggplant (Hogendoorn et al. 2000; Sadeh et al. 2007).

4.3 | Perspectives for Conservation

The first objective of this study was to identify bee species associated with crop flower visitation in Moroccan agroecosystems and highlight key ecological characteristics. This information is crucial for enhancing our understanding of bee ecology in Morocco and in Northern Africa, assessing the sensitivity of bee communities in agroecosystems to agricultural management, and developing effective conservation strategies (Kammerer et al. 2021; Nowakowski and Pywell 2016). It is also valuable to advise decision makers on agricultural landscapes like farmers, agricultural advisors, and policymakers.

The distribution range of bee species is a key consideration in conservation plans. Numerous studies have demonstrated that species with smaller geographic range are often more vulnerable (Loiseau et al. 2020). Conservation strategies, such as planting flowering plants, have been shown to benefit rare bee species in agricultural lands in European systems for example (Kremen and M'Gonigle 2015; MacLeod et al. 2020). In our context, preserving floral diversity in agroecosystems by sustainable agriculture practices (i.e., low weeding intensity) could benefit pollinator diversity (Sentil et al. 2022). Enhancing fields by borders or strips of marketable habitat enhancement plants like oil seeds, spices, vegetables or forage plants (Farming with Alternative Pollinators (FAP)) might be more attractive for farmers (Christmann and Aw-Hassan 2012; Christmann et al. 2017, 2021). Sentil et al. (2022) demonstrated that FAP fields with marketable habitat enhancement plants support even higher pollinator diversity than wild plants. Moreover, our findings suggest that conservation strategies should consider the interactions between pollinators and crops. It is important to implement practices that enhance bee habitats (Christmann et al. 2017, 2021; Christmann and Aw-Hassan 2012; Van Drunen et al. 2022) and promote efficient crop flower visitation. For instance, in the case of tomato and eggplant production, it is necessary to sustain *X. pubescens* in farms by providing nesting substrates (i.e., died wood), among other measures.

Ground-nesting bees were found to dominate Moroccan agroecosystems. As several studies demonstrated that landscape simplification (transitioning from semi natural to agricultural landscape) restricts the presence of above-ground nesting bees due to the scarcity of suitable nesting materials (St. Clair et al. 2022), this information is valuable in guiding agricultural practices towards reduced tillage and pesticide usage (Appenfeller et al. 2020; Stuligross and Williams 2020; Tschanz et al. 2022; Ullmann et al. 2016). Additionally, leaving areas of bare soil for nesting or areas with perennial crops without tillage and pesticides can help to conserve this particular group of bees within agricultural landscape (Christmann 2022; Thuiller et al. 2020). Ground-nesting bees are particularly susceptible to pesticide use, as they are more exposed to pesticide residues in the soil at various stages of their life (larval, pupal or adult) (Rondeau and Raine 2022).

It is crucial to establish a list of important bee species pollinating crops, along with their distribution and their key ecological characteristics. This initiative is essential to enhance the national database and facilitate targeted monitoring and conservation strategies (Hutchinson et al. 2021). Moreover, this information can be utilized to educate farmers about the presence and the role of wild bees on their farms and raise awareness about the implementation of practices aimed at conserving pollinators and enhancing pollination services (Christmann et al. 2021). Although progress has been made in this field in Morocco, there is still a lot of work to be done. It is desirable to conduct studies in different regions and crops to derive more generalizable conclusions regarding the diversity of crop pollinators, the interaction between pollinators and crops, and the vulnerability of Moroccan agroecosystems to environmental stressors. Additionally, further research is needed to establish a national monitoring system for wild bees and other wild pollinators, focusing on their geographic distribution, foraging behaviour, and

14390418, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/jen.70019 by Denis Michez - Universitaet De Mons (Umons) , Wiley Online Library on [13/05/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

life history. These future studies will contribute to expanding our knowledge about pollinators in this understudied country (Orr et al. 2021) and will help in developing a comprehensive conservation framework.

Author Contributions

Insafe El Abdouni: conceptualization, investigation, writing – original draft, methodology, visualization, writing – review and editing, formal analysis, data curation. **Ahlam Sentil:** data curation. **Patrick Lhomme:** methodology, writing – review and editing, data curation, supervision. **Oumayma Ihssane:** writing – review and editing, data curation. **Denis Michez:** conceptualization, funding acquisition, methodology, writing – review and editing, supervision, validation, project administration. **Youssef Bencharki:** writing – review and editing, data curation. **Ayyoub Skaou:** writing – review and editing, formal analysis. **Laila Hamroud:** data curation, writing – review and editing. **Pierre Rasmont:** conceptualization, funding acquisition, supervision, writing – review and editing, validation, project administration. **Stefanie Christmann:** funding acquisition, writing – review and editing, supervision, project administration, validation.

Acknowledgements

We thank all specialists that contributed to the taxonomical expertise: Holger H. Dathe, Achik Dorchin, Alain Pauly, Sebastien Patiny, Michael Terzo, Andreas Müller, Michael Kuhlmann, Thomas J. Wood, and Christian Schmid-Egger. We also received great help from Dr. Moulay Chrif Smaili, who contributed to farmers' selection and worked on pests and natural enemies. We also thank Dimitri Evrard for his support in data management and digitization.

The work is part of an ICARDA project funded by the German Federal Ministry for the Environment, Nature Protection and Nuclear Safety (BMU) within the International Climate Initiative (IKI). It was also partly supported by the 'Research Foundation of Flanders – FWO' under the EOS Project named CLIPS (n°3094785) and by the 'Académie de Recherche et d'Enseignement Supérieur (ARES)'.

Funding

This work was supported by The German Federal Ministry for the Environment, Nature Protection and Nuclear Safety (BMU) within the International Climate Initiative (IKI). Académie de recherche et d'enseignement supérieur (ARES) and 'Research Foundation of Flanders – FWO' under the EOS Project named CLIPS.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are openly available in Dryad at https://doi.org/10.5061/dryad.0gb5mkmgj.

References

Aguirre-Gutiérrez, J., W. D. Kissling, L. G. Carvalheiro, M. F. WallisDevries, M. Franzén, and J. C. Biesmeijer. 2016. "Functional Traits Help to Explain Half-Century Long Shifts in Pollinator Distributions." *Scientific Reports* 6, no. 24451: 1–13. https://doi.org/10.1038/srep24451.

Appenfeller, L. R., S. Lloyd, and Z. Szendrei. 2020. "Citizen Science Improves Our Understanding of the Impact of Soil Management on Wild Pollinator Abundance in Agroecosystems." *PLoS One* 15, no. 3: 1–15. https://doi.org/10.1371/journal.pone.0230007.

Blitzer, E. J., J. Gibbs, M. G. Park, and B. N. Danforth. 2016. "Pollination Services for Apple Are Dependent on Diverse Wild Bee Communities." *Agriculture, Ecosystems and Environment* 221: 1–7. https://doi.org/10.1016/j.agee.2016.01.004.

Bonfanti, J., J. Langridge, A. Avadí, et al. 2025. "Geographic, Taxonomic and Metric Gaps in Biodiversity Research Limit Evidence-Based Conservation in Agricultural Landscapes: An Umbrella Review." *Ecology Letters* 28, no. 10: e70220. https://doi.org/10.1111/ele.70220.

Bottero, I., C. Dominik, O. Schweiger, et al. 2023. "Impact of Landscape Configuration and Composition on Pollinator Communities Across Different European Biogeographic Regions." *Frontiers in Ecology and Evolution* 11: 1128228. https://doi.org/10.3389/fevo.2023.1128228.

Chao, A., N. J. Gotelli, T. C. Hsieh, et al. 2014. "Rarefaction and Extrapolation With Hill Numbers: A Framework for Sampling and Estimation in Species Diversity Studies." *Ecological Monographs* 84, no. 1: 45–67. https://doi.org/10.1890/13-0133.1.

Chaplin-Kramer, R., E. Dombeck, J. Gerber, et al. 2014. "Global Malnutrition Overlaps With Pollinator-Dependent Micronutrient Production." *Proceedings of the Royal Society B: Biological Sciences* 281, no. 20141799: 1–7. https://doi.org/10.1098/rspb.2014.1799.

Christmann, S. 2022. "Regard and Protect Ground-Nesting Pollinators as Part of Soil Biodiversity." *Ecological Applications* 32: 1–7. https://doi.org/10.1002/eap.2564.

Christmann, S., A. Aw-Hassan, T. Rajabov, A. S. Khamraev, and A. Tsivelikas. 2017. "Farming With Alternative Pollinators Increases Yields and Incomes of Cucumber and Sour Cherry." *Agronomy for Sustainable Development* 37, no. 4: 24. https://doi.org/10.1007/s13593-017-0433-y.

Christmann, S., and A. A. Aw-Hassan. 2012. "Farming With Alternative Pollinators (FAP)— An Overlooked Win-Win-Strategy for Climate Change Adaptation." *Agriculture, Ecosystems and Environment* 161: 161–164. https://doi.org/10.1016/j.agee.2012.07.030.

Christmann, S., Y. Bencharki, S. Anougmar, et al. 2021. "Farming With Alternative Pollinators Benefits Pollinators, Natural Enemies, and Yields, and Offers Transformative Change to Agriculture." *Scientific Reports* 11, no. 1: 1–11. https://doi.org/10.1038/s41598-021-97695-5.

Cooley, H., and M. Vallejo-Marín. 2021. "Buzz-Pollinated Crops: A Global Review and Meta-Analysis of the Effects of Supplemental Bee Pollination in Tomato." *Journal of Economic Entomology* 114, no. 2: 505–519. https://doi.org/10.1093/jee/toab009.

De Palma, A., M. Kuhlmann, S. P. M. Roberts, et al. 2015. "Ecological Traits Affect the Sensitivity of Bees to Land-Use Pressures in European Agricultural Landscapes." *Journal of Applied Ecology* 52, no. 6: 1567–1577. https://doi.org/10.1111/1365-2664.12524.

Direction des Études et des Prévisions Financières. 2019. "Le Secteur Agricole Marocain: Tendances Structurelles, Enjeux et Perspectives de Développement." In *DEPF Etudes*. Direction des Études et des Prévisions Financières.

Duchenne, F., E. Thébault, D. Michez, et al. 2020. "Phenological Shifts Alter the Seasonal Structure of Pollinator Assemblages in Europe." *Nature Ecology & Evolution* 4, no. 1: 115–121. https://doi.org/10.1038/s41559-019-1062-4.

Eilers, E. J., C. Kremen, S. S. Greenleaf, A. K. Garber, and A. M. Klein. 2011. "Contribution of Pollinator-Mediated Crops to Nutrients in the Human Food Supply." *PLoS One* 6, no. 6: e21363. https://doi.org/10.1371/journal.pone.0021363.

El Abdouni, I., P. Lhomme, S. Christmann, et al. 2022. "Diversity and Relative Abundance of Insect Pollinators in Moroccan Agroecosystems." *Frontiers in Ecology and Evolution* 10: 1–11. https://doi.org/10.3389/fevo.2022.866581.

14390418, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/jen.70119 by Denis Michez - Universitaet De Mons (Umons) , Wiley Online Library on [13/05/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Everaars, J. 2012. "The Response of Solitary Bees to Landscape Nest-Site Preference."

Forrest, J. R. K., R. W. Thorp, C. Kremen, and N. M. Williams. 2015. "Contrasting Patterns in Species and Functional-Trait Diversity of Bees in an Agricultural Landscape." *Journal of Applied Ecology* 52, no. 3: 706–715. https://doi.org/10.1111/1365-2664.12433.

Garibaldi, L. A., I. Steffan-dewenter, R. Winfree, et al. 2013. "Wild Pollinators Enhance Fruit Set of Crops Regardless of Honey Bee Abundance." *Science* 339: 1608–1611.

Garratt, M. P. D., D. J. Coston, C. L. Truslove, et al. 2014. "The Identity of Crop Pollinators Helps Target Conservation for Improved Ecosystem Services." *Biological Conservation* 169: 128–135. https://doi.org/10.1016/j.biocon.2013.11.001.

Genung, M., J. Reilly, N. Williams, A. Buderi, J. Gardner, and R. Winfree. 2022. "Rare and Declining Bee Species Are Key to Consistent Pollination of Wildflowers and Crops Across Large Spatial Scales." *Ecology* 104, no. 2: e3899.

Ghosh, S., and C. Jung. 2018. "Contribution of Insect Pollination to Nutritional Security of Minerals and Vitamins in Korea." *Journal of Asia-Pacific Entomology* 21, no. 2: 598–602. https://doi.org/10.1016/j.aspen.2018.03.014.

Graham, K. K., K. K. Graham, R. Isaacs, et al. 2024. "A Century of Wild Bee Sampling: Historical Data and Neural Network Analysis Reveal Ecological Traits Associated With Species Loss." *Proceedings of the Royal Society B: Biological Sciences* 291, no. 2028: 20232837. https://doi.org/10.1098/rspb.2023.2837.

Hogendoorn, K., Z. Steen, and M. P. Schwarz. 2000. "Native Australian Carpenter Bees as a Potential Alternative to Introducing Bumble Bees for Tomato Pollination in Greenhouses." *Journal of Apicultural Research* 39, no. 1–2: 67–74. https://doi.org/10.1080/00218839.2000.11101023.

Hutchinson, L. A., T. H. Oliver, T. D. Breeze, et al. 2021. "Using Ecological and Field Survey Data to Establish a National List of the Wild Bee Pollinators of Crops." *Agriculture, Ecosystems and Environment* 315: 1–9. https://doi.org/10.1016/j.agee.2021.107447.

IPBES. 2016. "The Assessment Report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on Pollinators, Pollination and Food Production." In *Science*, edited by S. G. Potts, V. Imperatriz-Fonseca, and H. T. Ngo, vol. 325, Numéro 5940. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). https://doi.org/10.1109/22.989993.

Jayasinghe, U. J. M. S. R., T. H. S. E. Silva, and W. A. I. P. Karunaratne. 2017. "Buzzing Wild Bee Visits Enhance Seed Set in Eggplant, *Solanum melongena*." *Psyche (Cambridge, Mass.)* 2017: 1–7. https://doi.org/10.1155/2017/4624062.

Kammerer, M., S. C. Goslee, M. R. Douglas, J. F. Tooker, and C. M. Grozinger. 2021. "Wild Bees as Winners and Losers: Relative Impacts of Landscape Composition, Quality, and Climate." *Global Change Biology* 27, no. 6: 1250–1265. https://doi.org/10.1111/gcb.15485.

Kleijn, D., R. Winfree, I. Bartomeus, et al. 2015. "Delivery of Crop Pollination Services Is an Insufficient Argument for Wild Pollinator Conservation." *Nature Communications* 6: 1–8. https://doi.org/10.1038/ncomms8414.

Klein, A. M., B. E. Vaissière, J. H. Cane, et al. 2007. "Importance of Pollinators in Changing Landscapes for World Crops." *Proceedings of the Royal Society B: Biological Sciences* 274, no. 1608: 303–313. https://doi.org/10.1098/rspb.2006.3721.

Kremen, C., and L. K. M'Gonigle. 2015. "Small-Scale Restoration in Intensive Agricultural Landscapes Supports More Specialized and Less Mobile Pollinator Species." *Journal of Applied Ecology* 52, no. 3: 602–610. https://doi.org/10.1111/1365-2664.12418.

Lhomme, P., D. Michez, S. Christmann, et al. 2020. "The Wild Bees (Hymenoptera: Apoidea) of Morocco." *Zootaxa* 4892, no. 1: 1–159. https://doi.org/10.11646/ZOOTAXA.4892.1.1.

Loiseau, N., N. Mouquet, N. Casajus, et al. 2020. "Global Distribution and Conservation Status of Ecologically Rare Mammal and Bird Species." *Nature Communications* 11, no. 1: 1–11. https://doi.org/10.1038/s41467-020-18779-w.

Maas, B., M. Brandl, R. I. Hussain, et al. 2021. "Functional Traits Driving Pollinator and Predator Responses to Newly Established Grassland Strips in Agricultural Landscapes." *Journal of Applied Ecology* 58, no. 8: 1728–1737. https://doi.org/10.1111/1365-2664.13892.

MacLeod, M., J. Reilly, D. P. Cariveau, et al. 2020. "How Much Do Rare and Crop-Pollinating Bees Overlap in Identity and Flower Preferences?" *Journal of Applied Ecology* 57, no. 2: 413–423. https://doi.org/10.1111/1365-2664.13543.

Mallinger, R. E., and C. Gratton. 2015. "Species Richness of Wild Bees, but Not the Use of Managed Honeybees, Increases Fruit Set of a Pollinator-Dependent Crop." *Journal of Applied Ecology* 52, no. 2: 323–330. https://doi.org/10.1111/1365-2664.12377.

Marshall, L., N. Leclercq, T. Weekers, et al. 2023. "Potential for Climate Change Driven Spatial Mismatches Between Apple Crops and Their Wild Bee Pollinators at a Continental Scale." *Global Environmental Change* 83: 102,742. https://doi.org/10.1016/j.gloenvcha.2023.102742.

Michener, C. D. 2007. *The Bees of the World*. 2e éd ed. Johns Hopkins University Press. https://doi.org/10.1016/0047-2484(91)90057-3.

Mouillot, D., D. R. Bellwood, C. Baraloto, et al. 2013. "Rare Species Support Vulnerable Functions in High-Diversity Ecosystems." *PLoS Biology* 11, no. 5: e1001569. https://doi.org/10.1371/journal.pbio.1001569.

Nieto, A., S. P. M. Roberts, J. Kemp, et al. 2014. *European Red List of Bees*. Publication Office of the European Union. https://doi.org/10.2779/77003.

Nooten, S. S., K. Odanaka, and S. M. Rehan. 2020. "Characterization of Wild Bee Communities in Apple and Blueberry Orchards." *Agricultural and Forest Entomology* 22, no. 2: 157–168. https://doi.org/10.1111/afe.12370.

Nowakowski, M., and R. Pywell. 2016. *Habitat Management and Creation for Pollinators*. Centre for Ecology & Hydrology.

Orr, M. C., A. C. Hughes, D. Chesters, J. Pickering, C. D. Zhu, and J. S. Ascher. 2021. "Global Patterns and Drivers of Bee Distribution." *Current Biology* 31, no. 3: 451–458.e4. https://doi.org/10.1016/j.cub.2020.10.053.

Pardee, G. L., S. R. Griffin, M. Stemkovski, et al. 2022. "Life-History Traits Predict Responses of Wild Bees to Climate Variation." *Proceedings of the Royal Society B: Biological Sciences* 289, no. 1973: 20212697. https://doi.org/10.1098/rspb.2021.2697.

Pisanty, G., and Y. Mandelik. 2015. "Profiling Crop Pollinators: Life History Traits Predict Habitat Use and Crop Visitation by Mediterranean Wild Bees." *Ecological Society of America* 25, no. 3: 742–752.

Polidori, C., A. Rubichi, V. Barbieri, L. Trombino, and M. Donegana. 2010. "Floral Resources and Nesting Requirements of the Ground-Nesting Social Bee, *Lasioglossum malachurum* (Hymenoptera: Halictidae), in a Mediterranean Semiagricultural Landscape." *Psyche: A Journal of Entomology* 2010: 1–11. https://doi.org/10.1155/2010/851947.

Potts, S. G., V. Imperatriz-Fonseca, H. T. Ngo, et al. 2016. "Safeguarding Pollinators and Their Values to Human Well-Being." *Nature* 540, no. 7632: 220–229. https://doi.org/10.1038/nature20588.

Rader, R., I. Bartomeus, L. A. Garibaldi, et al. 2016. "Non-Bee Insects Are Important Contributors to Global Crop Pollination." *Proceedings of the National Academy of Sciences of the United States of America* 113, no. 1: 146–151. https://doi.org/10.1073/pnas.1517092112.

14390418, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/jen.70119 by Denis Michez - Universitaet De Mons (Umons) , Wiley Online Library on [13/05/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Rahimi, E., and C. Jung. 2025. "Exploring Climate-Driven Mismatches Between Pollinator-Dependent Crops and Honeybees in Asia." *Biology* 14, no. 3: 234. https://doi.org/10.3390/biology14030234.

Rauf, A., S. Saeed, M. Ali, M. Hammad, and N. Tahir. 2021. "Comparative Efficiency of Native Insect Pollinators in Reproductive Performance of *Medicago sativa* L. in Pakistan." *Insects* 12, no. 1029: 1–13.

Reilly, J. R., D. R. Artz, D. Biddinger, et al. 2020. "Crop Production in the USA Is Frequently Limited by a Lack of Pollinators: Pollination Limitation in US Crops." *Proceedings of the Royal Society B: Biological Sciences* 287, no. 1931: 2–9. https://doi.org/10.1098/rspb.2020.0922rspb20200922.

Rondeau, S., and N. E. Raine. 2022. "Fungicides and Bees: A Review of Exposure and Risk." *Environment International* 165: 107311. https://doi.org/10.1016/j.envint.2022.107311.

Sabbahi, R. 2022. "Economic Value of Insect Pollination of Major Crops in Morocco." *International Journal of Tropical Insect Science* 42, no. 2: 1275–1284. https://doi.org/10.1007/s42690-021-00645-x.

Sadeh, A., A. Shmida, and T. Keasar. 2007. "The Carpenter Bee *Xylocopa pubescens* as an Agricultural Pollinator in Greenhouses." *Apidologie* 38, no. 6: 508–517. https://doi.org/10.1051/apido:2007036.

Scheper, J., M. Reemer, R. Van Kats, et al. 2014. "Museum Specimens Reveal Loss of Pollen Host Plants as Key Factor Driving Wild Bee Decline in The Netherlands." *Proceedings of the National Academy of Sciences of the United States of America* 111, no. 49: 17552–17557. https://doi.org/10.1073/pnas.1412973111.

Schleuning, M., J. Fründ, and D. García. 2015. "Predicting Ecosystem Functions From Biodiversity and Mutualistic Networks: An Extension of Trait-Based Concepts to Plant–Animal Interactions." *Ecography* 38, no. 4: 380–392. https://doi.org/10.1111/ecog.00983.

Sentil, A., S. Reverté, P. Lhomme, et al. 2022. "Wild Vegetation and 'Farming With Alternative Pollinators' Approach Support Pollinator Diversity in Farmland." *Journal of Applied Entomology* 146, no. 9: 1155–1168. https://doi.org/10.1111/jen.13060.

St. Clair, A. L., G. Zhang, A. G. Dolezal, M. E. O'Neal, and A. L. Toth. 2022. "Agroecosystem Landscape Diversity Shapes Wild Bee Communities Independent of Managed Honey Bee Presence." *Agriculture, Ecosystems & Environment* 327: 107826. https://doi.org/10.1016/j.agee.2021.107826.

Stuligross, C., and N. M. Williams. 2020. "Pesticide and Resource Stressors Additively Impair Wild Bee Reproduction: Stressors Additively Impair Wild Bees." *Proceedings of the Royal Society B: Biological Sciences* 287, no. 1935: 20201390. https://doi.org/10.1098/rspb.2020.1390.

Thuiller, W., G. Damien, G. Maya, et al. 2020. "Nesting Habitat Enhancement for Wild Bees Within Soybean Fields Increases Crop Production." *Apidologie* 50, no. 6: 833–844. https://doi.org/10.1007/s13592-019-00691-y.

Toni, H. C., B. A. Djossa, M. A. T. Ayenan, and O. Teka. 2020. "Tomato (*Solanum lycopersicum*) Pollinators and Their Effect on Fruit Set and Quality." *Journal of Horticultural Science and Biotechnology* 96, no. 1: 1–13. https://doi.org/10.1080/14620316.2020.1773937.

Tschanz, P., S. Vogel, A. Walter, T. Keller, and M. Albrecht. 2022. "Nesting of Ground-Nesting Bees in Arable Fields Is Not Associated With Tillage System Per Se, but With Distance to Field Edge, Crop Cover, Soil and Landscape Context." *Journal of Applied Ecology* 60, no. 1: 158–169. https://doi.org/10.1111/1365-2664.14317.

Ullmann, K. S., M. H. Meisnera, and N. M. Williams. 2016. "Impact of Tillage on the Crop Pollinating, Ground Nesting Bee, *Peponapis pruinosa* in California." *Agriculture, Ecosystems & Environment* 232: 240–246.

Van Drunen, S. G., J. E. Linton, G. Kuwahara, and D. Ryan Norris. 2022. "Flower Plantings Promote Insect Pollinator Abundance and Wild Bee Richness in Canadian Agricultural Landscapes." *Journal of Insect Conservation* 26, no. 3: 375–386. https://doi.org/10.1007/s10841-022-00400-8.

Vasiliev, D., and S. Greenwood. 2020. "Pollinator Biodiversity and Crop Pollination in Temperate Ecosystems, Implications for National Pollinator Conservation Strategies: Mini Review." *Science of the Total Environment* 744: 140,880. https://doi.org/10.1016/j.scitotenv.2020.140880.

Vázquez, D. P., W. F. Morris, and P. Jordano. 2005. "Interaction Frequency as a Surrogate for the Total Effect of Animal Mutualists on Plants." *Ecology Letters* 8, no. 10: 1088–1094. https://doi.org/10.1111/j.1461-0248.2005.00810.x.

Williams, N. M., E. E. Crone, T. H. Roulston, R. L. Minckley, L. Packer, and S. G. Potts. 2010. "Ecological and Life-History Traits Predict Bee Species Responses to Environmental Disturbances." *Biological Conservation* 143, no. 10: 2280–2291. https://doi.org/10.1016/j.biocon.2010.03.024.

Winfree, R., J. W. Fox, N. M. Williams, J. R. Reilly, and D. P. Cariveau. 2015. "Abundance of Common Species, Not Species Richness, Drives Delivery of a Real-World Ecosystem Service." *Ecology Letters* 18, no. 7: 626–635. https://doi.org/10.1111/ele.12424.

Winfree, R., N. M. Williams, H. Gaines, J. S. Ascher, and C. Kremen. 2008. "Wild Bee Pollinators Provide the Majority of Crop Visitation Across Land-Use Gradients in New Jersey and Pennsylvania, USA." *Journal of Applied Ecology* 45, no. 3: 793–802. https://doi.org/10.1111/j.1365-2664.2007.01418.x.

Wood, T. J., J. M. Holland, and D. Goulson. 2016. "Diet Characterisation of Solitary Bees on Farmland: Dietary Specialisation Predicts Rarity." *Biodiversity and Conservation* 25, no. 13: 2655–2671. https://doi.org/10.1007/s10531-016-1191-x.

Woodcock, B. A., M. P. D. Garratt, G. D. Powney, et al. 2019. "Meta-Analysis Reveals That Pollinator Functional Diversity and Abundance Enhance Crop Pollination and Yield." *Nature Communications* 10, no. 1: 1–10. https://doi.org/10.1038/s41467-019-09393-6.

Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Table S1:** The dominance of key crop-pollinating bee species by each agroecosystem (crops in each region). **Table S2:** Ratio between the relative abundance of key crop-pollinating bee species on the crop and their relative abundance outside the crop (%). Bees outside the crop means all bees collected by transects on other plants (crops and wildflowers) and by pan traps.

14390418, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/jen.70119 by Denis Michez - Universitaet De Mons (Umons) , Wiley Online Library on [13/05/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License