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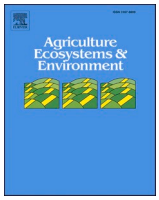

Flowering apricot trees increase the abundance and modulate the distribution of wild bees within Korla fragrant pear (*Pyrus sinkiangensis*) orchards, but apricot trees in the surrounding landscape do not increase wild bee abundance

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ABSTRACT

Pollinating insects rely on floral resources for survival and reproduction. Early flowering plants offer food resources for pollinating insects when floral resources are scarce, but they may also distract pollinating insects from pollination-dependent crops. Here we assessed how the abundance of bees and the pollination success of Korla fragrant pear (*Pyrus sinkiangensis*) is influenced by early flowering apricot trees within pear orchards or in the landscape at large, and how this influence is moderated by apricot flowering. The abundance of bees was measured using colored pan traps and pollination success was assessed by recording the initial fruit set and seed set. The density of apricot trees and land use types in radii of 0.5, 1.0, 1.5, and 2.0 km around focal pear orchards were assessed by landscape survey. The abundance of wild bees and honeybees was significantly higher in pear orchards with interspersed apricot trees than in mono-pear orchards. Pear trees next to an apricot tree row (5 m) had significantly higher wild bee abundance than pear trees at further distances (15 m, 30 m, 50 m, and 100 m). However, the positive effect of apricot trees on bee abundance in pear trees was only observed during apricot blooming, and the presence of apricot trees within or adjacent to pear orchards did not influence pear pollination success. The density of apricot trees in the surrounding landscape of pear orchards did not influence bee abundance and initial fruit set in pear orchards but it decreased seed set. Overall, our findings indicate that apricot trees in pear orchards can enhance bee abundance, but this effect only occurs at a relatively small spatial scale and during a short time span, and does not result in marked differences in pollination success. This indicates that flowering resources need to be close to or within the focal crop to have a positive effect on pollinating insect abundance.

1. Introduction

Many vegetable and fruit crops depend on insects for pollination, and these pollinator-dependent crops represent 35 percent of the global crop production (IPBES et al., 2016). As a consequence, there is increasing concern about the widespread decline in pollinator abundance and diversity (Biesmeijer et al., 2006; Potts et al., 2016; Powney et al., 2019) and the associated risk of pollination deficits and consequent yield losses (Kremen et al., 2002; Potts et al., 2005; Garratt et al., 2014; Reilly et al., 2020). The decline in flowering plants in agricultural landscapes is believed to be an important factor in pollinator declines (IPBES et al., 2016; Roulston and Goodell, 2011; Goulson et al., 2015). Increasing floral resources (e.g., flowering crop species or wild plants) may therefore mitigate the decline of wild pollinators (Scheper et al., 2015; Jönsson et al., 2015; Shaw et al., 2020).

The abundance of pollinating insects is generally positively associated with the availability of flower resources (Russo et al., 2017; Blaauw and Isaacs, 2014), but this does not mean that the establishment of flowering plants will necessarily increase the pollination of a target crop (Diekötter et al., 2010; Holzschuh et al., 2011). This is because flowering plants may act as “pollinator magnets” that attract pollinators away from the target crop, a mechanism referred to as the “aggregation”

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hypothesis (Venturini et al., 2017). On the other hand, flower resources may also support the reproduction and survival of pollinator populations, which may result in higher pollinator abundance in the surroundings, i.e., the "exporter" hypothesis (Morandin, Claire, 2013; Kremen et al., 2019). Depending on the dominance of the "exporter" and "aggregation" mechanisms, the presence of alternative floral resources may enhance or compromise pollinator visitation of a target crop. Many factors influence whether flowering plants have positive or negative effects on a specific crop species, such as the characteristics of the (crop) plant species, the distance between alternative floral resources and the target crop (Montero-Castaño et al., 2016), pollinator foraging behavior (Marzinzig et al., 2018; Bänsch et al., 2020) and the dispersal capacity of pollinators (Steffan-Dewenter et al., 2002; Zurbuchen et al., 2010). Moreover, the responses of pollinators to floral resources may be scale-specific (Westphal et al., 2006; Kovács-Hostyánszki et al., 2013; Montero-Castaño et al., 2016). Thus, pollinator responses to floral resources can be complex and are still incompletely understood.

Korla fragrant pear (*Pyrus sinkiangensis*; hereafter "pear") is a high-value fruit crop species, and its production is concentrated in irrigated areas in the arid plains of Xinjiang, China (e.g., Korla region, Aksu region). Like most Rosaceae, the flowers of Korla fragrant pear are self-incompatible and depend on insect pollination or artificial pollination to ensure the transfer of compatible pollen and sufficient fruit set (Li et al., 2022). However, pear flowers are not attractive to pollinators because of low quantity and quality of the nectar (Free, 1993; Pamminger et al., 2019). Moreover, pear production landscapes in the Korla region can be hostile environments for pollinators because of 1) the high agrochemical use to control weeds, pests, and diseases; 2) the limited amount of semi-natural habitats that may offer nesting sites for wild bees; and 3) the limited availability of floral resources before and after pear flowering. While pear pollination can be ensured by introducing managed honeybees and artificial pollination (e.g., hand pollination or pollen spraying), artificial pollination requires substantial labor and/or capital investment (Partap and Ya, 2012). Hence, ecologically-based low cost measures are in demand to strengthen pollination services. Supporting pollinators with alternative food resources could be such a measure.

Apricot trees (*Prunus armeniaca* L.) flower in late March, approximately one week before Korla fragrant pear starts flowering, providing flower resources for insect pollinators in early spring. Apricot and pear trees are the most common flowering plants in pear production areas in Xinjiang in the early season, being more common than other rosaceous trees, such as peach and plum. Apricots have a low economic value and are therefore usually not grown in monocultures, but scattered apricot trees are common in or adjacent to pear orchards, home gardens, and in roadsides. Apricot flowers are more attractive to bees than pear flowers (Lan et al., 2021), therefore apricot trees within or around pear orchards could potentially influence pollinator communities and pollination success in pear orchards via the "exporter" and "aggregation" mechanisms. However, it is not clear whether these mechanisms can explain spatial patterns of pollinator abundance in pear orchards and the associated pear pollination success, and if so, at what spatial scales.

Here we assessed how the presence of early flowering apricot trees within orchards or in the landscape surrounding orchards influences the abundance of bees and pollination success in pear, and how this influence is moderated by apricot flowering. First, we studied how the presence of interspersed apricot trees in pear orchards influenced the abundance of wild bees and honeybees and pollination success in pear orchards (Experiment 1, Fig. 1a). Second, we studied the effect of apricot tree rows at the edge of pear orchards on the abundance of wild bees and honeybees, and pollination success in pear orchards at different distances from the apricot trees (Experiment 2, Figs. 1b, 2). Third, we assessed the effect of apricot tree density in the landscape around the orchards on the abundance of wild bees and honeybees and pollination success in pear orchards (Experiment 3, Fig. 1c).

If the aggregation hypothesis is at play, we expect that 1) pear orchards with interspersed apricot trees have a higher bee abundance and higher pollination success than mono-pear orchards; 2) the effect on bee abundance is or mainly apparent during apricot flowering; 3) the abundance of bees and pollination success in pear trees declines with increasing distance from an apricot tree row; 4) an increasing apricot density in the surrounding landscape of pear orchards decreases the bee abundance and associated pollination success in pear orchards by attracting bees away from pears. If the exporter hypothesis is at play, we

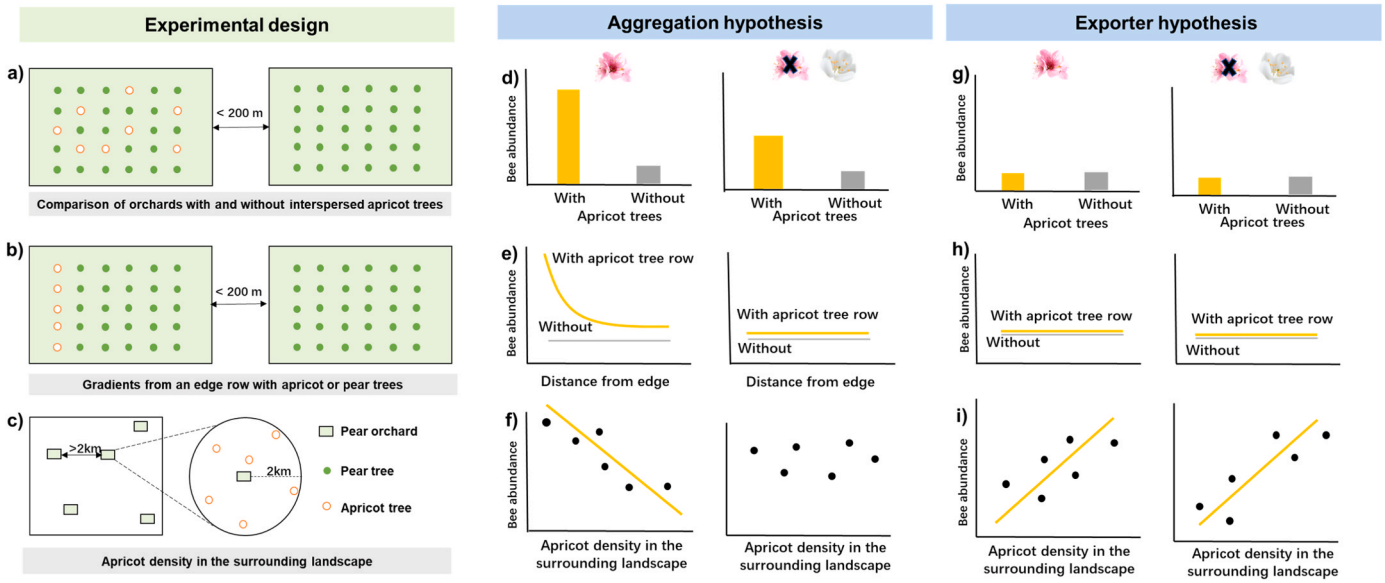

Fig. 1. Experimental design and hypothesized relationships. In the column "Experimental design", the large green rectangles indicate pear orchards, the green dots indicate pear trees, and the white dots indicate apricot trees. a) Experiment 1: the influence of interspersed apricot trees on bee abundance in pear orchards; b) Experiment 2: distribution of bees in orchards with or without an apricot edge row; c) Experiment 3: the influence of apricot trees in the surrounding landscape on bee abundance in pear orchards. Panels d, e, and f illustrate expected relationships under the Aggregation hypothesis while panels g, h, and i illustrate expected relationships under the Exporter hypothesis. Pink and white flowers indicate flowering times of apricot and pear, respectively. We hypothesized that pollination success (initial fruit set and seed set) in pears is positively related to bee abundance (not shown in the figure).

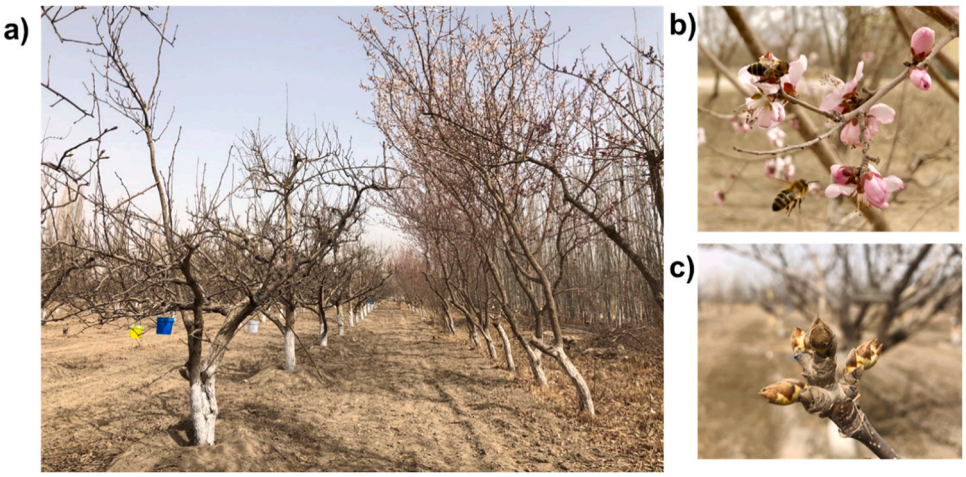

Fig. 2. Pear orchard with an apricot edge row in Korla, Xinjiang, China. The orchard has pear trees on the left and an apricot edge row on the right (a), a close-up of apricot flowers (b), and a close-up of pear flower buds (c) in early spring in Korla, Xinjiang, China. The photos were taken on 31 March 2019 before pear flowering when apricot was already blooming.

expect 1) no effect of interspersed apricot trees in pear orchards on bee abundance or pollination success; 2) no effect on bee abundance or pollination success of distance to an apricot tree row; 3) a higher bee abundance and greater pollination success in landscapes with more apricots.

2. Materials and methods

2.1. Study area

The study was conducted in Korla, Xinjiang, north-west China (E 85.48°, N 41.45°), which is the main pear cultivation area in Xinjiang with 60 % of the provincial production (Xinjiang Statistical Yearbook, 2019). The total area of arable land in Korla is approximately 100, 000 ha, 26 % of which consists of Korla fragrant pear, and 65 % of which is cotton. The remaining land area is used for cultivating other fruit trees such as apricot, peach, and jujube, and other arable crops such as maize, sugar beet, alfalfa, and vegetables (Xinjiang Statistical Yearbook, 2019). The region has a cold arid desert climate (Kottek et al., 2006), with an average annual precipitation of 60 mm and an average annual temperature of 11°C (http://data.cma.cn/). Crop production relies on irrigation from the Kongque River, which originates from the nearby Tianshan mountain range.

Korla fragrant pear blooms for approximately two weeks in early April and pears are harvested in September. Pears are frequently treated with insecticides and fungicides throughout the growing season, except from one week before flowering until the end of flowering to avoid direct impacts on pollinators. Boron-based growth regulators are applied during flowering to enhance the initial fruit set (Perica et al., 2001). Mature pear trees are approximately 5 m high and are grown in rows at approximately 5 m distance between trees within the rows and approximately 5 m between rows. Korla fragrant pear *(Pyrus sinkiangensis)* orchards usually contain 4–8 % randomly interspersed Dangshan pear (*Pyrus bretschneideri*) trees as pollinizer to allow cross-pollination.

Selected pear orchards were 15–20 years old, which is full fruit bearing age and representative for the orchards in the area. The selected orchards had little or no flowering ground cover during the pear flowering period. There were no honeybee hives in the orchards and the orchards were not artificially pollinated. The experiments were conducted in 2019 and 2020, with different orchards selected in each year.

2.2. Experiment 1: effect of interspersed apricot trees on bee abundance and pollination services in pear orchards

To assess the effect of the presence of interspersed apricot trees on pear pollination, we compared the abundance of wild bees and honeybees, initial fruit set, and seed set in mixed apricot-pear and mono-pear orchards in 2020 (Fig. 1a; Table S1). Four sites were selected. The distance between the sites was at least 500 m. At each site, we selected two orchards, one with apricot trees interspersed between pear trees (mixed apricot-pear), and one with only pear trees (mono-pear control). The distance between the orchards within a site was not more than 200 m to ensure the orchards were in largely the same landscape setting. The mixed apricot-pear orchards contained at least 6 % apricot trees.

The bee abundance in each focal orchard was measured using colored pan traps (Zou et al., 2017) during pear flower blooming in early spring (see detailed description in Supplementary Methods S1). A total of four sampling rounds were conducted from 31 March 2020–12 April 2020. Sampling round 1 coincided with the peak and late apricot blooming period, while sampling rounds 2, 3, and 4 took place after apricot blooming had finished and during early and peak blooming of the pears. We grouped pollinators into two taxa: honeybees (*Apis mellifera*) and wild bees. We distinguished wild bees from other insects in traps but did not identify them to species in this study. Information on identity is given in another synchronous study in 2018–2021 in Korla fragrant pear orchards (Unpublished data, Table S2). Our previous study showed the number of other potential pollinators, such as butterflies (1.1 %), moths (10 %), hoverflies (1.6 %), and wasps (0.7 %) in traps in Korla fragrant pear orchards were relatively low and hardly observed as pear flower visitors and thus omitted from analysis (Li et al., 2022).

We assessed initial fruit set by determining the proportion of fruitlets per flower cluster at the end of April (for a total of 10 trees x 12 flower clusters per tree = 120 flower clusters per orchard) (see detailed description in Supplementary Methods S2). The seed set (number of mature seeds per pear) was assessed in early September before harvest. In each orchard five pear trees were selected in a five-point pattern and from each tree six random pears were taken, for a total of 30 pears per orchard. The average number of seeds of 30 pears per orchard was used for the analysis of seed set.

2.3. Experiment 2: gradients from an edge row with apricot or pear trees

To assess the relationship between pear pollination and the distance from an apricot tree row at the orchard edge, we compared the abundance of wild bees and honeybees, initial fruit set, and seed set in pear

trees at five different distances (5, 15, 30, 50, and 100 m) from an edge row of apricot trees (strip-apricot pear orchard) and an edge row of pear trees (mono-pear orchard) in 2020 (Fig. 1b; Table S3). Four sites (different from those of Experiment 1) were selected. Within each site, we selected one pear orchard with a row of apricot trees at the edge and no other apricot trees in the orchard (treatment) and another pear orchard without apricot trees (control). The distance between sites and orchards with a site was not more than 200 m, as in Experiment 1.

We measured bee abundance at different distances from the edge row using pan traps. We used at each distance from the edge row three trees, with approximately 10 m distance within the row. We assessed initial fruit set at the end of April by measuring initial fruit set on three trees per distance (for a total of 3 trees x 12 flower clusters per tree = 36 flower clusters per distance). Before harvest, we took six random fruits from each of five trees at each distance to assess seed set. The protocols for the assessment of bee abundance, fruit set and seed set were the same as in Experiment 1.

2.4. Experiment 3: apricot density in the surrounding landscape

To assess how the density of apricot trees in the surrounding landscape influenced pear pollination, we assessed wild bee abundance, initial fruit set, and seed set in 15 mono-pear orchards in 2019 and another 13 mono-pear orchards in 2020 (Fig. 1c; Table S4). The distance between orchards in the same year was at least 2 km. The abundance of wild bees and honeybees in 2019 and 2020, initial fruit set in 2020, and seed set in 2019 and 2020 were measured in each focal pear orchard using the same procedure as in Experiment 1, except for the procedure of initial fruit set assessment in 2019 (see detailed description in Supplementary Methods S3).

The number of apricot trees in radii of 0.5, 1.0, 1.5, and 2.0 km around focal pear orchards was assessed by landscape survey at the end of March 2019 and 2020 when the apricot trees are easily recognized by their pink flowers. We drove through the landscape with a car recording the number of apricot trees and their location on a printed satellite map. The flowering apricot trees in each land parcel were counted.

The land use in the surrounding landscape was also assessed because the bee habitats in different land use types also could influence the bee abundance and associated pollination success (Ockermüller et al., 2023). The land use types in the landscape sectors were assessed by ground observation in early September 2019 and 2020 when the annual crops were nearly mature and could be easily identified. The landscape data were digitized in ArcGIS 10.8 to calculate the percentage of each land use type around focal orchards (see detailed description in Supplementary Methods S4 and Tables S5 and S6).

2.5. Statistical analyses

We used linear mixed models (LMMs) and generalized linear mixed effects models (GLMMs) to analyse data of Expt. 1 and explore how the abundance of wild bees and honeybees, initial fruit set, and seed set (response variables) were influenced by treatment (presence or absence of scattered apricot trees; categorical variable), sampling round (categorical variable) and their interaction. If multiple observations per site were used, "Site" was included as a random effect. In addition, we analysed the effect of interspersed apricot trees on the above four response variables in separate analyses for each sampling round using generalized linear effects models (GLMs).

Similarly, we used LMMs and GLMMs to analyse the data of Expt. 2 and explore how the abundance of wild bees and honeybees, initial fruit set, and seed set (response variables) were influenced by the treatment (presence or absence of apricot tree row; categorical variable), distance from the edge row (categorical variable), sampling round (categorical variable), and their interactions (explanatory variables). "Site" was included as a random effect if necessary. To avoid redundant models and spurious results, a multi-model inference procedure based on the bias-corrected Akaike's information criterion (AICc, corrected for small sample sizes) was performed for bee abundance as response variable (see Supplementary Methods S5). We conducted follow-up analyses using separate generalized linear effects models (GLMs) for each sampling round.

Third, we used LMMs and GLMMs to analyse the data of Expt. 3 by exploring whether variation in abundance of wild bees and honeybees, initial fruit set, and seed set (response variables) in pear orchards were influenced by the apricot density (tree/km^2) and seven land use types in the surrounding landscape (response variables). To avoid multicollinearity, we excluded tree crops from the model (Fig. S1). To account for differences in the sampling duration between rounds, we included the log-transformed sampling days as an offset variable in the model (Zuur et al., 2009). This means that the response is effectively analysed based on the number of wild bees captured per day. We conducted analyses based on apricot densities in concentric circles of 0–0.5, 0–1.0, 0–1.5, and 0–2.0 km radii around the focal field. Variance inflation factor (VIF) values for the explanatory variables in each global model were calculated and were found to be less than four, indicating that covariation between explanatory variables was not a problem in the full model (Dormann et al., 2013). The residuals of all models were used to check for spatial autocorrelation using Moran's I (Gittleman and Kot, 1990), and we detected no significant spatial correlation in any of the analyses ($p > 0.05$).

For all analyses, we used a negative binomial error distribution to analyze the count data (including the abundance of wild bees and honeybees, and number of fruitlets). Due to the substantial overdispersion of initial fruit set rate when fit with a binomial error distribution, this data was analysed using a normal error distribution. The seed set was an average of 30 fruits per orchard, and we used for this data a normal error distribution.

The models were validated using histograms of normalized residuals and plots of residuals against fitted values (Zuur et al., 2009). All statistical analyses were performed using R version 4.0.5 (R Core Team, 2018). We used the glmer or lmer function of the "lme4" package (Bates et al., 2015) to analyse results of Experiments 1 and 2, and the glm or lm function of the "MASS" package (Ripley et al., 2018) to analyse results of Experiment 3. Means and standard errors of the mean are reported throughout the text.

3. Results

3.1. Experiment 1: comparison of orchards with and without interspersed apricot trees

We trapped 539 wild bees and 49 honeybees in apricot-pear orchards and 245 wild bees and 55 honeybees in mono-pear orchards in four sampling rounds. The abundance of wild bees in mixed apricot-pear orchards was significantly higher than in mono-pear orchards ($p < 0.001$) (Table S6). The abundance of wild bees significantly decreased with sampling round (Table S6). 79 % of the variation was explained by the sampling round, and treatment explained 20 % of the variation that was not explained by the sampling round (Table S7). The abundance of honeybees was not significantly influenced by treatment, sampling round, and their interaction. 7 % of the variation in honeybee abundance was due to the sampling round, and treatment explained 2 % of the variation that was not explained by sampling round (Table S7). When analyzing the data for each round separately, we found a significant difference between the apricot-pear and mono-pear orchards only during apricot flowering; the abundance of wild bees was a factor 3.6 higher in apricot-pear orchards than in mono-pear orchards ($p < 0.001$) while the abundance of honeybees was a factor 2.8 higher in the mixed orchards ($p = 0.048$), but not after apricot blooming (Fig. 3; Tables S8 and S9). Fruit set and seed set of pears were not significantly influenced by the presence of apricot trees in orchards (Table S10).

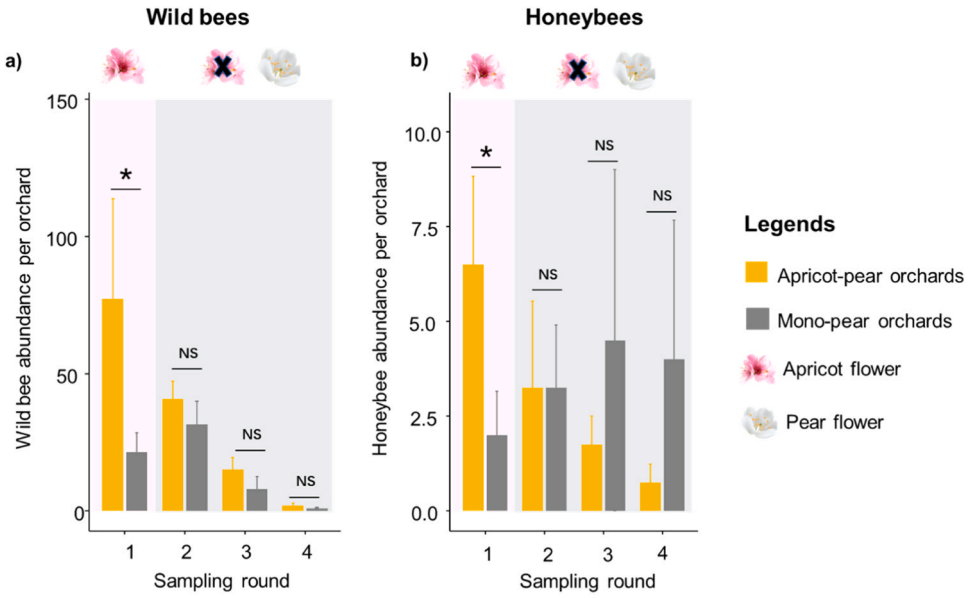

Fig. 3. Wild bee abundance (a) and honeybee abundance (b) in apricot-pear (orange bars) and mono-pear orchards (grey bars) in four sampling rounds in 2020. Sampling round 1 coincided with apricot blooming while pear started blooming. Sampling rounds 2, 3, and 4 were after apricot blooming and during the early and peak blooming of pear. Error bars represent the standard error of the mean of each treatment per sampling round. Asterisks (*) indicate significant treatment effect ($p < 0.05$) and NS indicate non-significant differences ($p > 0.05$; Table S8).

3.2. *Experiment 2. Gradients from an edge row with apricot or pear trees*

We collected a total of 2577 wild bees (1423 and 1154 individuals in apricot row-pear orchards and mono-pear orchards, respectively) and 404 honeybees (234 and 170 individuals in apricot row-pear orchards and mono-pear orchards, respectively) in four paired sites in Experiment 2.

The abundance of wild bees and honeybees was significantly influenced by sampling round ($p < 0.001$), and was not significantly influenced by treatment, sampling distance and their interaction (Tables S11 and S12). Most of the variation in bee abundance was due to the sampling round (33 % for wild bees and 46 % for honeybees), treatment and sampling distance explained a small part (< 3 %) of the variation that was not explained by the sampling round (Table S13).

During apricot blooming (sampling round 1), the abundance of wild bees and honeybees was 5.2-fold and 2.6-fold higher in pear trees adjacent to the apricot tree row (5 m) than in pear trees adjacent to the control pear row (wild bees: $p < 0.001$, honeybees: $p = 0.241$). A significant influence on bee abundance was not detected at the subsequent three distances from the tree rows (15 m, 30 m, and 50 m) though it was

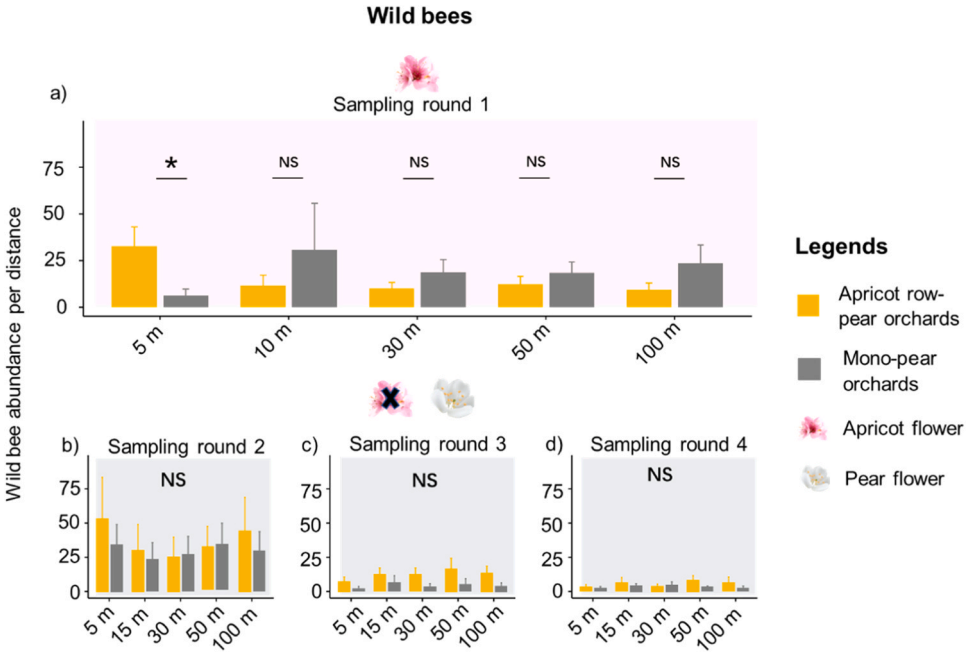

Fig. 4. The abundance of wild bees during apricot blooming (a) and after apricot blooming (b, c, and d) in Korla fragrant pear trees at distances of 5, 15, 30, 50, and 100 m from apricot edge tree rows (orange bars) and pear tree rows (grey bars). Sampling round 1 coincided with apricot blooming when pear started blooming. Sampling rounds 2, 3, and 4 were after apricot blooming and during the early and peak of pear blooming. Error bars represent the standard error of the mean. Asterisks (*) indicate the significant effect of treatment ($p < 0.05$) and NS indicate a non-significant effect of treatment ($p > 0.05$; Table S16).

again significant at 100 m for honeybee abundance ($p = 0.002$) (Figs. 4 and 5; Tables S14 and S15). After apricot blooming (sampling rounds 2, 3, and 4), the abundance of wild bees and honeybees was not significantly influenced by treatment and distance from the tree row (Figs. 4 and 5; Tables S14 and S15). The fruit set and seed set of pears were not significantly influenced by the treatment and distance from the tree row (Tables S16, S17, and S18).

3.3. Experiment 3: apricot trees at the landscape scale

We collected 2306 wild bees and 600 honeybees in 28 orchards during a 12-day sampling period in 2019 and another 12-day in 2020. Per orchard, we caught on average 82.4 ± 12.3 wild bees (range 13–289) and 21.4 ± 3.5 honeybees (range 0–75).

The abundance of wild bees and honeybees was not significantly influenced by apricot density in the surrounding landscape at four spatial scales (Tables S20 & S21). Likewise, the initial fruit set of pears was not significantly influenced by the density of apricot trees in the surrounding landscape (Tables S22 and S23). However, the seed set of pears was significantly and negatively influenced by the density of apricot trees at a scale of 0.5 ($p = 0.004$) and 1.0 km ($p = 0.006$), but not at larger spatial scales (Table S24). The seed set in 2019 was significantly higher than in 2020 (Table S24).

4. Discussion

We assessed the influence of apricot as an early flowering tree species on the abundance of bees and pollination success in Korla fragrant pear at three spatial scales. Here we report four key findings: i) scattered apricot trees in pear orchards increased the bee abundance in pear orchards during apricot flowering, but not after apricot flowering; ii) during apricot blooming, the abundance of wild bees and honeybees was higher in pear trees adjacent to apricot tree rows at the edge of the orchard than adjacent to other pear trees, but this effect did not extend further into the orchard; iii) the increased bee abundance in mixed apricot-pear orchards during apricot blooming did not lead to higher pollination success; iv) apricot trees in the surroundings of pear orchards did not significantly influence wild and honeybee abundance in pear orchards.

4.1. Effect of apricot trees on the abundance of wild bees and honeybees in pear orchards

The abundance of wild bees and honeybees was higher in mixed apricot-pear

orchards than in mono-pear orchards, but only when the apricot trees were blooming (Figs. 3a and 3b, Expt. 1). This response of wild bees and honeybees aligns with the general hypothesis that a diversified plant community may attract more pollinators than species-poor plant communities (Campbell et al., 2017; Albrecht et al., 2020). Flowering apricot trees within focal pear orchards thus appear to act as “magnets” that attract and arrest wild bees in the orchard from the surrounding area (Diekötter et al., 2010; Montero- Castaño et al., 2016). However, since this bee attraction effect was only observed during apricot blooming this suggests that 1) this is an instantaneous aggregation effect; 2) it does not lead to retention of bees that may contribute to the pollination of pear trees after apricot flowering. These findings suggest that establishing apricot trees in pear orchards may facilitate wild bees and honeybees in pear orchards, but this effect only occurs during apricot flowering and does not affect pollination of pear.

4.2. Spatially confined spillover effects of bees around apricot trees

During apricot blooming, we found that apricot tree rows only increased the abundance of wild bees and honeybees on adjacent pear trees and not on pear trees at greater distances (Figs. 4a and 5a, Expt. 2). These results are in line with studies that reported aggregation of pollinators to flowers-rich habitats (Kleijn et al., 2018; Kohler et al., 2007; Morandin, Claire, 2013; Nicolson, Wright, 2017; Zamorano et al., 2020) and that found declining pollinator abundance with distance from

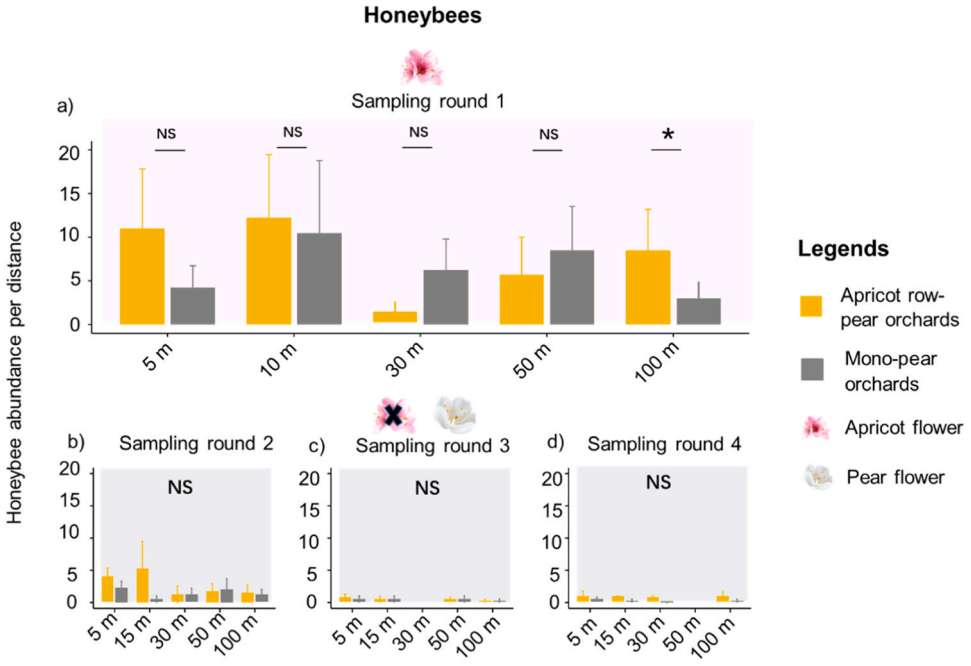

Fig. 5. The abundance of honeybees during apricot blooming (a) and after apricot blooming/during pear blooming (b, c, and d) in Korla fragrant pear trees at distances of 5, 15, 30, 50, and 100 m from apricot edge tree rows (orange bars) or pear tree rows (grey bars). Sampling round 1 coincided with apricot blooming and pear was not yet blooming. Sampling rounds 2, 3, and 4 took place after apricot blooming and during the early and peak of pear blooming. Error bars represent the standard error of the mean. Error bars represent the standard error of the mean. Asterisks (*) indicate the significant effect of apricot tree row (treatment) ($p < 0.05$) and NS indicate the non-significant effect of apricot tree row (treatment) ($p > 0.05$; Table S16).

flower-rich habitats (Albrecht et al., 2020). In apricot row-pear orchards, the wild bee abundance-distance relationship was relatively steep (Fig. 4a), indicating that apricot trees arrest bees in a relatively small radius of approximately five meters around the tree. Therefore, to maximize benefits from the bee attraction effect of apricot trees the spatial distribution of apricot trees in pear orchards should be taken into consideration.

4.3. Increased bee abundance by apricot did not lead to increased pollination

In contrast to our hypothesis, the higher bee abundance near apricot trees did not result in a higher fruit or seed set in pears. This finding does not align with studies that report increased pollination services in target crops associated with enhanced abundance of wild bees and honeybees near flowering habitats (Blaauw and Isaacs, 2014, Holzschuh et al., 2012; Földesi et al., 2016). The absence of increased pollination success in our study could have several causes. First, the bee aggregation effect of apricot trees was only local and short-term, and therefore it may not have had a meaningful effect on fruit and seed set. Second, the Korla fragrant pear pollination is mostly done by honeybees (Li et al., 2022), and the abundance of honeybees in our study orchards was relatively low because the orchards did not contain beehives and there are no feral honeybees in the study region. Third, pear flowers are not attractive for wild bees (Monzón, et al., 2004; Li et al., 2022), and therefore a higher wild bee abundance associated with apricot trees does not mean that the wild bees will also visit pear flowers. Thus, our results suggest that the increased wild bee abundance associated with apricot trees does not lead to a meaningful improvement of pollination in the pear crop. This result is consistent with the finding of Li et al. (2022) that wild bees do not frequently visit Korla fragrant pear flowers and most of the pollination of this crop is done by honeybees.

4.4. Apricot trees in the surrounding landscape do not influence pollinator abundance in pear orchards

The presence of apricot trees in the surrounding landscape did not influence pollinator abundance and pollination success on pear orchards but it had a negative effect on seed set at the scale of 0.5 and 1.0 km (Table S24, Expt. 3). The lack of effect of apricot trees in the surrounding landscape in pear orchards may be explained by the following two factors. First, the apricot trees in the surrounding landscape may have been too few and too far to have a measurable effect on the abundance of wild bees and honeybees in pear orchards. Second, honeybee abundance strongly depends on the location and number of honeybee hives, which depends on decision-making by beekeepers and not on the presence of apricot trees in the surrounding landscape. In contrast, previous studies showed that when the flowering resources appeared in large areas at the landscape scale, the abundance of pollinators in the target crop can be either boosted (Rundlöf et al., 2014) or diluted (Shaw et al., 2020). While we did not measure an effect of apricots in the landscape on wild bee and honeybee abundance in pear orchards, the reduction of seed set in landscapes with more apricot trees does suggest that apricots in the landscape negatively affect pollination services. This then provides indirect evidence for the aggregation hypothesis, i.e. apricots in the wider landscape attract bees away from pear orchards. This is in agreement with the results of Experiments 1 and 2 which provided direct evidence for aggregation of wild bees and honeybees to apricot trees.

In this study we used pan traps to study the effect of apricot trees on the abundance of wild bees and honeybees, but we did not use other methods such as transect walking with net or visual observation. Transect walking is not convenient in pear orchards but direct observations on flower visitation are feasible (Li et al., 2022). In earlier work we found that wild bees made few visits to pear flowers even if they were abundant in Korla fragrant pear orchards (Li et al., 2022). The low quantity and quality of nectar of the pears is the likely cause of the low visitation (Free, 1993; Pamminger et al., 2019). On the other hand, honeybees do visit the pear flowers (Li et al., 2022). Hence, the results shown in this paper do provide evidence for the aggregation hypothesis mainly for the wild bees (significant results in all three experiments), but most of the pollination services are provided by honeybees which are not efficiently trapped with pan traps (Hutchinson et al., 2021). Further work could hence complement our findings by evaluating the effects of apricot trees on flower visitation by honeybees.

5. Conclusions

Korla fragrant pear requires cross-pollination to secure satisfactory fruit production, but pollinator abundance may be too low to provide the required pollination services in our study region. Our findings indicate that the presence of apricot trees, an early flowering species, within Korla fragrant pear orchards increased the abundance of wild bees and honeybees, however, this effect occurred only during apricot flowering and did not lead to improved pollination success as measured by fruit set and seed set. On the contrary, presence of apricot trees in the wider landscape at 500 and 1000 m radius around pear orchards resulted in lower seed set in pear, indicating that pollination had been less efficient in orchards in landscapes with more apricot trees. All the results indicate that apricot trees have an aggregation effect on pollinators. When pollinators aggregate around flowering apricot trees this had a short distance exporter effect on nearby pear trees. The effect of such an exporter effect on pollination of pear trees may be limited as there is little temporal overlap in flowering of apricot and pear.

CRediT authorship contribution statement

Wopke van der Werf: Writing – review & editing, Validation, Supervision, Methodology, Formal analysis. **Yanhui Lu:** Writing – review & editing, Validation, Supervision, Methodology, Funding acquisition, Conceptualization. **Bing Liu:** Writing – review & editing, Supervision, Methodology, Investigation, Data curation, Conceptualization. **Felix J. J. A. Bianchi:** Writing – review & editing, Supervision, Software, Methodology. **Qian Li:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.agee.2024.109146.

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