



"Farming with Alternative Pollinators" approach increases pollinator abundance and diversity in faba bean fields

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Abstract

Pollinators are threatened worldwide and strategies and measures to support their conservation are proliferating. Among them, the approach "Farming with Alternative Pollinators" (FAP) aims to support pollinators by seeding strips of pollinator-attracting cultivated plants surrounding the crops, and simultaneously providing income to the farmer. In this study we assessed whether this approach supports pollinator diversity in agro-ecosystems and increases flower visitor diversity and abundance in faba bean fields in north-west Morocco. We tested the impact of FAP using a variety of marketable habitat enhancement plants (MHEP): flax, coriander, arugula, chia and canola. A total of 62 pollinator species were recorded, among which almost half of them are new records for the region. Most wild pollinators recorded in faba bean were digger bees (genus *Anthophora*) and long-horn bees (genus *Eucera*). MHEP shared diverse flower visitors with faba bean and hosted diverse pollinator groups that did not meet their food requirements from the main crop. The FAP approach highly increased flower visitor abundance and diversity in the whole FAP fields, however it did not generate significant pollinator spillover towards the main crop. Implications for insect conservation: our results show that the FAP approach is an effective approach to mitigate pollinator decline in agro-ecosystems.

Keywords Pollinators · Faba bean · Canola · Coriander · *Anthophora* · *Eucera*

Introduction

The huge contribution of pollinators to ecosystem services and agricultural production is being increasingly recognized (Klein et al. 2007; Potts et al. 2016; Christmann 2019a). Worldwide pollinators ensure the sexual reproduction of 87% of all the flowering plants (Ollerton et al. 2011) and the production of more than 75% of the leading food crops (Klein et al. 2007). Unfortunately, pollinators have significantly declined over the last two decades (Biesmeijer et al. 2006; Potts et al. 2010; Goulson et al. 2015; IPBES 2016; Gill et al. 2016; Goulson 2019). As a result, pollination services may become less available for wild or domesticated

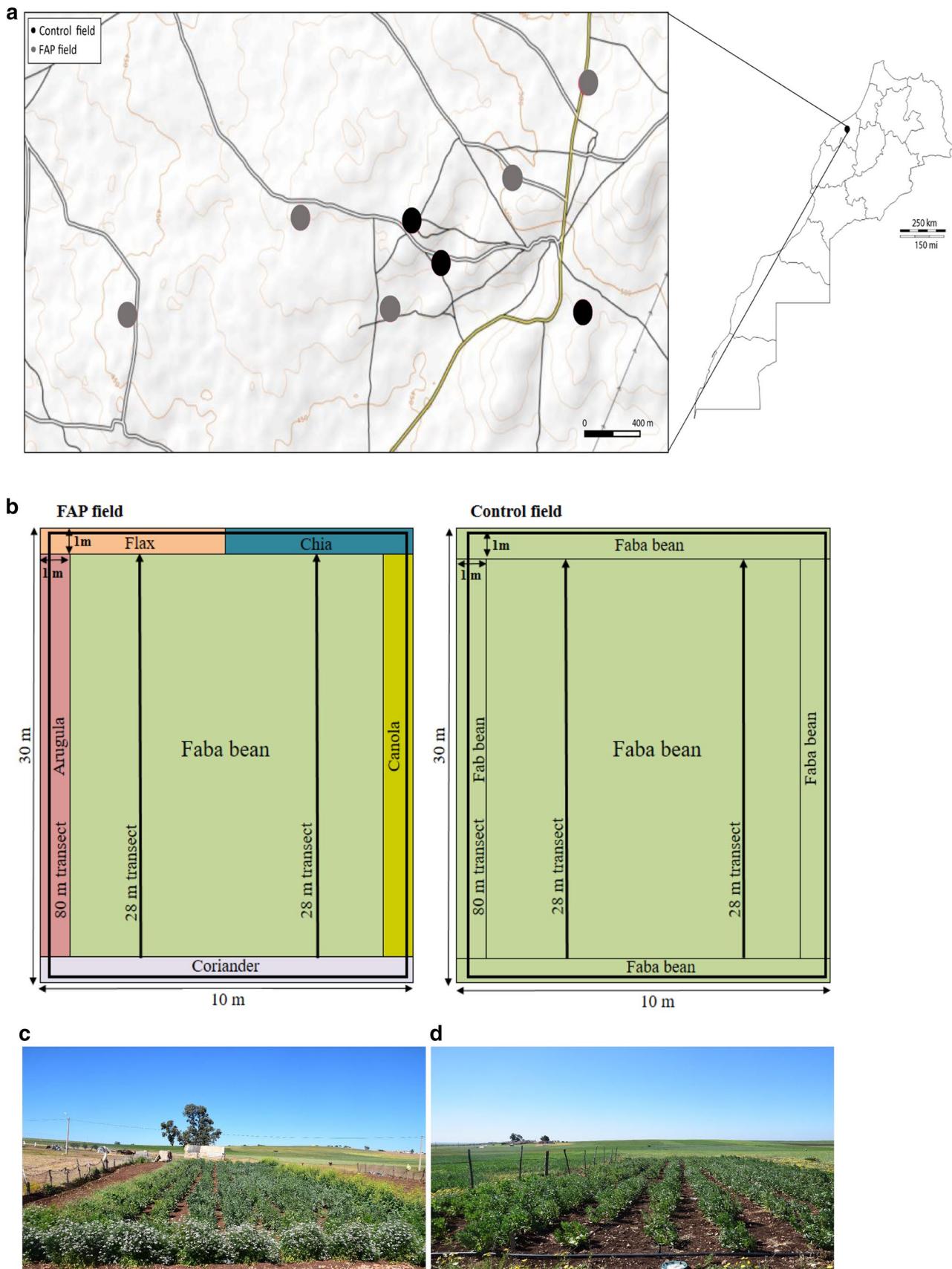
plants and more costly due to higher rental fees for honey bees (Ferrier et al. 2018; Reilly et al. 2020). The main drivers of pollinator loss are land-use changes, agricultural intensification, pesticide use, plant extinction and invasive species (Potts et al. 2010; Gill et al. 2016; Mogren et al. 2016; Vanbergen et al. 2018; Gill et al. 2016; Sánchez-Bayo and Wyckhuys 2019).

Nearly 40% of the land on Earth has been converted to agricultural land and roughly half of the remaining land is desert (Foley et al. 2005). Agricultural practices are negatively impacting the natural habitats and floral resources required to sustain pollinators (Aizen and Harder 2009; Gill et al. 2016; Aizen et al. 2019). First, homogenous landscapes can threaten specialist pollinators (i.e. pollinators with narrow floral choices) if they are not able to forage on the pollinator dependent crops. Moreover, the flowering period of pollinator dependent crops can be shorter (i.e. a few weeks) than the time needed for the pollinator to accomplish its full cycle of development. Outside this crop blooming period, pollinators would require additional floral resources. Last, pollinator independent crops like wheat and barley do not provide nectar or pollen

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◀Fig. 1 **a** Map of Morocco on the right side and map of the study region with the locations of the eight sites (five FAP fields and three control fields) on the left side. **b** Experimental designs of FAP and control fields. In the left, FAP field (faba bean in 75% of the field surrounded by Marketable Habitat Enhancement Plants). In the right, control field (faba bean only), the three arrows correspond to the three transects. **c** Photo of FAP field of faba bean surrounded by marketable habitat enhancement plants in full bloom; coriander in the bottom, canola on the right side, arugula on the left, chia and flax on the top (Ouled Sghir, Settat). **d** Photo of control field of faba bean in full bloom (Ouled Sghir, Settat)

for pollinators. In Morocco, cereals cover 54% of arable lands (Ministry of Agriculture, Fisheries, Rural development, Water and Forests 2019). The increase of the relative importance of pollinator independent crops and the agricultural intensification (e.g. development of monoculture) adopted by farmers may therefore lead to a huge loss of ecosystem services provided by these insect pollinators. This loss can have strong negative cascading effects on the pollination services provided to wild plants and the remaining pollinator-dependent crops (Lever et al. 2014; Christmann 2019a).

Within the EU, Agri-Environment Schemes (AES) provide financial support to farmers in order to adopt agricultural practices to boost pollinator diversity and abundance. The budget allocated to implement this approach from 2007 to 2013 was up to € 22.2 billion (McCracken et al. 2015; EU 2020). This approach, although important, is not scalable to low and middle-income countries such as Morocco due to the high costs of farmer subsidization (Christmann et al. 2017). To achieve pragmatic solutions, farmers need to be involved in pollinator protection. They can contribute to the mitigation of the environmental impact of managed landscapes through the seeding of pollinator dependent crops that offer pollen and nectar resources and provide simultaneous income.

“Farming with Alternative Pollinators” (FAP) (Christmann and Aw-Hassan 2012; Christmann et al. 2017, 2021; Christmann 2019b) is a new approach aiming to increase farm income as an incentive for farmers to engage in pollinator protection. Alternative pollinators refer to wild pollinators that farmers currently do not value for their wide contribution in agricultural production (Christmann et al. 2017). Farmers dedicate 25% of their fields to seed marketable habitat enhancement plants (MHEP) that provide pollen and nectar for pollinators. The MHEP potentially offer nutrition and shelter to many flower visitors and can complement the food requirement for generalist bees that do not meet this requirement with the main crop. Additionally, as Kleijn et al. (2015) confirmed for wild flower strips, MHEP can also host specialist species that are not able to forage on the main crop. Therefore, MHEP from FAP approach can contribute to supporting pollinator diversity, pollination service

and produce marketable products for sale (Christmann et al. 2017, 2021).

In order to assess the impact of the FAP approach on pollinator diversity and abundance on species level, a study on faba bean was carried out in 2019 in the Settat region in north-west Morocco. Faba bean is one of the staple crops in Morocco and represents 48% of grain-legume area. Production of this legume in Morocco in 2017 was around 280,000 tons (Matieres 2019). In Settat, faba bean represents 15% of grain-legume area (SPMOCA Settat 2019). Faba bean is a pollinator dependent crop (Klein et al. 2007; Bishop and Nakagawa in press). It is self-fertile with about equal amount of self and cross-pollination occurring depending on the insect pollinators (Palmer et al. 2009). Pollination of faba bean in Europe is mainly provided by honey bees (*Apis mellifera*), bumble bees (genus *Bombus*) and digger bees (genus *Anthophora*) (Bond and Kirby 1999; Pierre et al. 1999; Carré et al. 2009; Marzinzig et al. 2018). The pollination of faba bean in Morocco is not yet documented.

This study aims to (1) identify the main visitors of faba bean in Settat, (2) test if the FAP approach increases species richness and abundance of flower visitors in faba bean fields compared to monocultural control sites and (3) assess if the flower visitors collected in faba bean are also visiting the MHEP and vice versa. Based on previous studies, our hypotheses are that (1) the main faba bean visitors are long tongued bees; (2) FAP increases the insect species diversity and abundance as floral and flower visitor diversities are correlated; (3) MHEP and main crop share common floral visitors.

Materials and methods

Study area

The study was conducted in Ouled Sghir, a semi-arid rural municipality in the north-west of Morocco, it is 20 km distant from Settat city of the Chaouia-Ouardigha region. The landscape is characterized by relatively homogeneous land dominated by intensively cultivated land (90%), followed by forest fragments and urban areas. Cereal production occupies almost 90% of the arable land while pollinator dependent crops such as faba bean, alfalfa, flax and clover do not exceed 4% of the arable land (SPMOCA Settat 2019).

Study field trials

The main crop selected was faba bean (*Vicia faba*, Fabaceae) and the MHEP were: chia (*Salvia hispanica*, Lamiaceae), canola (*Brassica napus*, Brassicaceae), flax (*Linum usitatissimum*, Linaceae), arugula (*Eruca sativa*, Brassicaceae) and coriander (*Coriandrum sativum*, Apiaceae). The selection

of MHEP was made together with participating farmers and was based on their attractiveness to pollinators (Vastola 2015; Holzschuh et al. 2016; Thom et al. 2018; Shaikel et al. 2019; Sharma and Meena 2019) and their period of bloom that should partly overlap with that of faba bean. Since flower color and morphology play an important role in the attraction of flower visitors (Wester and Lunau 2017), the selected MHEP had various flower shape, size, tube length and color (Online Resource 1). Eight fields of 300 m² (30 × 10 m) were selected (5 FAP fields and 3 control fields) (Fig. 1a). In FAP fields, the main crop (faba bean) occupied 75% of the field area with the same planting scheme and cultivars and the MHEP were planted in the margins of the main crop (25% zone) (Fig. 1b, c). The control fields had faba bean as monoculture in 100% of the field (Fig. 1b, d). Strips of flax and chia were 4 m long and 1 m wide each, the strip of coriander was 8 m long and 1 m wide and strips of canola and arugula were 30 m long and 1 m wide each (Fig. 1b). The fields were managed with similar farming practices (i.e. dung, pesticide and water treatments). A herbicide containing the active ingredient glyphosate was applied at low dose on faba bean every 15 days from the early flowering stage to control broomrapes. The MHEP and faba bean were sown in 2018 in early (5–6th) and late November (29–30th), respectively. Bee hives were absent from the farmers' land.

The sites were distant of minimum 600 m, which corresponds to the average foraging distance of the main wild pollinator groups including solitary bees, hoverflies and bumble bees (Gathmann and Tscharntke 2002; Wratten et al. 2003; Elliott 2009). The landscape and potential regional pollinator community were similar around the study sites.

Insect sampling and identification

The abundance and species richness of flower visitors at the faba bean and MHEP were recorded using transect walks. The insect samplings were conducted between February and April 2019 when faba bean and MHEP were flowering. Four insect samplings were carried out; three during the blooming of the main crop (13–14 February, 26–27

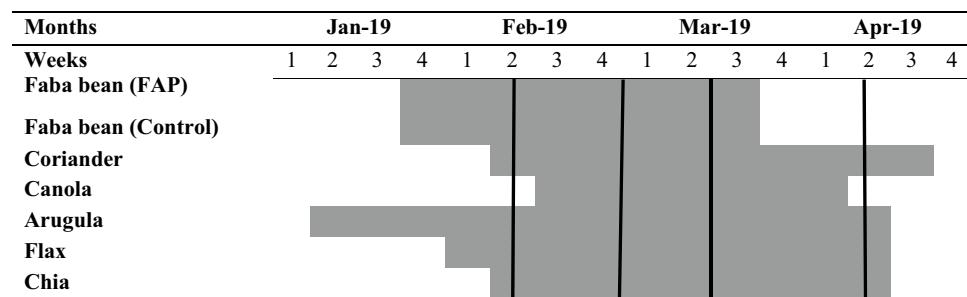
February and 11–12 March) and one after (26–27 April). Each sampling lasted 2 days (4 fields per day). We assessed the impact of the FAP approach on faba bean pollinators using data from three insect samplings (i.e. when faba bean was in bloom) (Table 1) and we investigated the impact of the FAP approach on supporting pollinators in the agro-ecosystem using the pollinators recorded in the four insect samplings (i.e. during and outside the blooming period of the main crop) (Table 1). The sampling of flower visitors in the 75% zone in FAP and control fields consisted of walking alongside two transect corridors of 28 m long and 4 m wide during 5 min each (Fig. 1b). The collector walked slowly in the middle of the 4 m transect corridor and collected the insects visiting the faba bean flowers on both sides. The flower visitors of MHEP were collected alongside a transect of 80 m long and 1 m wide during 10 min (Fig. 1b), pausing the timer to note the MHEP from which the specimens were collected. In the 25% zone of the control fields the flower visitors were recorded alongside a transect of 80 m long and 1 m wide for 10 min (Fig. 1b). The insects were collected using a sweep net and an insect vacuum.

All insects that visited the flowers were collected except honey bees (*Apis mellifera*), the bumblebee (*Bombus terrestris*) and the carpenter bee (*Xylocopa pubescens*), that were counted and identified visually on site. The collected insects were put inside killing jars filled with cyanide, then transported back to the lab where they were pinned and labeled. The wild bees were identified to the genus level using the key of Michez et al. (2019) then sent to specialists for identification to the species level using comparative collections or identification keys (Brooks 1988; Priesner 1957; Osten et al. 2000; Michez et al. 2004; Bogusch and Straka 2012). The remaining Hymenoptera and insect visitors were identified by the authors to the lowest taxonomic level feasible.

Statistical analyses

All analyses were conducted with R statistical software (version 3.6.3; R Core Team 2020). The descriptive part on the list of species visiting faba bean and the MHEP was made

Table 1 Flowering time of the main crop and the marketable habitat enhancement plants



The grey color represents the flowering time and the black bars the insect sampling time

including the eight studied fields. For the statistical analysis of the comparison between treatments, we excluded two FAP fields that were not successfully maintained (lack of water and nutrients and injury from plant pests and diseases) to ensure fair comparison between trials, that can be potentially biased by the low maintenance of these fields.

Impact of FAP approach on flower visitor community

We assessed the impact of the FAP approach on supporting pollinators and promoting pollination service by comparing two pollinator variables: abundance (the number of flower visitors/field/sampling) and species richness (the number of flower visitor species/field/sampling), both in 100% of the fields and in 75% of the fields. First, we investigated the effect of the approach on supporting pollinators in the agro-ecosystem by comparing pollinator variables between FAP and control fields in 100% of the field area (i.e., the addition of the 3 transects, 2 transects from the 75% central zone with faba bean and the transect from the 25% zone with faba bean or MHEP). Second, as pollinator visits to flowers are a reliable predictor of pollination service (Garibaldi et al., 2013), we assessed the contribution of the approach to pollination service by comparing pollinator variables between FAP and control fields in the 75% central zone with faba bean. We analyzed separately the abundance of honey bees and wild pollinators, as honey bees were by far the most abundant. Linear Mixed Models (LMM) were used to test for differences in pollinator abundance and species richness between FAP and control fields when data were normally distributed. When test assumption of normality was not met and pollinator variables (i.e. pollinator abundance and species richness) could not be transformed to normality, Generalized Linear Mixed Models (GLMM) were used. Generalized linear mixed models were fitted with negative binomial error distribution. We included field as a random effect to account for the multiple samplings per field. The normality was tested numerically using a Shapiro test (Mvnormtest package; Jarek 2012). Linear mixed models and generalized linear mixed models with a negative binomial distribution were fitted with the function lmer and glmer.nb, respectively from the lme4 library (Bates et al. 2015). Generalized linear mixed models were tested for over-dispersion using the dispersion_glmer function in the package blmeco (Korner-Nievergelt et al. 2015) and P values of the linear mixed model residues were interpreted using Satterthwaite's approximations to determine denominator degrees of freedom within the package lmerTest (Alexandra et al. 2020).

Plant-visitor network

The observed visitors of faba bean and MHEP were pooled within a single visitation matrix (I^*J), in which visitor

species are listed in rows, and plant species in columns. The cell values in the matrix indicated the abundance of visitor 'I' on plant species 'J'. The plant visitation network was made using the visitation matrix (I^*J). To highlight the most important MHEP that strengthen the network we quantified four species-level indices: degree, species strength, effective partners and proportional generality. The species degree indicates the number of interactions per target species. In this case it is the sum of flower visitor species related to a single plant species. The species strength is the sum of dependencies of each species (i.e., number of links per species, weighted by the number of interactions) (Bascompte et al. 2006), it aims at quantifying a species' abundance across all its partners (Dormann et al. 2020). The number of effective partners equals the number of partners of a species assuming that all the interactions were equally common. Within a plant-visitor network, the proportional generality presents the number of plants visited by a pollinator in relation to the number of plants resources available in the network (Dormann et al. 2009).

We constructed the bipartite quantitative (weighted) network using the package Bipartite (Dormann et al. 2020) and the species-level indices were assessed using the function Species level within the same package.

Pollinators in common between faba bean and MHEP in FAP fields

We pooled the visitation data of each crop (faba bean and MHEP) from the four insect samplings and the different plots within a weighted matrix, in which the flower visitors are listed in columns and faba bean and the five MHEP are listed in rows. To determine how similar the flower visitor community was between faba bean in FAP fields and each MHEP, we measured the Bray–Curtis (BC) dissimilarity distance among pairs of crops (faba bean in FAP fields vs MHEP) using the package Vegan with the function Vegdist (Oksanen et al. 2019).

Results

In total, 825 insect flower visitors were collected in this study belonging to 62 species or morphospecies. Based on the checklist of the wild bees of Morocco (Lhomme et al. 2020), almost half of the species are new records for this region (Online Resource 2).

Insect visitors of faba bean

We recorded 261 visitors on faba bean flowers belonging to 17 species and five families of Hymenoptera (99%) and two families of Lepidoptera (1%). 93% of faba bean visitors

recorded were Apidae, 3% were Andrenidae, 2% belonged to Scoliidae and Tiphidae and 2% included Pieridae, Halictidae and Sphingidae (Table 2).

Impact of FAP approach on flower visitor community of MHEP and faba bean

The comparison between FAP and control fields was performed using the three control fields and the three FAP fields that were properly maintained. The flower visitor abundance on entire fields was four times higher in FAP fields compared to control fields (514 and 116 flower visitors recorded in three FAP and all control fields together, respectively). Considering separately wild pollinators and honey bees in 100% of the fields, abundance of wild pollinators visiting FAP fields was significantly higher in comparison to control fields (GLMM; $P = 9.3 \times 10^{-8}$; Fig. 2a). The abundance of honey bees in 100% of the fields did not exhibit a significant difference among the treatments (GLMM; $P = 0.66$; Fig. 2b). The wild pollinator abundance in the 75% zone (i.e. faba bean) did not vary significantly among FAP and control fields (GLMM; $P = 0.06$; Fig. 2c). Honey bee abundance in the 75% zone was not significantly supported by the FAP approach (GLMM; $P = 0.382$; Fig. 2d).

The wild pollinator species richness was significantly higher in FAP fields than in control fields in 100% of the fields (GLMM; $P = 4.5 \times 10^{-7}$; Fig. 2e). The difference in wild pollinator species richness recorded in the 75% zone was

not significant among FAP and control (LMM; $P = 0.226$; Fig. 2f).

All the species-level indices (i.e. degree, species strength, effective partners and proportional generality) were higher in faba bean in FAP fields than faba bean in control fields (Table 3). The total number of interactions and the sum of dependencies of faba bean in FAP fields compared to control fields were higher. Although the proportional generality is low in FAP fields, it remains higher compared to faba bean in control fields.

Due to MHEP, the blooming period in FAP fields started two weeks before the blooming of the main crop and extended over 4 weeks after the end of blooming of the main crop (Table 1).

Pollinator shared between faba bean and MHEP in FAP fields

In total, 564 visitors belonging to 61 species have been recorded during all transect walks on MHEP. Coriander had the highest pollinator density (4.2 individuals/m²), followed by flax (2.3 individuals/m²) and chia (1.85 individuals/m²). Canola and arugula attracted 1.5 individuals/m² and 0.57 individual/m², respectively. Similarly, pollinator species density showed a similar trend. Indeed, chia, flax and coriander presented the highest species density with (0.95 species/m²), (0.75 species/m²) and (0.65 species/m²), respectively. Followed by canola (0.2 species/m²) and arugula (0.14 species/m²) (Online resources 3, 4, 5, 6 and 7).

Table 2 Rank abundance of faba bean flower visitor species

Species	Family	Rank	Abundance	Proportion	Accumfreq
<i>Apis mellifera</i>	Apidae	1	169	64.8	64.8
<i>Anthophora fulvitarsis</i>	Apidae	2	25	9.6	74.3
<i>Eucera nigrilabris</i>	Apidae	3	18	6.9	81.2
<i>Eucera numida</i>	Apidae	4	14	5.4	86.6
<i>Anthophora</i> sp.	Apidae	5	6	2.3	88.9
<i>Andrena aerinifrons</i>	Andrenidae	6	5	1.9	90.8
<i>Eucera</i> sp.	Apidae	7	5	1.9	92.7
<i>Dasyscolia ciliata</i>	Scoliidae	8	3	1.1	93.9
<i>Tiphia</i> sp.	Tiphidae	9	3	1.1	95
<i>Anthophora dispar</i>	Apidae	10	2	0.8	95.8
<i>Pieridae</i> sp1	Pieridae	11	2	0.8	96.6
<i>Andrena flavipes</i>	Andrenidae	12	1	0.4	96.9
<i>Andrena</i> sp.	Andrenidae	13	1	0.4	97.3
<i>Andrena verticalis</i>	Andrenidae	14	1	0.4	97.7
<i>Bombus terrestris</i>	Apidae	15	1	0.4	98.1
<i>Eucera clypeata</i>	Apidae	16	1	0.4	98.5
<i>Lasioglossum</i> sp.	Halictidae	17	1	0.4	98.9
<i>Melecta</i> sp1	Apidae	18	1	0.4	99.2
<i>Nomada</i> sp14	Apidae	19	1	0.4	99.6
<i>Sphingidae</i> sp.	Sphingidae	20	1	0.4	100

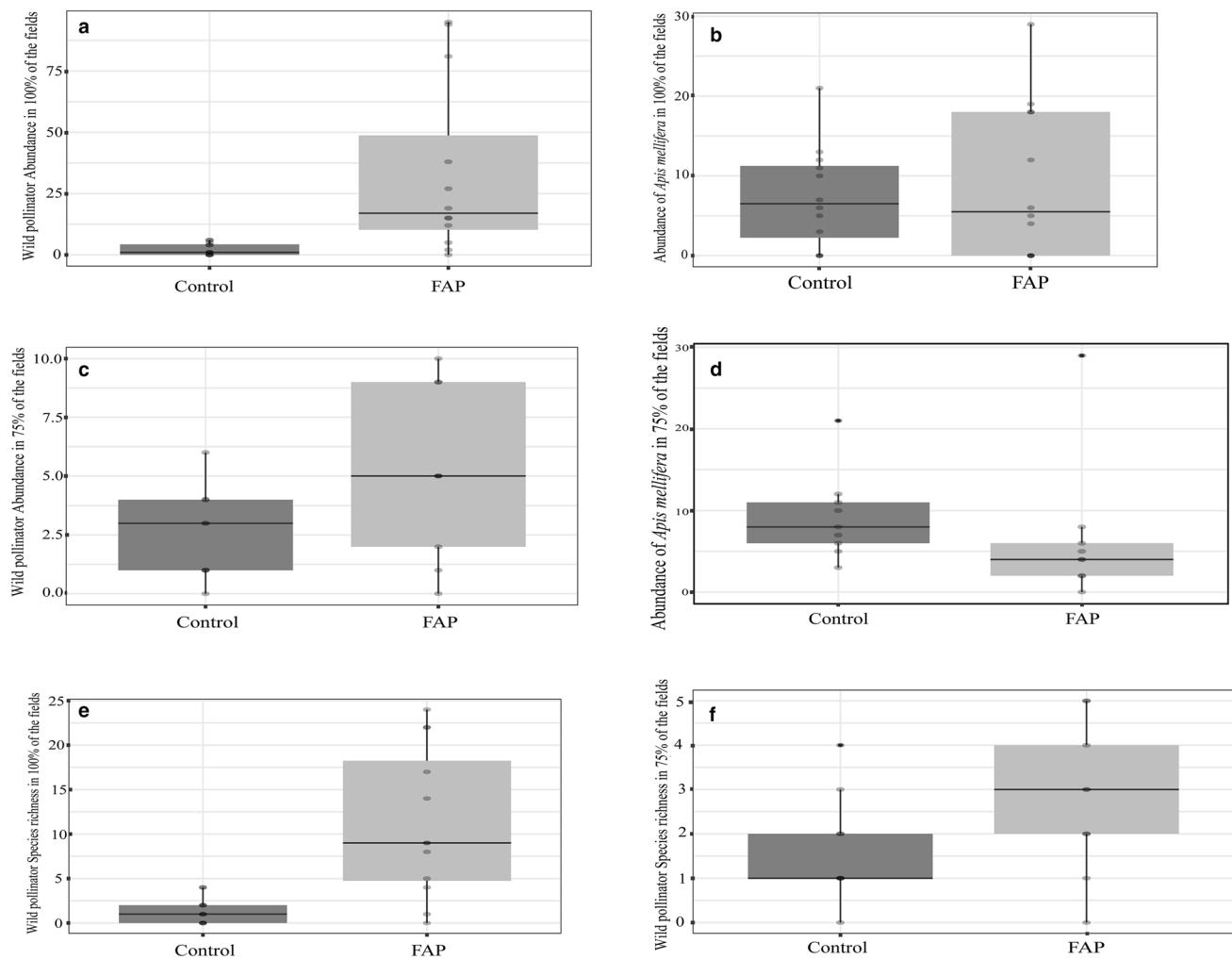


Fig. 2 **a** Wild pollinator abundance in the whole FAP and control fields, **b** Honey bee abundance in the whole FAP and control fields, **c** Wild pollinator abundance in the 75% zone in FAP and control fields, **d** Honey bee abundance in the 75% zone in FAP and control fields, **e** Wild pollinator species richness in the whole FAP and control fields, **f** Wild pollinator species richness in the 75% zone in FAP and control

fields. Box plots show the median and 25–75% percentiles. Whiskers show all data excluding outliers. Outliers (circles) are values being more than 1.5 times box length from upper and lower edge of respective box. Asterisks indicate significant differences (Linear mixed model and generalized linear mixed models with negative binomial distribution; *P<0.05; **P<0.01, ***P<0.001)

Table 3 Comparison of species-level indices among the low trophic nodes (MHEP and faba bean in FAP and control fields)

	Degree	Species strength	Effective partners	Proportional generality
Canola	28	15.96	13.7	0.8
Coriander	21	13.58	12.4	0.72
Arugula	20	9.04	11.1	0.64
Flax	9	1.49	6.4	0.37
Chia	19	10.04	17.3	1.01
Faba bean FAP	14	6.54	5	0.29
Faba bean control	9	3.32	2.5	0.14

The species-level indices of canola showed the highest effective partners, species degree, species strength and proportional generality in the visitation network, followed by coriander, arugula, chia and flax respectively (Table 3). As result, canola was highly dominant in the network with broader visitor's breadth (Fig. 3).

All MHEP overlapped in term of insect visitors with faba bean. The BC distance showed that 30% of flower visitors occurred in both MHEP and faba bean. Though, the BC distance (Fig. 4) and the composition of species overlap differed among the MHEP. Specifically, the BC distance in the community of pollinators between faba bean and canola, arugula, flax, chia and coriander were 0.64, 0.79, 0.79, 0.87 and 0.98 respectively. Canola was visited by *A. mellifera*, *Dasylochia ciliata*, *Andrena aerinifrons*, *Eucera nigrilabris*

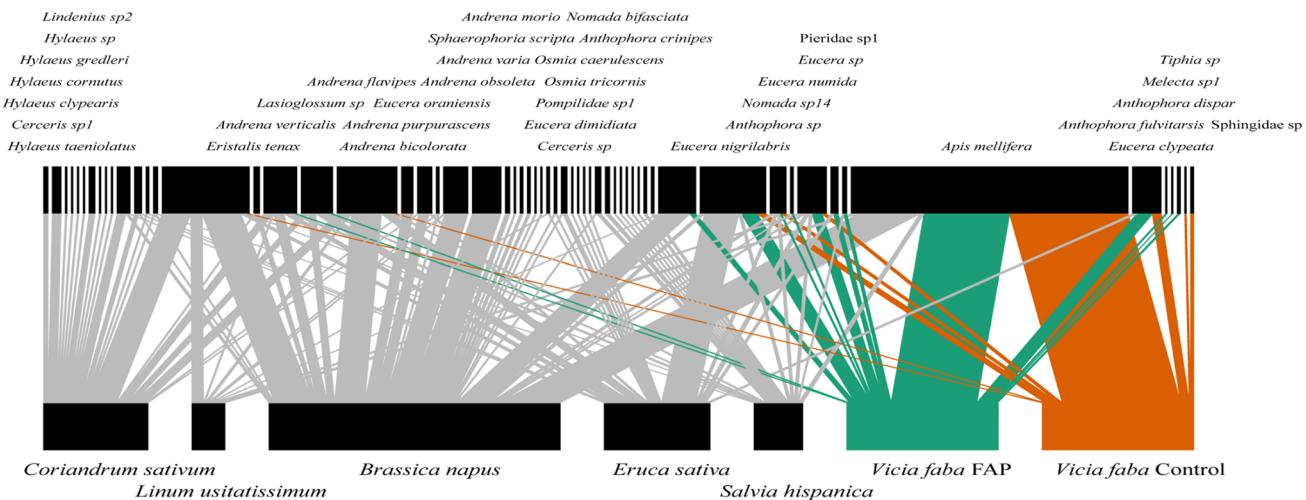


Fig. 3 Plant–visitor network. The lower section represents the plant species (MHEP + faba bean in FAP and control Fields), the upper section indicates the pollinator community. Interactions between species of the two trophic levels are represented in grey, except for faba beans

and its interactions in FAP fields, which are represented in green, and faba beans and its interactions in control fields, which are represented in orange. Bars for MHEP and their visitors are grey

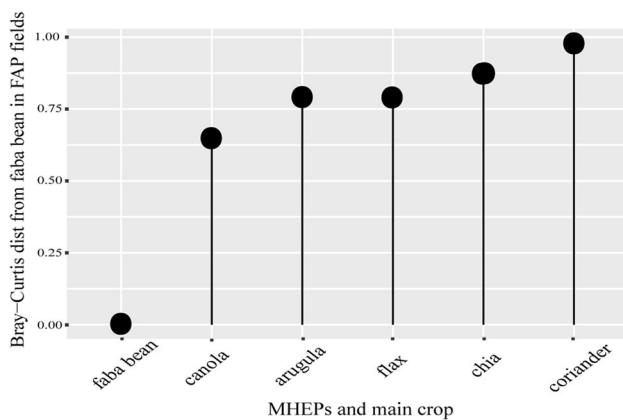


Fig. 4 Results of Bray–Curtis dissimilarity distance of MHEP to faba bean. The black bars represent the distance of MHEP from faba bean

and shared these bee species with the main crop. Faba bean was mainly visited by *Anthophora fulvitarsis* and *E. nigrilabris* and shared these bee species with arugula. Flax was frequently visited by *A. mellifera*, *D. ciliata* and *Eucera numida* that were also recorded in the main crop, whereas chia shared *A. mellifera* and *E. numida*, *Anthophora* sp. and *E. nigrilabris* with faba bean.

Discussion

Faba bean visitors

Our findings revealed that faba bean was visited in Settat by 17 insect species and that 93% of the specimens recorded

on faba bean flowers belonged to Apidae family. The three major groups comprising 99% of the total visits from this family; were *Apis* (70%), *Eucera* (16%) and *Anthophora* (13%). These visitors are all generalist long tongued bees (Michez et al. 2019). They are able to reach the curved nectar tube of the corolla while other genera like *Andrena*, present on other plants in FAP field, have probably a too short tongue. Faba bean visitors can benefit from high content of sugar concentration in the nectar (Stoddard and Bond 1987; Köpke and Nemecek 2010) and great protein content in the pollen (Samorville 2002; Vaudo et al. 2020).

These results confirmed the results of previous studies on faba bean visitors from other countries. The honey bees *A. mellifera* was recorded as one of the frequent flower visitors of faba bean in many countries (Pierre et al. 1996; Cunningham and Le Feuvre 2013) including Mediterranean countries like Algeria (Aouar-sadli et al. 2008). On the contrary, the genera *Anthophora* and *Eucera* are major wild bee groups recorded in faba bean only in Mediterranean countries like Spain and Algeria (Bond and Kirby 1999; Benachour et al. 2007; Aouar-sadli et al. 2008; Shebl and Farag 2015). At species level, to our knowledge, it is the first time that *A. fulvitarsis* and *E. nigrilabris* are recorded on faba bean. In northern Europe, visitors of faba bean are mainly bumble bees (Garratt et al. 2014) but in Morocco these species are rare and only one individual of *Bombus terrestris* was observed during this study. The low abundance of bumble bees recorded in this study could be explained by the climate. In fact, bumble bees are cold-adapted species that are relatively more abundant in cooler climates (Rasmont et al. 2015). Further, the early flowering time of faba bean that occurred during colony growth of bumble

bees (Rasmont et al. 2008, 2015) may also explain the low abundance of bumble bees. Other solitary bee species from genera *Andrena*, *Lasioglossum*, *Melecta* and *Nomada* were less frequent (i.e. recorded once or twice foraging on faba bean flowers in our study), these results are similar to those suggested in several studies (Bond and Kirby 1999; Benachour et al. 2007; Shebl and Farag 2015).

Though wild pollinators recorded on faba bean were less abundant than honey bees, previous studies found the pollination efficiency of wild pollinators to be higher compared with honey bees (Kendall and Smith 1975; Marzinzig et al. 2018). Wild pollinators, particularly solitary bees handle flowers more efficiently than honey bees, they make more contact with the reproductive organs and exhibit legitimate flower visits (Marzinzig et al. 2018).

Impact of the FAP approach on flower visitor community

The visitor species abundance and richness were significantly higher in FAP fields than control fields. This additional diversity is associated to the higher plant diversity in FAP fields and the long bloom duration of the MHEP. The 28 new records for the region were all collected in FAP fields and only two species out of the total 28 bee species were recorded in control fields.

Previous studies highlighted the positive relationship between floral resources richness and pollinator diversity (Ebeling et al. 2012; Isbell et al. 2017; Garibaldi et al. 2019) and provided evidence that flower strips increase pollinator diversity at the field edge but show no consistent spillover into the main crop (Zamorano et al. 2020). Some wild bees such as bumble bees tend to prefer fields with diverse floral resources to meet their food requirements at a reduced foraging cost (Goulson 2003).

Bee species recorded in MHEP were present in the surrounding areas. However, given the landscape composition in the study region where cultivated lands occupy 90% of the landscape area, some species could be present but not necessarily in high number. Mass flowering MHEP such as coriander, canola and arugula probably created a magnet effect, because the high density of available flowers attracted pollinators from the surrounding areas. This could boost their abundance and help to maintain their populations in the next season. The bee species from the genera: *Hylaeus*, *Sphecodes*, *Osmia* and *Xylocopa* sampled during this study were recorded only on MHEP as they are mainly generalist and need to diversify their resources (Michez et al. 2019). To meet their optimal nutritional requirement, bees need to balance their intake from various plants (Vaudo et al. 2020). Even if pollinator dependent crops may provide a large quantity of flower rewards, these habitats may fail to support bee health since they provide a single source of pollen or nectar

(Vaudo et al. 2015). The presence of MHEP can be even more critical for specialist species as they can have high pollen requirement of the respective host plant, with up to 1000 flowers needed to rear a single larvae (Müller et al. 2006). Global pollinator decline is strongly associated with expansion of monocultures at the expense of semi natural areas that provide pollinators with diverse and copious floral rewards (Potts et al. 2010; Goulson 2019). Consequently, many studies (Isbell et al. 2017; Sutter et al. 2017; Garibaldi et al. 2019; Bennett et al. 2020) recommended to provide a range of floral resources for different pollinator species to meet their specific diet requirements and thus help to sustain healthy populations that can endure disease and stress (Vaudo et al. 2015).

In line with previous studies on the impact of wildflower hedgerows and strips (Morandin and Kremen 2013; Albrecht et al. 2020), MHEP did not increase crop pollinator abundance and species richness. This finding could be explained by the time of the establishment of MHEP, which was identified as an important driver of variability in effectiveness of flower strips on crop pollinator abundance and species richness (Albrecht et al. 2020). As Morandin and Kremen (2013) confirmed for hedgerows, newly established MHEP may act as a magnet effect, rather than inducing a spillover of pollinators towards the main crop. Since wild bee communities oscillate from year to year and species need time to colonize new habitats, the success of MHEP in enhancing crop pollinator abundance and species richness may increase with their age, as it was confirmed for wild flower strips (Blaauw and Isaacs 2014).

Pollinator species overlap in FAP fields

A proportion of 30% of the flower visiting species collected on faba bean were also recorded on the MHEP. The mass flowering crops with high number of flowers such as coriander attract high numbers of insect visitors (Westphal et al. 2003). Coriander is characterized by several pollinator-attractive traits (e.g. exposed nectar, abundant pollen production, high floral coverage and open flowers) allowing a great variety of flower visiting insect species to access its' flower rewards (Bendifallah et al. 2013; Azpiazu et al. 2020). Though, the majority of studies on coriander pollinators did not report visits of long tongue bees (Singh et al. 2010; Bendifallah et al. 2013; Sharma and Meena 2019).

Although chia is a self-pollinating plant, many insect species are attracted to its flowers (Vastola 2015), which is corroborated by our results. Chia did not share a high proportion of flower visiting species with faba bean, probably because chia occupied a small surface in FAP fields (4 m^2) or its' different flower shape compared to faba bean excluded bee groups visiting Fabaceae from accessing nectaries due to long corolla tubes, narrow flower entrances

or lack of landing surfaces (Wester and Claßen-Bockhoff 2007; Wester et al. 2020). The great pollinator abundance and species densities recorded in flax are in conformity with the findings of Navatha et al. (2012) who reported that flax attracts diverse and abundant flower visitors. This diversity could be explained by the high number of the rewarding showy flowers of flax (Thom et al. 2018). The low proportion of insect visitors shared with faba bean and flax could be attributed to the limited area devoted to plant it within FAP fields (4 m^2).

The wide-open flowers and the large amounts of nectar and pollen produced by cabbage plants such as canola (Bommarco et al. 2012) and arugula (Masierowska 2003) attract a high number of pollinator species. Though pollinator abundance and species densities on these plants were not high compared to the other MHEP, they are still important given the high number of pollinator species collected on these plants (Online resources 3 and 5). The great proportion of pollinator species, which shared faba bean, canola and arugula as foraging resource could be explained by the large area occupied by these plants (30 m^2 for each). Even if coriander and chia did not share a great number of flower visitor species with faba bean, they hosted a wide range of insect species belonging to diverse pollinator groups from wild bees (*Osmia*, *Andrena*, *Hylaeus*, *Lasioglossum*, *Xylocopa*, *Sphecodes*) to sphecid wasps (*Cerceris*, *Oxybelus*), hover flies (*Eristalis*, *Episyrphus*) and butterflies (Pieridae).

The high amount of nectar and volatile oils produced by coriander (Kant et al. 2019) also attract a large number of natural enemies (Bendifallah et al. 2013; Kant et al. 2019; Sharma and Meena 2019). Throughout the insect samplings, several predators were observed on the MHEP and in the main crop (ladybirds, hover flies, sphecid wasps and parasitoid wasps). These natural enemies may also contribute to pest control in faba bean and MHEP, consequently preventing losses in yield and farmers income (Christmann et al. 2017).

The FAP approach with the use of diverse MHEP varying in bloom phenology and functional traits supported a diverse range of pollinators throughout the flowering period of faba bean as well as before and after. The approach is highly efficient from a pollinator conservation point of view. From the farmers' perspective, further studies are required to assess the effect of the FAP approach on crop pollination and yield over longer time periods and other crops. The impact of reducing 25% of the surface of faba bean and increasing the diversity of floral resources in favor of pollinators was visible in pollinator abundance and species richness in the whole fields. Similar to two pilot projects (Christmann et al. 2017, 2021), our experiment showed FAP-induced benefits for pollinator conservation. This approach should be assessed in other

countries and different insect pollinated crops, as using MHEP might be more acceptable for farmers than e.g. wildflower strips (Kleijn et al. 2019).

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Declarations

Conflict of interest The authors of the manuscript entitled “Farming with Alternative Pollinators” approach increases pollinator abundance and diversity in agro-ecosystems declare that they have no conflict of interest.

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