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PAPER

# How pollinator dependence may mediate farmer adoption of pollinator supporting practices and perceptions: a case study from western France

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**Keywords:** bees, perception, pollination, agri-environment schemes, dependence, attitude, knowledge

Supplementary material for this article is available online

## Abstract

There is limited knowledge on why farmers adopt pollinator-supporting practices, which is crucial to stimulate their adoption. The dependence of farmers on pollination may influence their perception of pollinators and their willingness to adopt these practices. We addressed why farmers adopt pollinator-supporting practices using a 2011 survey conducted within a cereal plain in western France, where farmers were moderately dependent on pollination for crops like oilseed rape and sunflower. We assessed the factors influencing the adoption of practices to promote pollination, including pollination dependence. We found no effect for pollination dependence. Conversely, we found that farm size, pesticide use, advisory services and the perception of costs decreased the willingness to adopt, while older farmers were more incline to adopt. We also evaluated perceptions related to pollinators: more than 85% of farmers considered bees important for crop production and recognized pesticides as a major cause of decline. We found no effect of pollination dependence on farmers' perceptions. Compared to similar studies over the past decade, we found similarities, particularly regarding pollinator-related perceptions. Finally, we compared the willingness to adopt in 2011 with the actual adoption in 2024, showing that there has been little change. This raises questions on the pathways to promote the adoption of pollinator-supporting practices to ensure for the future of pollinator conservation.

## Introduction

Pollinators are interlinked to the maintenance of ecosystems and human welfare by ensuring plant reproduction and crop production (Potts *et al* 2016). It is commonly acknowledged that pollination is a critical ecosystem service for agriculture (Woodcock *et al* 2019): 75% of cultivated crops in the world depend on insect pollination (Klein *et al* 2007) and pollination services have been estimated to have a market value of between \$235 and 577 billion per year (IPBES 2016). Animal-based pollination is widely carried out by insects, particularly bees, which visit more than 90% of the leading types of crop (Klein *et al* 2007). Yet despite their key role, pollinators are threatened worldwide, especially in farmland, due to land-use changes involving the destruction, fragmentation and degradation of semi-natural habitats (Potts *et al* 2010, Goulson *et al* 2015, Hallmann *et al* 2017), which reduce floral and nesting resources (Baude *et al* 2016). Pollinators are also impacted by both pesticide exposure and toxicity (Sánchez-Bayo ans Wyckhuys 2019). Sustainable management strategies are therefore needed to halt pollinator decline without affecting food production (Garibaldi *et al* 2014, IPBES 2016).

There is growing evidence that pollinator-supporting practices (PSPs) benefit pollinators, pollination services and farmers' revenues (Decourtye Mader and Desneux 2010, Garibaldi *et al* 2014, Kovács-Hostyánszki et al 2017). These practices include planting flower strips (at field edges or within crops) and hedgerows to offer nesting sites and floral resources for pollinators, increasing their abundance and diversity (Kremen et al 2019). Flowering cover crops, fallows and semi-natural habitats have also been shown to increase pollinator abundance (IPBES 2016) by providing floral resources—especially during periods of flower shortage (i.e. between mass-blooming periods; Bretagnolle and Gaba 2015). In parallel, reducing the amount and toxicity of agricultural chemicals, as well as applying them outside of the pollinator activity period, directly benefits pollinators by decreasing their mortality rate (in the case of insecticides) and indirectly benefits them by increasing flower abundance (in the case of herbicides; Kovács-Hostyánszki et al 2017). Yet despite the known effectiveness of PSPs, scientific advice and international policies, PSPs have met with low adoption by farmers. Therefore, identifying the determinants of PSP adoption remains critical (Breeze *et al* 2019, Kleijn *et al* 2019).

The literature on the determinants of the adoption of PSPs has identified that traditional socioeconomic determinants of adoption, such as age, advisory services, or farm size, play a role (Garbach and Morgan 2017; Hevia *et al* 2021, Faure *et al* 2024). Farmers' perceptions also influence adoption, such as the perceptions of the constraints imposed by these practices (Dessart et al 2019) or the perceived importance of pollinators for yields (Hevia *et al* 2021, Osterman *et al* 2021). Despite these findings, some determinants have not yet been explored: one particular factor that has not been studied is the farmers' pollination dependence. This refers to the percentage of production (either in quantity, quality or both) and, therefore, income that the farmer derives from insect pollination (Klein *et al* 2007). We suspect that the farmer's pollination dependence may influence their perception of pollinators (Breeze *et al* 2019), and more broadly, their willingness to adopt PSPs. Indeed, their economic pollination dependence could encourage them to adopt conservation practices to protect their income. To our knowledge, no study has examined how pollination dependence might explain the heterogeneity in the willingness to adopt PSPs and the perceptions related to pollinators. Furthermore, a qualitative literature review shows that the studies focusing on farmers' perceptions of pollinators have exclusively surveyed farmers who are highly dependent on pollination in high-income countries (table 1). The pattern is the same for mid or low-income countries (Ali *et al* 2020, Christmann *et al* 2022). Yet, it is in the least dependent agricultural systems, such as cereal plains, where the highest rates of insect decline are observed (Sánchez-Bayo ans Wyckhuys 2019).

In this study, we focused on the effect of farmers' pollination dependence on the perceptions related to pollinators as well as on PSP adoption. We expected that the less the system depends on it, the lower the willingness to adopt these practices. We investigated whether pollination dependence is a determinant of the WTA alongside others within the same area. We also assessed farmers' perceptions of pollinators in this area and then compared them with perceptions measured across other systems. We focused on the study area of Zone Atelier Plaine & Val de Sevre, a cereal plain located in western France (Bretagnolle *et al* 2018b). This area is primarily dominated by arable crops that are minimally dependent on pollination (i.e., cereals), but the degree of dependence varies among farms because of crop rotation choices, which gives an ideal case study for our issue. We used a farmers' survey conducted in 2011, which assessed the intention to adopt or the adoption of ten PSPs, as well as perceptions related to pollinators. This survey was carried out within the broader framework of long-term monitoring of agricultural practices in this long-term research site that continues today (Bretagnolle *et al* 2018a). These data allowed us to evaluate several determinants of the WTA the practices, including pollination dependence, and to derive the farmers' perceptions on the importance of pollinators as well as their views about bee decline. Since the survey was conducted more than a decade ago, this study also provided an opportunity to report the perceptions of farmers regarding pollinators at the time, and to compare them with contemporary surveys to observe the evolution over a decade.

## Material and methods

### Study area and context

Our study was conducted at the long-term socio-ecological research site 'Zone Atelier Plaine & Val de Sèvre' located in western France (Deux-Sèvres, France; figure S1; (Bretagnolle *et al* 2018b). This is a rural agricultural area of almost exclusively arable and crop-livestock mixed farming covering 435 km$^2$ with a temperate Atlantic oceanic climate. The most common crops are winter wheat (33.8% of the total area), maize (9.6%), sunflower (10.4%), oilseed rape (8.3%), pea (2%) and meadows (13.5%), including both permanent grasslands and temporary hay such as alfalfa. The landscape has been strongly simplified over the past 40 years, with a 40%

**Table 1.** Overview of selected studies on farmers' perceptions of pollinators in high-income countries (since 2011). This review compares the perceived importance of pollinators for production and their causes of decline with findings from the current study. Source: Compiled by the authors.

| | *Faure et al (this study)* | (Gaines-Day and Gratton 2017) | (Hanes *et al* 2015) | (Hevia *et al* 2021) | (Maas *et al* 2021) | (Osterman *et al* 2021) | (Bloom *et al* 2021) |
|---|---|---|---|---|---|---|---|
| Survey year | 2011–2012 | 2011 | 2012 | 2018 | 2018 | 2019 | 2019 |
| Country | France | USA | USA | Spain | Germany & Austria | UK & Germany & Poland | USA |
| Number of farmers | 103 | 127 | 76 | 376 | 128 + 178 | 25 + 35 + 30 | 106 |
| Dominant crops | Cereals | Cranberry | Blueberries | Diverse | Diverse | Oilseed rape | Cucurbits |
| Pollination dependence | Low | High | High | High | Mid | High | High |
| *Importance of pollinators* | | | | | | | |
| Actual question for importance of pollinators | *Do you consider bees as an important production factor to take into account for crop production?* | *How important do you think honey bees are for cranberry pollination?* | *How important do you think native bees are for pollinating blueberries in Maine?* | NA | *How do you assess the importance of pollinators for agricultural production?* | *How important are honeybees for your crop?* | |
| Likert scale - equivalent | 4 points Likert scale | 5 points Likert scale | 5 points Likert scale | 6 points Likert scale | 5 points Likert scale | 4 points Likert scale | |
| | 1 : No, not important | 1 : Not at all important | 1 : Very unimportant | 1 : Unimportant | 1 : Unimportant | 1 : Not at all important | |
| | 2 : A little important | 2 : Slightly important | 2 : Somewhat important | 2 | 2 : Less important | 2 : Minor | |
| | 3 : Moderately important | 3 : Somewhat important nor unimportant | 3 : Neither important nor unimportant | 3 | 3 : Neutral | 3 : Somewhat important | |
| | 4 : Important | 4 : Very important | 4 : Somewhat important | 4 | 4 : Important | 4 : Very important | |
| | | 5: Extremely important | 5: Very important | 5 | 5: Very important | | |
| | | | | 6: Very important | | | |
| Importance of pollinators for production (4-pts equivalent) | Mean OSR: 3.83 Mean Sunflower: 3.81 | Mean: 3.2–3.5 | Mean: 3.56 | Mean: 3.29 | Mean: 3.42 | Mean: 3.67 | |
| *Causes of decline* | | | | | | | |
| Actual question for pollinator decline | *In your opinion, the difficulties faced by bees and beekeepers are primarily linked, in order of importance, to:* | | | NA | | | *How would you rate the importance of each of the following factors in impacting pollinator health?* |
| *Ranking by cause* | | | | | | | |
| Pesticides | 1 | | | 1 | | | 2 |
| Pathogens - Predators | 1 | | | 3 | | | 1 |
| Lack of resources | 3 | | | 2 | | | 3 |
| Apicultural practices | 4 | | | | | | 4 |

decrease in grasslands and semi-natural habitats, which have been replaced by arable crops (Gaba and Bretagnolle 2021). The two main pollinated crops are oilseed rape and sunflower (Perrot *et al* 2018, 2019). Thus, farmers are only moderately dependent on pollination for their income. The site is part of the European network of long-term monitoring infrastructures (Mollenhauer *et al* 2018), where biodiversity data is collected annually on selected fields, with a sample that changes from year to year. Since 2009, the farmers who own these fields are contacted after each season, and a face-to-face questionnaire is administered by an interviewer to collect data on agricultural practices (e.g. pesticide use and soil operations).

**Sampling method and data collection**

In this study, we focused on data collected in 2011 because in addition to the annual survey on agricultural practices, farmers were surveyed on pollinator-supporting practices and their perceptions of pollinators. This additional survey was added as part of the research programme 'POLINOV', a project aiming to understand the interactions between bees and intensive agricultural areas in order to provide more sustainable cropping systems (Decourtye *et al* 2014). For the 2011 season, the sampling was as follows: out of the 13,000 fields in the study site, 1500 were randomly sampled. These fields were owned by 200 farmers, who were all contacted to participate in the research programme. A total of 103 farmers participated, representing 1/4 of all operating farmers in the whole study site and owning 36% of the total agricultural area. Farmers were surveyed during face-to-face interviews from November 2011 to March 2012. Consent for an anonymous data use was asked to all participants. The full raw questionnaire used in 2011–2012 is available in the Supplementary Material 1.

**Socioeconomic and agricultural data**

In the first part of the 2011 survey, and in the context of the annual survey carried out in the study area, socio-economic and agronomic variables were obtained. More precisely, data were collected on the characteristics of the farmer (age) and farm (farming system, annual work unit, farm area, crop rotation, proportion of grassland, advisory service by government body). For each farm, we estimated a pollination dependence index based on its area of pollinated crops over the last 5 years (i.e. oilseed rape, sunflower and alfalfa) usingdata on land use from the research area database (Bretagnolle *et al* 2018a). Farmers were also asked if they hosted beehives on their farm near pollination-dependent crops. Finally, information was requested about agricultural practices on sampled fields, such as the use of agrochemicals and mechanical operations (details in Supplementary Material 2).

Agricultural practices were collected for one to six different crops per farm, including winter cereals (wheat and barley), maize, sunflower, oilseed rape and temporary grasslands (alfalfa; Supplementary Material 2). Of these, oilseed rape, sunflower and alfalfa production are partially (~30%) dependent on insect pollination (Klein *et al* 2007, Perrot *et al* 2018, 2019). From this data, we derived chemical-use intensity on all crops using the treatment frequency index (*TFI*; more details in Supplementary Material 2), which measures the intensity of application as the dosage applied per unit of cultivated area in relation to the recommended dosage per crop type (Möhring *et al* 2019). We also derived the intensity of soil management using two metrics: the number and average depth of mechanical soil operations from sowing to harvest. Given the heterogeneity in terms of type of crops and number of fields, we standardized *TFI* by dividing them by the maximal *TFI* per crop type and then averaged the index for each farmer (see more details in Supplementary Material 2). Our relative *TFI* index (denoted $TFI_{rel}$) thus provides a hierarchy of management intensity among the farmers sampled in the study, rather than an estimation of management intensity *per se*.

**Perceptions related to pollinators and pollinator-supporting practices**

In the second part of the survey, as part of the POLINOV project, perceptions related to pollinators were evaluated. First, the farmers were asked for their opinions on the importance of bees as a production factor through the pollination they provide. The response was given on a four-level ordinal scale from 'no' (it is not important) to ' important'. This serves as a proxy for the perception of the importance of pollinators for crops. Next, the farmers' opinions were solicited on the causes of bee decline. Four causes were given (bad apicultural practices, lack of food resources, pesticides, and pathogens or predators) and the farmers had to rank them from the most to the least important. Farmers were also asked for any agreement with a beekeeper. This has been observed in the area, whereby the farmer provides the beekeeper with shelters for hives near their pollinated crops to enhance pollination levels. This can be interpreted as a proxy for the importance farmers place on pollinators in general, or on honeybees specifically. Finally, a series of questions were asked regarding the perception of barriers that might exist to implementing PSPs. The responses were in a yes/no format to statements about the barriers. These barriers related to the lack of information on the benefits of pollination, lack of economic resources, and technical difficulties, can be interpreted as perceptions of PSPs from farmers.

Farmers' adoption or intention to adopt was then evaluated for ten PSPs (Supplementary Material 3, table S1; figure 1): three related to off-field practices and seven to in-field practices. For more details on PSP choices, please refer to Supplementary Material 3. For each practice, farmers were asked if they 'adopted' the practice, or if they had the intention to adopt it, to which they could answer 'yes', 'maybe', or 'no'. Furthermore, after the survey, we evaluated the cost of each practice, which provided additional information to understand their level of adoption (Supplementary Material 4).

**Willingness to adopt score**

To quantify farmers' WTA, we computed a composite indicator—a so-called 'score'—for each farmer. It was based on survey responses for eight PSPs[8] . This improved the robustness of the analysis as it reduces potential measurement errors, given that practices and farm situations were widely variable (Floress *et al* 2018). We transformed the qualitative PSP variables into numerical ones. Concretely, we assigned a value $Y_{p,i}$ to each farmer $i$, being equal to 1 for 'no', 2 for 'maybe', 3 for 'yes' and 4 for 'already adopted' the practice $p$. While the first three measured behavioural intention, the last measured an actual behaviour. The literature has shown that the two should be distinguished in analyses because of an 'intention–behaviour' gap: people do not always do what they intend (Sheeran and Webb 2016; for farmers see Floress *et al* 2018). Such gap may arise in our study, either due to a projection bias[9] or an interviewer bias[10]. Therefore, we used a unified treatment of adoption and intention to improve the sample size and thus the robustness of the study. Because we focused on adoption rather than intention, we transformed $Y_{p,i}$ with an increasing convex function, therefore giving more weight to the 'already adopted' response. We chose the exponential function because it had the greater explained variance rate (see Supplementary Material 5). The score related to WTA was calculated as follow:

$$WTA_i = \frac{1}{n} \sum_{p=1}^{n} \exp\ (Y_{p,i}) \tag{1}$$

where $n = 8$ is the number of PSPs. $WTA_i$ was considered as the dependent variable in the models presented below. Thus, the variable ranges from 2.72 to 54.60 and has no unit. The score can be interpreted as the average level of acceptability of the PSPs. For example, a WTA between 7.39 and 20.09 means that on average, the farmer intends to adopt the practices but has not yet adopted many. Similarly, a score between 20.09 and 54.60 means that the farmer is rather favourable towards the PSPs and has even already adopted some.

**Statistical analyses**

We performed descriptive statistics on the raw adoption or opinion levels of the ten pollinator-friendly practices to report the heterogeneity in the acceptability of these practices. We then performed a bidirectional stepwise selection based on Akaike Information Criterion (AIC; Claeskens and Hjort 2008) to uncover the determinants that better explained farmers WTA. The farmer's $i$ WTA score is assumed to be:

$$WTA_i = \beta_0 + \beta_x x_i + \varepsilon_i \tag{2}$$

where the candidate determinants are represented by $x_i$. $\beta_0$ is the intercept, $\beta_x$ is the vector of coefficients, and $\varepsilon$ is the error term. The analysis was conducted with a sample size of 97 farmers because of missing data for some practices. All independent variables were initially checked for correlation (Supplementary Material 6). The variables used in the complete (pre-selection) model are reported in table 2. Yes/no and two-level categorical variables were converted into dummy variables. The multilevel ordered categorical variable was treated using polynomial contrasts with a quadratic effect. We also included the interaction between the perceived economic risk of implementing PSP and the farm size, a proxy for the amount of money available to the farmer. $TFI_{rel}$, tillage depth and the number of soil operations were standardized using z-scores. The resulting model was checked for multicollinearity by computing the variation inflation factor using the R package car (Fox *et al* 2012), which was lower than 1.14. Lastly, we performed frequency analyses on the farmers' perceptions of the importance of pollinators for yields and the number of farmers who provided shelter for beehives. These are two proxies for the importance accorded to the pollinators. We also analysed the farmers' classification of the causes of decline using rank analysis. To do so, we assigned numbers to the ranks given by the farmers, i.e., the most important cause of decline was assigned a 1, the second most important a 2, and so on. A non-parametric paired Friedman test was then used to detect significant differences in the ranked causes of decline and to determine if some causes are highlighted more than others. The correlation between pollination dependence and each perception-related variable was tested using either Kruskal–Wallis, Wilcoxon or Kendall tests according to the nature of the variable.

[8] Two PSPs (left fields fallow and planted grass margins along watercourses) were excluded because half of the farms were not eligible for these practices (42% and 44% respectively).

[9] A projection bias is a self-forecasting error, in which the respondent overestimates how much her/his future self will share the same beliefs, values and behaviours as her/his current self.

[10] An interviewer bias occurs when respondents give affirmative responses to please the interviewer.

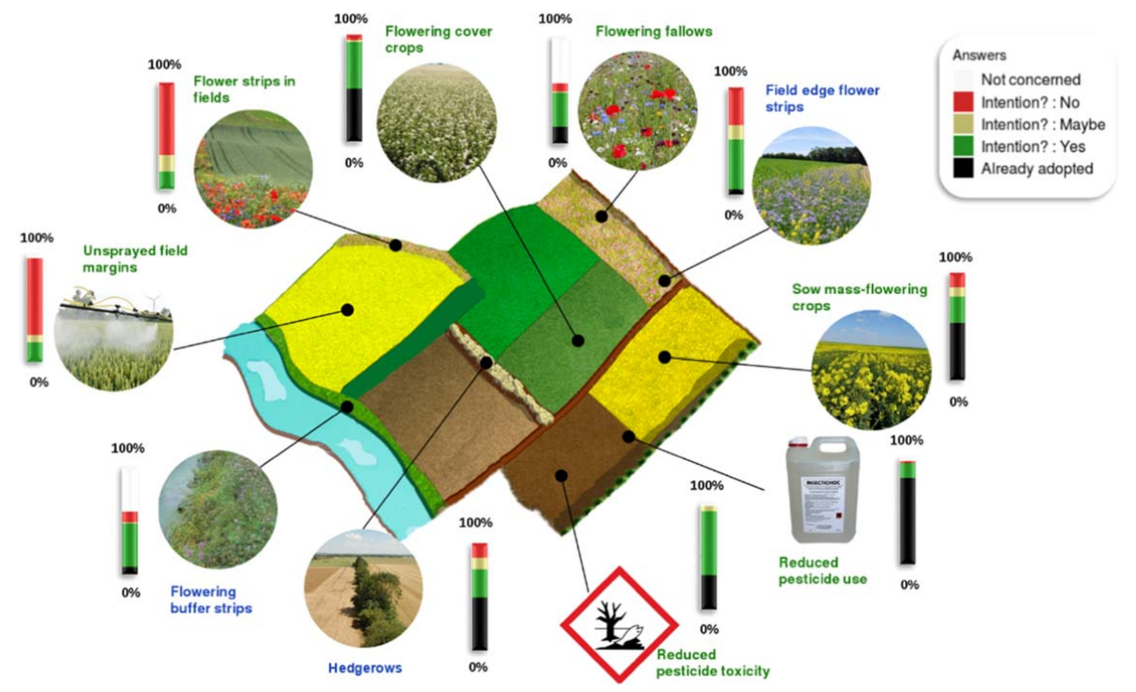


**Figure 1.** Pollinator-supporting practices studied and their acceptability, with in-field practices (in green) and off-field practices (in blue). Adoption (in black) and intention to adopt ('yes' in green, 'maybe' in brown and 'no' in red) PSPs are also represented.

All statistical analyses were realized using R Version 4.1.2 (R Core Team 2018). For all models, we checked prerequisites of homogeneity of variances and normality of the residuals using the 'plot' function of R base. To illustrate the variable effects mediating the WTA score, we plotted the model averaged predictions with raw survey data, using the effects package in R (Fox *et al* 2022).

## Results

### Data description

Of the 103 farmers, 99 were conventional farmers and 4 were organic farmers. 48% of the farmers were cereal farmers and 52% farmed crops for livestock (table 2). Agricultural land per farm was on average 159.4 ha (SD ± 106.4 ha), with an average field size of 7.4 ha (±5 ha). The percentage of pollination-dependent crops was on average 18% per farm (SD ± 9%). Cereal farmers carried out crop rotations commonly found in the area: i.e. cereal–oilseed rape–cereal or cereal–oilseed rape–cereal–sunflower. They also grew irrigated maize. Mixed-farm farmers had more diversified crop rotations, which included temporary grasslands (alfalfa, ray grass). They also had permanent grasslands for livestock. As a consequence, the mean grassland area was higher for mixed farms, with approximately 21% of total agricultural land area compared to cereal farms (7%). The number of workers was twice as high in mixed farms compared to cereal farms. Regardless of the farming system, crop yields were 5.9 $t.ha^{-1}$ (±11.2 $t.ha^{-1}$) for winter cereals, 2.8 $t.ha^{-1}$ (±0.65$t.ha^{-1}$) for oilseed rape, and 2.3 $t.ha^{-1}$ (±0.7 $t.ha^{-1}$) for sunflower, which was consistent with crop yield at the national scale in 2011 (Agreste 2014).

*TFI* was 3.5 (±1.3) for winter wheat (2011 French average 3.8), 6.4 (±2.2) for oilseed rape (2011 French average 5.5), 1.6 (±1.1) for maize (2011 French average 1.5), and 1.3 (±0.7) for sunflower (2011 French average 1.7; Agreste 2013, table 2). Tillage depth was 11.1 cm (±8.7 cm) including no-till crops and 16.6 cm (±4.7 cm) without no-till fields. The number of mechanical soil operations was 2.7 (±1.3) per year (2011 French average 3.1; Agreste 2014).

### Willingness to adopt pollinator-supporting practices

We observed a high heterogeneity concerning willingness to adopt PSPs (figure 1). The most accepted and reported practice was reduction in pesticide use, which met almost 95% approval of all farmers surveyed (i.e. including 'yes' and 'maybe' reported intention to adopt) and implemented by more than 80%. Hedgerows and sowing of mass-flowering crops and flowering cover crops were also widely adopted (more than 50% adopted for each practice). These showed a wide acceptability rate: 75% of the farmers stated their intention to adopt them in the future. Reducing pesticide toxicity was less adopted (~30%) though widely intended by farmers (more than 90% were favourable). Although largely accepted by farmers, flowering fallows and buffer strips were rarely adopted; this may partly be explained by the fact that some of the farmers in our sample did not have eligible lands for these PSPs. Similarly, flower strips along field edges were seldom adopted (11%), although more than 50% shared their willingness to implement these. A little over 35% of farmers were unfavourable to such practices. Unsprayed field margins and flower strips in fields were not adopted by surveyed farmers, who were generally reluctant to adopt such practices (70%).

On average, the WTA-related score was 26.04 (CV: 20%, range 13.6–38.0, $n = 103$). The score of 26.04 indicates a moderate to high willingness to adopt, as it is above the average score of 20, which corresponds to the response 'yes, I intend to adopt the practice.' Additionally, the coefficient of variation of 20% suggests that the dispersion is relatively moderate compared to the average score.

### Determinants of the willingness to adopt

The results of the model selection procedure are provided in table 3 and illustrated in figure 2. The model selection did not retain pollination dependence, indicating that it did not significantly impact farmers' WTA (figure 2(a)). Among the socioeconomic variables, farmer age was positively correlated with the WTA score (figure 2(b)), whereas agricultural advisory services and pesticide use were negatively correlated (figures 2(c) and (d)). The perceived cost associated with PSPs played on the WTA score. When farmers perceived these practices as costly, the WTA score decreased by an average of 17.58 points, as shown in table 3. This result can be supplemented by our average estimate of the costs of practices in Supplementary Material 4 (figure S2), using the literature. The more expensive a practice is to implement, the less it appears to be adopted. This suggests that both the cost and the perceived cost of the practice could play a role. Among farmers who did not perceive these practices as costly, farm size was a determining factor, with smaller farms scoring higher than larger ones (figure 2(f)). Finally, the perception of the importance of bees for production, specifically oilseed rape (OSR), was positively correlated with the WTA score (figure 2(e)).

### Perception of pollinators

When asked if they consider bees important for crop production, farmers positively answered and no farmer considered bees as unimportant (table 4). 89.3% and 86.4% of farmers stated that bees are important for oilseed rape and sunflower, respectively. We did not find any link between these perceptions and pollination dependence (Kruskal–Wallis tests: $\chi^2 = 2.421$, $p = 0.298$ for OSR; $\chi^2 = 0.164$, $p = 0.921$ for sunflower). Additionally, about 15% of farmers worked with beekeepers and had beehives near their fields. These farmers were no more dependent on pollination than others (Wilcoxon test: $W = 634$, $p = 0.811$). The results of the causes of bee decline ranked by the farmers are displayed in figure 3, '1' being the most important cause and '4' the less important. A significant Friedman test (Friedman $\chi^2 = 63.66$; p-value $<0.001$) showed there is a significant difference in how farmers ranked various causes. Bee-related pathogens and pesticides were rated very closely, with average ranks of 1.9 and 2.1 respectively. Lack of resources followed with an average rank of 2.7, and apicultural practices were last at 3.2. Finally, Kendall tests between rank and pollination dependence were insignificant for each cause (Apicultural practices, $\tau = -0.0784$, $p = 0.312$; Lack of resources, $\tau = 0.0667$, $p = 0.383$; Pesticides, $\tau = 0.0251$, $p = 0.742$; Pathogens and predators, $\tau = -0.0134$, $p = 0.862$), indicating that there was no link between the perception of the causes of pollinator decline and the farmer's pollination dependence.

## Discussion

Understanding the determinants of farmers' acceptability of PSPs is critical to increase their adoption. Pollination dependence may influence the WTA pollinator-supporting practices but no study has explored it. We expected that the higher the farms' pollination dependence, the higher the WTA and the pollinator perception. We found no evidence of this, since (i) the rate of pollination dependence did not significantly influence the WTA, and (ii) the farmers perceived the importance of pollinators even though the overall production in the studied area is only slightly dependent on pollination.

### Farmers' perceptions of pollinators

Our results showed that farmers' perception of the importance of pollinators for production was not correlated with their farm pollination dependence. More generally, the overall perception was high, despite a relatively low pollination dependence of our sample. The latter was evidenced by the low proportion of farmers collaborating with beekeepers (only 15%, compared to, for example, 59% in Osterman *et al* 2021; and 77% in Hanes *et al* 2015). The overview of studies on farmers' perceptions of pollinators in high-income countries confirms that our study is the first to focus on a system with relatively low pollination dependence (table 1). Similarly to our study, a very high perception of the importance of pollinators for crop production has been shown in other

**Table 2.** Variables included in the model, definitions and descriptive statistics.

| Factor | Definition/question | Categorical variable | Continuous variables | |
|---|---|---|---|---|
| | | *Farmers* | *Mean* | *SD* |
| | ***SOCIO-ECONOMIC AND AGRICULTURAL VARIABLES*** | | | |
| Age | Age of farmer in study year | | 53.7 | 9.7 |
| Farm size | Farm area in hectares | | 159.4 | 106.4 |
| Agricultural system | Farmers grow only crops (=0) or have a mixed crop–livestock farming system | 0: 49 | | |
| | | 1: 54 | | |
| Apiaries on farm | Farmers provided a location for apiaries to beekeepers, close to their mass-flowering crop fields | Yes: 15 | | |
| | | No: 88 | | |
| Pollination dependence | The proportion of pollinated crops in the crop mix | | 0.18 | 0.09 |
| Pesticide use (*TFI*) | Treatment frequency index: theoretical number of pesticide treatments per hectare, based on standard dose | | Wheat: 3.5 | Wheat:1.3 |
| | | | Oilseed rape: 6.4 | Oilseed rape: 2.2 |
| | | | Maize:1.6 | Maize: 1.1 |
| | | | Sunflower: 1.3 | Sunflower: 0.7 |
| Tillage depth | Depth of tillage on average (in centimeters) | | 11.1 | 8.7 |
| Number of mechanical soil operations | Number of mechanical operations | | 2.7 | 1.3 |
| Advisory services | The farmer is advised by the local Chamber of Agriculture (French government body representing farmers) | Yes: 46 | | |
| | | No: 57 | | |
| Diversity of information sources | Number of information sources cited by the farmer | | 1.8 | 0.11 |
| ***PERCEPTIONS*** | | | | |
| Perceived economic cost of PSPs | Do you think that the lack of economic resources is a barrier for changing practices to preserve pollinators throughout the season? | Yes: 59 | | |
| | | No: 44 | | |
| Perceived knowledge needs of PSPs | Do you think that the lack of information and technical support on the impact of pollinators as crop auxiliaries, is a barrier for changing practices to preserve pollinators throughout the season? | Yes: 50 | | |
| | | No: 53 | | |
| Perceived competence concerning PSPs | Do you think that difficulties in implementing these changes on a technical level, is a barrier for changing practices to preserve pollinators throughout the season? | Yes: 41 | | |
| | | No: 62 | | |
| Importance of poll. for oilseed rape | Do you consider bees as an important production factor to take into account for oilseed rape production? (multi-level ordered) | Important: 92 | | |
| | | Moderate: 5 | | |
| | | Little: 6 | | |
| | | No: 0 | | |

**Table 3.** Selected model for WTA-related score ($n = 97$). Significant effects are shown by $^{*}p < 0.1$, $^{**}p < 0.05$ and $^{***}p < 0.01$.

| Regression of WTA for flower strips adoption | |
|---|---|
| | *Dependent variable:* |
| | WTA score |
| Age | $0.128^{**}$ |
| | (0.056) |
| Advisory services | $-2.564^{**}$ |
| | (1.091) |
| Farm size | $-3.914^{***}$ |
| | (1.377) |
| Treatment Frequency Index (relative index) | $-1.201^{**}$ |
| | (0.533) |
| Tillage depth | −0.842 |
| | (0.543) |
| Perception of cost : Yes | $-17.583^{*}$ |
| | (8.882) |
| Importance pollination for OSR (linear) | $4.584^{***}$ |
| | (1.516) |
| Importance pollination for OSR (quadratic) | −3.416 |
| | (2.357) |
| Farm size × Perception of cost : Yes | $3.279^{*}$ |
| | (1.792) |
| Intercept | $39.697^{***}$ |
| | (7.496) |
| Observations | 97 |
| $R^2$ | 0.336 |
| Adjusted $R^2$ | 0.267 |
| Residual Std. Error | 5.018 (df = 87) |
| F Statistic | $4.883^{***}$ (df = 9; 87) |
| *Note:* | $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$ |

studies, regardless of the country, cropping system, or year of the survey. Although this indicates a generally high perception among farmers of pollinators and their role in production, further work is needed to confirm that this perception is not dependent on the cropping system. Nevertheless, this widespread perception could be explained by the cultural and social importance of pollinators, which has long been anchored in society, as highlighted by Hall and Martins (2020). It is important to note that there might be a significant difference in perception of the role of pollinators for production between different types of pollinators, particularly between wild and domesticated ones (Osterman *et al* 2021). Our study also showed that farmers considered pathogens and predators, as well as pesticides, as the most important causes of pollinator decline. These results are confirmed by more recent studies such as Hevia *et al* (2021) and Bloom *et al* (2021), particularly regarding pesticides (table 1), and suggesting that farmers recognize the impact of pesticides on bee health.

### Acceptability of pollinator-supporting practices

Our findings also revealed a high heterogeneity in the acceptability of PSPs. The studied practices involved a wide range of implementation time, complexity, risk and even reconsideration of the farming system, all of which crucially affect practice uptake (Liu *et al* 2018, Dessart et al 2019). In our study, the most accepted practices were generally the least costly. This is in line with Piñeiro *et al* (2020), which showed that financial aspects play a crucial role in farmers' decisions to adopt sustainable practices. Furthermore, the least onerous practices in terms of additional management requirements were often preferred to time-consuming ones. These include lowering pesticide use and toxicity, maintaining existing hedgerows, including more mass flowering crops, and/or replacing traditional cover crops by flowering crops, which involve few additional tasks and rely on the existing agricultural system. These practices interfere little with usual farming operations, as also found by Kleijn *et al* (2019).

Following the same logic, among PSPs already adopted, the least adopted one in our study was the addition of flower strips—inside or outside the fields. Farmers tend to not adopt the practices that are likely to involve additional work time or take land out of production (Bailey 2015, Faure *et al* 2024). In their reasoning for

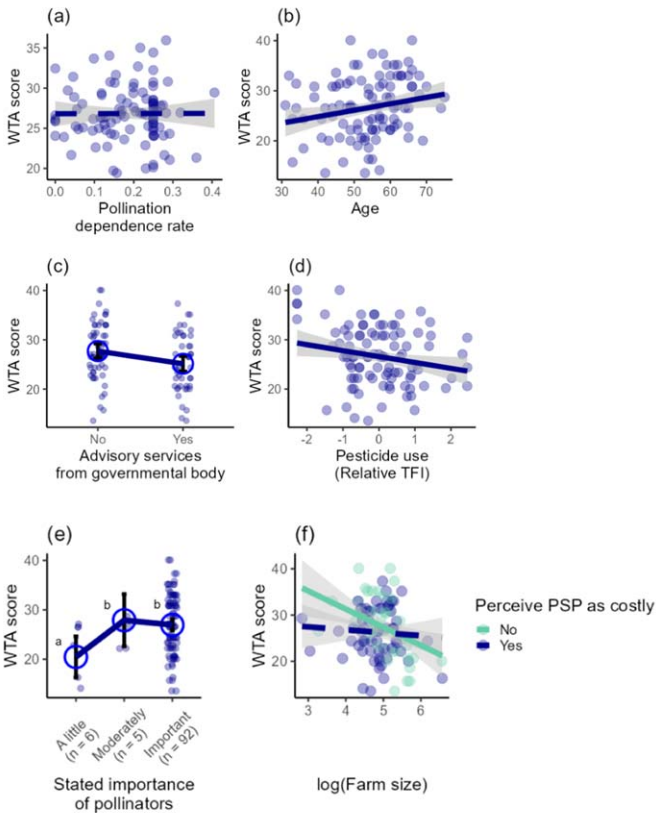


**Figure 2.** Model averaged predictions plotted with raw survey data for variables mediating the WTA score. The variables are (a) the pollination dependence, (b) farmers' age, (c) advisory services, (d) pesticide use, (e) the stated importance of pollinators for production, and (f) the farm size modulated by the perception of the cost incurred by the practices. Solid lines represent significant effects while dashed lines represent non-significant effects. Letters in plot (e) indicate the groups implied by the Kruskal–Wallis test.

**Table 4.** Summary statistics of the answers to: 'Do you consider bees as an important production factor to take into account for [oilseed rape/sunflower] production?'.

| | Frequency | Per cent |
|---|---|---|
| Oilseed rape | | |
| No, not important | 0 | 0 |
| A little important | 6 | 5.8 |
| Moderately important | 5 | 4.9 |
| Important | 92 | 89.3 |
| Sunflower | | |
| No, not important | 0 | 0 |
| A little important | 5 | 4.8 |
| Moderately important | 9 | 8.8 |
| Important | 89 | 86.4 |

adopting PSPs, farmers are often more sensitive to the decrease in expected yields than to the benefits. While researchers have shown that reducing input costs can often compensate for a drop in yields (Boussemart *et al* 2011, Jacquet *et al* 2011, or see Catarino *et al* 2019 for the pollination case), their reference point to calculate losses or gains is revenue, whereas farmers calculate from yield. Many farmers also concern about weeds spreading from herbaceous strips (Mante and Gerowitt 2009, Uyttenbroeck *et al* 2016, Jerome Faure *et al* 2024). One study conducted in the same area as ours reported a perceived risk of weeds due to sown grass (Cordeau *et al* 2011). This concern and the associated reticence to leave field margins unsprayed can be interpreted in a similar way. Even if this practice does not incur extra costs (the additional costs, such as loss of production, are hedged by pesticide cost savings), farmers are apprehensive that weeds will spread and potentially lead to lower yields (de Snoo 1999).

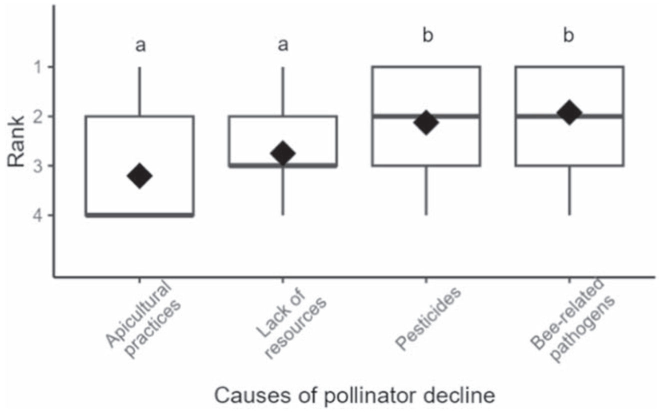


**Figure 3.** Statistics on how farmers ranked the causes of pollinator decline in our sample. The average rank is indicated by a black diamond for each cause. A Friedman test (Friedman chi-squared = 63.664, p-value = 9.684e-14) confirms a difference between the ranks, groups with non-significant differences in mean are indexed with letters.

The acceptability measured here reflects the situation in 2011 in the study area. Based on the long-term monitoring in the LTSER Zone Atelier Plaine & Val de Sèvre, farmers' surveys up to 2021 have shown that neither the quantity used (Treatment Frequency Indicator; Möhring *et al* 2019) nor the toxicity (Load Index; Möhring *et al* 2019) have been reduced in conventional farms. This could be explained by the deep sociotechnical lock-in involving the pesticide issue (Guichard *et al* 2017). Furthermore, a reduction of the number of agri-environment schemes related to pesticides has been observed (Gaba and Bretagnolle 2021). However, at the same time, the number of organic farms has largely increased, including likely some farmers that participated to the survey in 2011 who stated their willingness to reduce pesticides. In addition, the neonicotinoid insecticides have been banned in 2018 which has reduced the toxicity of conventional agriculture for pollinators (Bub *et al* 2022). Regarding non-pesticide practices, researchers in the area observed that over ten years, the adoption rate has essentially remained the same, with no increase for any of the practices (Gaba and Bretagnolle 2021). In other words, intentions likely have not translated into adoption. This observation is common in Europe, as reported notably by Kleijn *et al* (2019), and is consistent with findings of the failures of the 2014–2020 CAP biodiversity policies (Pe'er *et al* 2020). Economic constraints and the risks involved often outweigh the tangible benefits of these practices.

### Determinants of the willingness to adopt PSPs

Our study is the first, to our knowledge, to study the pollination dependence as a determinant of the acceptability of PSPs. We did not find an effect of pollination dependence, but the variations in dependence remain relatively low and alternative crops exist for the surveyed farmers. Moreover, pollinated crops are annual, and crop rotation implies that pollination demand shifts spatially. Consequently, implementing perennial ecological infrastructures, such as herbaceous strips, loses interest. It would be relevant to test the effect of pollination dependence in a study area where some farmers have permanent crops such as fruit orchards, while others have annual crops such as cereals and mass-flowering crops.

Regarding the significant determinants of PSP acceptability, we have shown that pesticides and farm size had a negative impact. These findings are consistent with literature on pro-environmental practices (Klebl et al 2024) and specifically on PSPs (Park *et al* 2020, Bloom *et al* 2021). In Europe, farm size and pesticide use are associated with intensive farm management (Tilman *et al* 2002, Lechenet *et al* 2014). The often-cited explanation is economic; larger farms are more profit-oriented, while the objectives of biodiversity conservation and economic profitability often conflict (Eastwood *et al* 2010, Gosling and Williams 2010). Additionally, larger farms might lose more due to their efficiency (Schulz *et al* 2014) However, our results did not support this, as the perception of costs did not affect acceptability among large-scale farmers, unlike smaller ones. This suggests that the reluctance of larger farms may be due to psychological or moral reasons, such as different environmental concerns or risk perceptions (Dessart et al 2019). Given that larger farms often have more land and show more intensive management, it is crucial to research how to engage these farms in adopting these practices.

One way to motivate these farmers could be through agricultural advisory services. However, our study showed that they decreased acceptability, contrasting with other studies that found the opposite (Liu *et al* 2018, Foguesatto *et al* 2020). A study by Piñeiro *et al* (2020) reviewing 18,000 articles found that extension agencies, both public and private, enhanced the rate of adoption of sustainable practices. Our contrasting result may be due to the diversity of agricultural advisory services, which depend on the policy orientation of the advisers. In our case, the local Chamber of Agriculture provides advisory services to farmers, and he advisers generally have similar educational backgrounds to the farmers. Hence, these advisers, such as some farmers in our study, were probably not willing to promote PSPs. Incentivizing all these stakeholders therefore seems necessary to promote the adoption of PSPs.

Another way could be more bottom-up, where farmers and other stakeholders with different characteristics form networks to exchange on PSPs. For example, we found that older farmers were more willing to adopt. In this context, peer-to-peer networks pairing older and younger farmers could increase willingness. Similarly to Garbach and Morgan (2017), we showed that farmers who recognized the importance of pollinators were more willing to adopt too. Thus, such networks could influence reluctant farmers by promoting the sharing of information, knowledge, and vision, as shown by Šūmane *et al* (2018). Including local scientists in these networks is also important to avoid a disconnection between the information farmers are sharing and its local relevance (Kleijn *et al* 2019). For example, farmers in the sample rank lack of resources as the third most significant cause of decline, whereas it is actually the primary cause in the study area (Perrot *et al* 2022). Another example is the benefits to yield (Perrot *et al* 2018, 2019) and farmers' economic performance (Catarino *et al* 2019, Faure *et al* 2023) which were both quantified in the study area, providing strong arguments in favor of PSPs.

The last point of discussion is the validity of these determinants more than ten years after the survey. Regarding socioeconomic determinants, literature has shown that they are stable over time, for example Liu *et al* (2018) did not observe major changes in the socioeconomic determinants of sustainable practice adoption between 2008 and 2018. This is not the case for farmers' perceptions, which studies have shown to evolve over time. For example, perceptions of risk change from year to year (Finger *et al* 2023). These shifts in perceptions are often linked to significant events that can alter the emotions and psychology of farmers, as demonstrated with the COVID-19 pandemic (Rose *et al* 2023). However, regardless of how the determinants of willingness to adopt have evolved, the formation of farmer networks is key to promoting sustainable agriculture (Šūmane *et al* 2018). In parallel, continuing contemporary research on the perceptions and determinants of PSP acceptability is crucial to increase pollinator conservation.

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## Data availability statement

The data cannot be made publicly available upon publication because they contain sensitive personal information. The data that support the findings of this study are available upon reasonable request from the authors.

## Declarations

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

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## Conflict of interest

We have no conflict of interest to declare.

## Authors' contributions

JF: Conceptualisation, Methodology, Software, Validation, Formal analysis, Data curation, Writing - Original draft, Writing—Review & Editing, Visualization SG: Conceptualisation, Methodology, Formal analysis, Resources, Writing - Original draft, Writing—Review & Editing, Supervision LM: Conceptualisation, Supervision AD: Methodology, Funding acquisition FA: Methodology, Writing—Review & Editing, Funding acquisition

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