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Original research article

Strengthening apicultural and agricultural partnerships with ecological knowledge to boost crop pollination in Croatia

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ABSTRACT

Effective crop pollination hinges on the alignment of agricultural and apicultural practices with ecological knowledge. This study explores the dynamics between Croatian beekeepers and farmers, revealing overlapping but often uncoordinated approaches to pollination. Survey data indicate that 83.8% of beekeepers work part-time, aligning with broader trends observed across Europe. While honey production remains the primary source of income, pollination services contribute minimally, partly due to logistical barriers, weak institutional frameworks, and limited market incentives. Apiary placement is strongly influenced by seasonal floral resources, with a preference for grasslands, and selective avoidance of certain crops due to pesticide risks or low nectar flow. Farmers have reported a significant dependence on animal pollination (median 42.5%) and a strong reliance on managed honeybee colonies, however, wild insect pollinators and habitat enhancements remain underutilized. Despite widespread awareness, constraints, including technical gaps and financial limitations, hinder further engagement. The research emphasizes the urgent need to incorporate ecological knowledge into policy and practice. Promoting cooperative relationships, ecosystem service-based incentives, and regionally adapted training could enhance pollination outcomes. Part-time beekeepers could be a vital resource for expanding insect pollination services if they received better support. To strengthen partnerships between beekeepers and farmers in Croatia, it is necessary to coordinate efforts across policy, education, and land-use planning to fully unlock the ecological and economic potential of pollination.

Key words: beekeeping practices; insect pollination; honeybee colonies; bumblebee colonies; semi-managed wild bees

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Introduction

Pollination is an essential ecosystem service provided by pollinators, such as bees, butterflies and other insects, that help with the reproduction of flowering plants. This includes many crops that are vital for human consumption. Recent scientific studies have offered new insights into the pollination services provided by insects in various environments, including urban areas, forests, and agricultural settings (LIANG et al., 2023; ULYSHEN et al., 2023; GAZZEA et al., 2023). These studies highlight the diverse importance of pollination services and underscore the need for coordinated conservation efforts to support pollinator populations (SLADONJA et al., 2023), and mitigate the negative impacts of environmental and biotic stressors (PIOT et al., 2022; TLAK GAJGER and MUTINELLI, 2024). Recent studies have shown that wild solitary bees significantly enhance crop pollination with higher species richness (EU ENVIRONMENT, 2022), but wild bumblebees and honeybees also offer complementary services (MIÑARRO and GARCÍA, 2021). Although conservation of wild bees is essential for sustainable pollination and ensuring stable crop yields, managed honeybee colonies (*Apis mellifera*) are economically crucial pollinators, particularly in large, homogenous agricultural landscapes where wild pollinator diversity may be lower. European studies show they provide nearly half of the recorded crop visits (KLEIJN et al., 2015) and are essential for ensuring stable and predictable pollination services. Additionally, the reliability and scalability of honeybee pollination highlight their critical importance in global agriculture (KLEIJN et al., 2015). Unlike wild bees, honeybee colonies can be managed, transported, and strategically placed to maximize the efficiency of crop pollination, making them indispensable for large-scale food production (EU ENVIRONMENT, 2022). Recent research highlights the importance of integrating ecological knowledge into farming and beekeeping practices to support pollination services. Specifically, the relationships between farming practices, landscape composition, and pollination outcomes have become a focal point of agroecological studies (BOMMARCO et al., 2013; BREEZE et al., 2019; MONTOYA et al., 2020). Landscapes that include a high proportion of semi-natural habitats, and exhibit structural complexity, such as increased field border density or floral diversity, tend to support more abundant and diverse pollinator communities (BAUDE et al., 2016; DAINESE et al., 2019; ALBRECHT et al., 2020). For example, configurational landscape heterogeneity has been shown to enhance wild bee richness, and improve crop pollination in orchards and arable systems (HASS et al., 2018; TLAK GAJGER et al., 2022; ANDERS et al., 2023; DAR et al., 2023).

Despite the growing evidence base, the implementation of pollinator-friendly practices remains inconsistent, often hindered by gaps in ecological understanding, policy misalignment, or limited cooperation between agricultural and apicultural stakeholders (GARIBALDI et al., 2017). Croatia, with its diverse agricultural regions and active beekeeping sector (TOMLJANOVIĆ et al., 2020), offers a valuable case study for investigating these dynamics. This analysis aimed to examine survey responses from beekeepers and farmers in Croatia. The survey gathered detailed information on their practices, motivations, and barriers related to pollination services. By understanding these factors, the study seeks to inform strategies to strengthen partnerships between the agricultural and apicultural sectors through the application of ecological knowledge, ultimately improving pollination services and sustainable crop production.

Materials and methods

This study employed a structured survey (questionnaire) originally developed by BREEZE et al. (2019), which was subsequently adapted to the Croatian language and context to reflect the unique characteristics of the national apicultural and agricultural sectors. The revised survey aimed to evaluate practices, motivations, and perceived obstacles related to pollination services among beekeepers and farmers.

The survey consisted of two distinct sections tailored to each respondent group. The beekeeping section collected detailed information on the respondents' length of experience, the number of honeybee colonies managed, and primary income sources (e.g., honey production and pollination services). Questions also addressed seasonal hive transportation practices, including whether hives were relocated during the year and the underlying reasons for such movements. Beekeepers were further asked to report preferred and avoided crop and plant species for apiary placement, along with explanations for these choices. Additionally, they identified factors that facilitate or constrain hive relocation, and expressed their views on potential measures to enhance the provision of pollination services in Croatian agricultural landscapes. The farmer section focused on crop production practices, including the types of crops grown, yield losses, and perceptions of pollination deficits. Farmers were asked whether they employed managed insect pollinators, especially honeybee or bumblebee (*Bombus* spp.) colonies, or solitary bees, as well as to specify the costs, quantities, and sources of these services. Respondents also described their motivations for using the services of insect pollinators, and outlined any habitat management strategies or measures implemented to support wild insect pollinators (e.g., floral field margins, pesticide use reduction, or conservation schemes).

The survey was distributed to targeted groups of beekeepers and farmers across Croatia, ensuring broad representation of agroecological and operational diversity. A total of 181 responses were received from beekeepers. Of these, 160 responses were fully completed and included in the analysis. The remaining 21 responses were excluded because they were terminated early, before the fifth question, rendering them incomplete for analytical purposes. From the farmers, 27 responses were received. However, only 18 were deemed sufficiently complete for inclusion in the study, with the remaining 9 excluded due to missing or inconsistent data. The final sample thus comprised 160 responses from beekeepers and 18 responses from farmers. Exceptions were a farmer's questionnaire that contained at least of the important questions answered due to its valuable data for discussion. Due to practical constraints and a lower willingness to participate, the final sample size for farmers was considerably smaller than for beekeepers, which may influence the representativeness of the farmer data in subsequent analyses. All participants were informed of the study's aims, and assured anonymity and confidentiality, in accordance with the established ethical research standards. Data were collected and processed in compliance with research ethics guidelines.

Statistics. All statistical analyses were conducted using R and RStudio. Descriptive statistics were used to summarize responses to closed-ended questions, and visualizations, such as bar plots, violin plots, and alluvial diagrams, were generated to illustrate response distributions and patterns across respondent groups. The ggplot2 and ggalluvial packages were used for data visualization, while custom R scripts were created to preprocess and organize the survey data for grouped comparisons. Open-ended responses were qualitatively analyzed by identifying recurring themes and summarizing the key messages expressed by respondents. The analysis focused on comparing the perspectives of farmers and beekeepers regarding pollination services, crop preferences, hive movement, and habitat management practices.

Results

In response to the first question, whether they consider themselves professional beekeepers, 26 individuals (16.25%) answered "Yes", while the remaining 134 respondents (83.75%) identified themselves as part-time beekeepers. Most of the respondents reported having between 1 and 15 years of experience, with the highest number indicating 2 to 5 years. Notably, some individuals reported having 50 and 55 years of experience. The majority of beekeepers manage 20 to 50 colonies, with a significant number also reporting 120 colonies. The most extreme values recorded were 400, 550, and 600 honeybee colonies, which were identified as outliers.

Fig. 1. presents a scatter plot illustrating the relationship between the number of years of beekeeping experience and the number of honeybee colonies currently managed by each respondent. To quantify the strength and direction of this non-linear relationship, the Spearman correlation coeffi-

cient is given. The Spearman coefficient calculated is 0.55, indicating a moderate positive correlation between experience and the number of honeybee colonies. This suggests that, in general, beekeepers with more years of experience tend to manage a greater number of honeybee colonies. However, the correlation is not very strong, implying that other factors, such as available resources, purpose, or time commitment, may also influence the number of honeybee colonies managed.

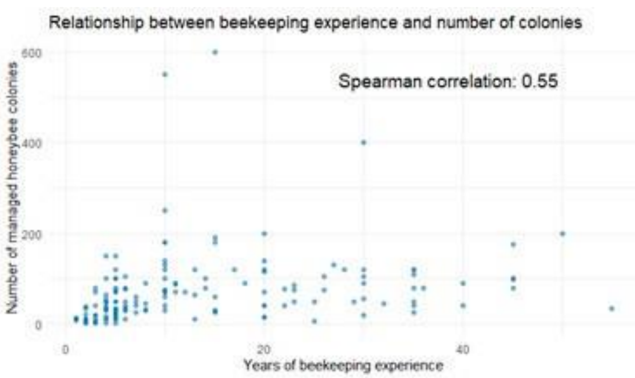

Fig. 1. Scatterplot of the relationship between beekeeping experience and number of colonies currently managed by respondents

Each point represents an individual respondent

An analysis of income sources among beekeepers reveals that most of the beekeeping income is generated through honey production, with a median contribution of 70 %. In contrast, pollination services and other sources, such as beeswax or other honeybee products, contribute significantly less, with median values of 23.5 % and 20 %. This suggests that honey remains the primary economic driver for most beekeepers, while other income streams play a supplementary role. However, it is important to note that only 21 out of the 160 respondents provided data on income distribution, indicating that these findings are based on a relatively small subset of the sample. The spread of responses, visualized through violin plots (Fig. 2), also indicates considerable variability, reflecting diverse beekeeping practices and market opportunities among those who did respond.

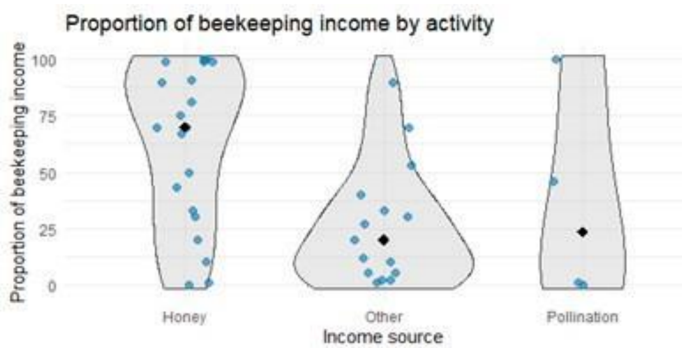

Fig. 2. Proportion of beekeeping income from honey production, pollination services and other sources

The violin plots represent the distribution and density of responses for each activity, while the black markers indicate the median value within each group

We examined the responses to the question of whether beekeepers relocate their hives at different times of the year. Among the 160 respondents, 62 indicated “Yes”, while 73 answered “No”. The remaining 25 responses were missing (Non-applicable; NA). This distribution suggests that hive relocation is a practice adopted by a substantial proportion of beekeepers, though a slightly larger group prefers to keep their hives stationary. The alluvial plot (Fig. 3) provides insights into seasonal patterns of hive placement across different habitat types. Across all seasons, grassland consistently emerges as the most commonly used habitat for hive placement. During the spring, most beehives are found in grasslands and, notably, this is the only season when hives are placed in orchards. In addition to grasslands and orchards, hives can also be found in gardens and croplands, while forests are the least favored habitat for hives. In summer, grassland remains the dominant habitat, but garden use drops to its lowest, with only one respondent placing hives there. A vineyard appears exclusively in summer, used by a single individual. Notably, forest habitats become most popular in summer, suggesting they may offer favorable conditions or resources during this period. In autumn, hive placement is again highest in grasslands, showing the peak number of respondents using this habitat in any season. Other habitats, such as forests, gardens and croplands, are used to a lesser but roughly equal extent. In winter, beekeepers keep their hives close and accessible, so most of them are kept in grasslands, while gardens become notably more popular in this season. Forest habitats continue to be used, but by a smaller group. These seasonal transitions suggest that while grasslands provide year-round suitability for hive placement, other habitats are chosen more selectively, depending on the time of year.

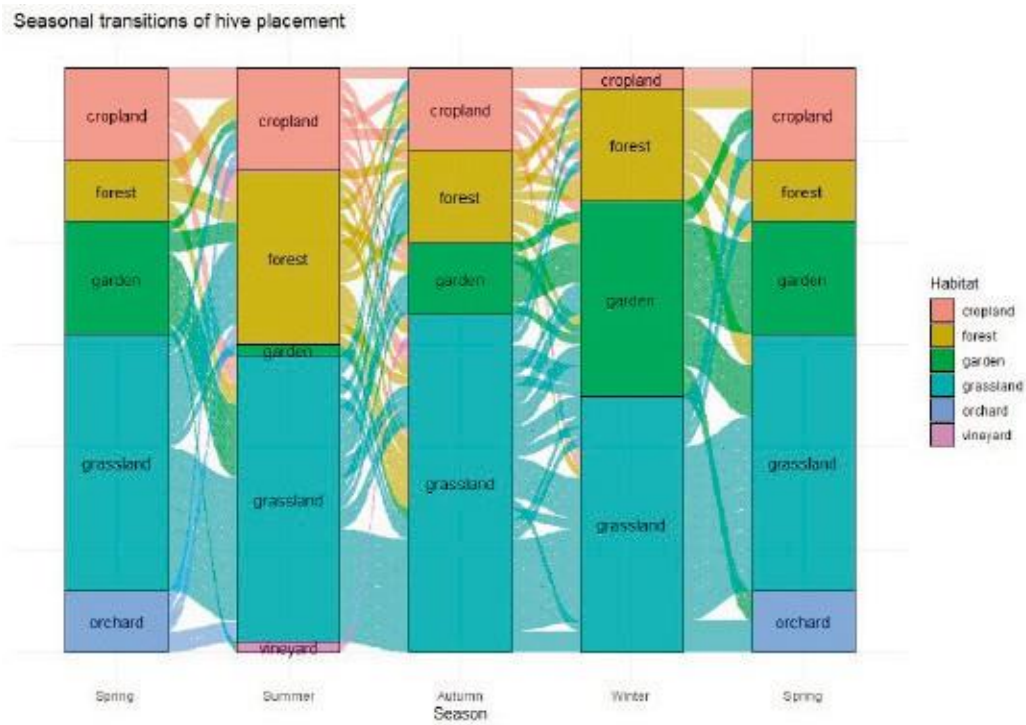

Fig. 3. Seasonal shifts in hive placement habitats shown as an alluvial plot, with flow width indicating the number of respondents making each transition. Habitat categories are displayed as strata for each season

We then analyzed the responses from the beekeepers who indicated that they do not move their hives, focusing on their reasons. The reason most frequently cited was that they keep the hives on their property (32.2 %). This was followed by concerns about reducing the risk of pests or diseases (18.9 %), lack of time (17.5 %), and lack of help or resources (17.5 %). A smaller proportion of respondents indicated that they do not see a need to move the hives (7.7 %) or selected other reasons (6.3 %). Fig. 4. presents a pie chart that visually summarizes these responses, with each segment showing the number and percentage of respondents who selected each reason.

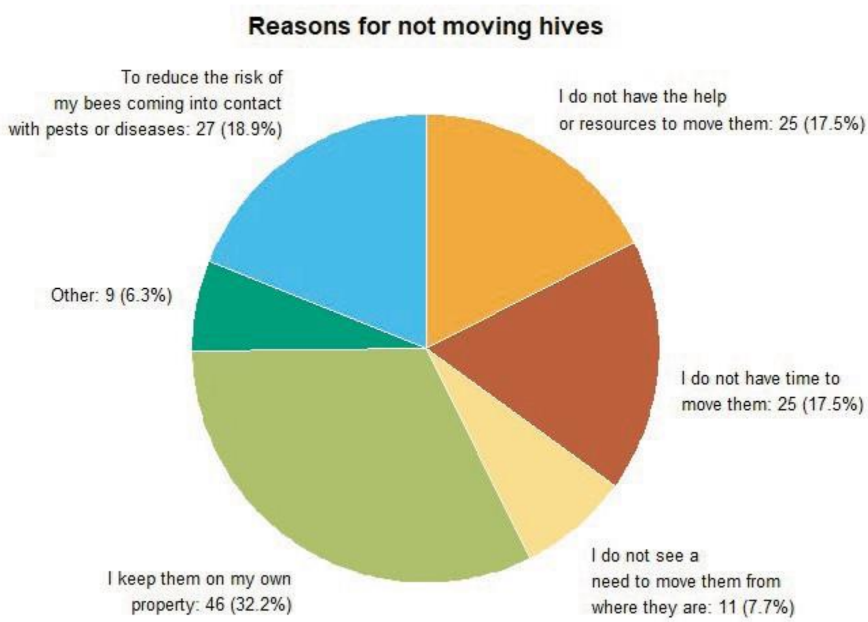

Fig. 4. Reasons for not moving hives, showing number and percentage of beekeepers selecting each reason

To better understand beekeepers' preferences and avoidance patterns regarding crop and plant species near their hives, respondents were asked to list up to three crop plants and three other plant species they either prefer or avoid placing their hives near (within 1 km). While the questionnaire allowed for multiple entries per respondent, many participants listed only one or two options. Therefore, for clarity and consistency, we combined the responses across all three slots and present the total number of mentions for each species.

Among the crop plants (Fig. 5), oilseed rape (*Brassica napus var. oleifera*) was both the most preferred crop (mentioned 35 times) and also avoided by some beekeepers (7 mentions), suggesting mixed experiences of its suitability for beekeeping. Maize (*Zea mays*) showed a similar pattern, being preferred by 20 respondents but also avoided by 12. Other commonly preferred crops included sunflower (*Helianthus annuus*; 23 mentions), apple (*Malus domestica*; 10), and wheat (*Triticum aestivum*; 9). In contrast, crops such as grapevine (*Vitis vinifera*), *T. aestivum*, and sour cherry (*Prunus cerasus*) wereal-so among the more frequently avoided crops. Beekeepers expressed strong preferences for a variety of non-crop flowering plants and trees (Fig. 6). Black locust (*Robinia pseudoacacia*) was by far the most commonly preferred plant, cited by 64 respondents. Other highly favored species included sweet chestnut (*Castanea sativa*; 35 mentions), small-leaved lime (*Tilia cordata*; 29 mentions), desert false indigo (*Amorpha fruticosa*; 12 mentions), common sage (*Salvia oficinalis*; 10 mentions), and goat willow (*Salix caprea*; 10 mentions). Although far fewer respondents listed plants they wished to avoid, some species such as *V. vinifera*, *Z. mays*, and *B. napus var. oleifer*a appeared in the avoid list.

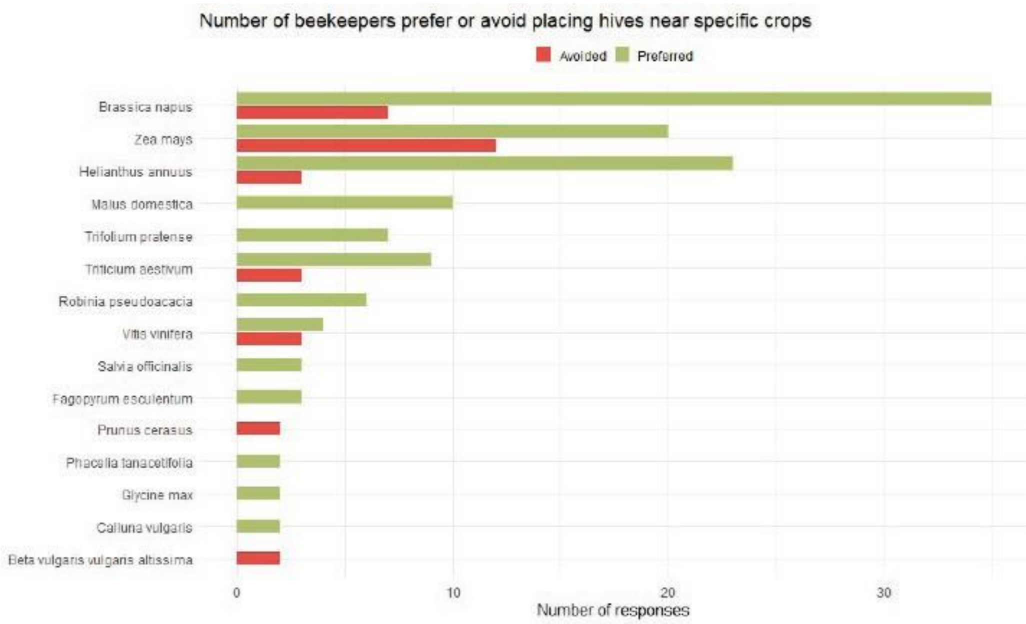

Fig. 5. The number of beekeepers who indicated which crop they prefer or avoid for apiary placement

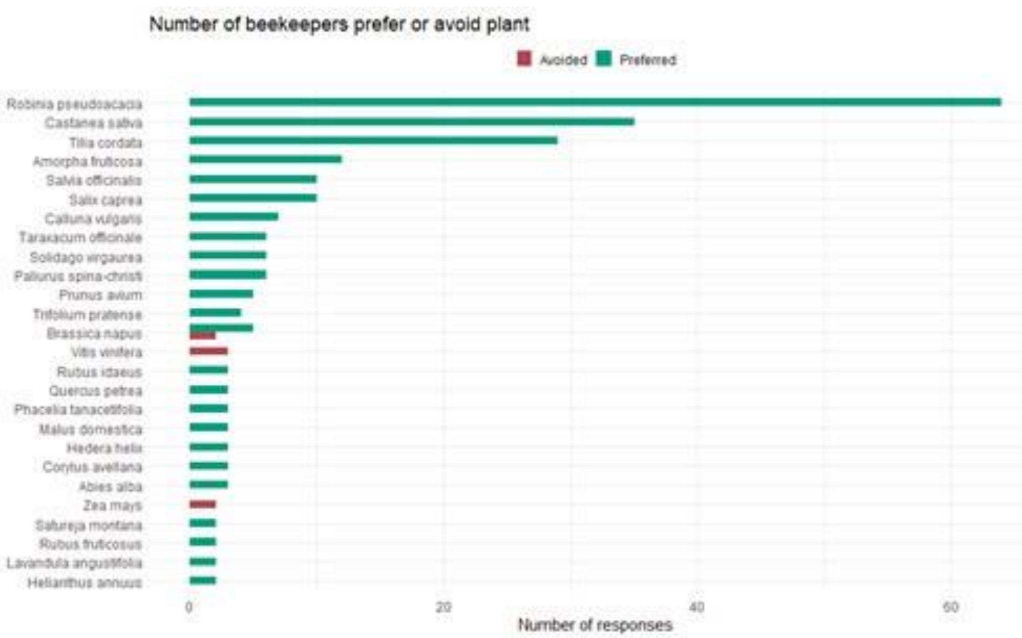

Fig. 6. The number of beekeepers who indicated whether they prefer or avoid each plant

To better understand the motivations behind beekeepers' decisions to place hives near specific crops or avoid them, we produced two types of visualizations. The first set of graphs presents an aggregated overview of all reasons given for preferring or avoiding crops/plants, regardless of the crop/plant species mentioned. The second set breaks down the reasons within each crop/plant species, showing which motivations were associated with specific crops/plants. From the aggregated results, the most frequently cited reason for placing hives near crops was that "it is good for colony growth and survival" (55 responses), followed by "it produces good yields of honey" (50), and "it is the most widely available forage at the time of the year it flowers" (44). Other common reasons included ease of access (42), the crop's importance for honeybee colony sustainability (31), and its reliable honey yields (25). These responses highlight the importance of both colony health and honey production potential in apiary placement decisions. On the other hand, the most frequent reasons for avoiding certain crops were concerns about pesticide exposure (40 responses), the presence of toxins in nectar or pollen (20), and unreliable honey quality or yield. Some beekeepers also indicated that moving honeybee colonies to certain areas poses disease risks, and that they do not receive compensation for pollination services.

When examining reasons within individual crops, clearer patterns emerged: rapeseed (*B. napus var. oleifera*) was among the most controversial crops. While it was preferred for reasons such as colony growth (23 mentions), forage availability (18), and honey yield (16), it was also avoided due to being a crop, primarily due to the perceived pesticide risk (7), and poor nectar quality or potential toxicity (5). Sunflowers (*H. annuus*) were widely preferred for honey yield (19), forage availability (11), and honey reliability (11), though a few respondents (3) expressed concerns about pesticides. Apples (*M. domestica*) was favored for easy access, honeybee colony health, and pollination benefits. Maize (*Z. mays*) was the most avoided. While some marked it as preferred for other/unspecified reasons, it was also avoided due to pesticide concerns (10), toxins, and lack of payment for pollination. Other crops such as red clover (*Trifolium pratense*), black locust (*R. pseudoacacia)*, buckwheat (*Fagopyrum esculentum*), phacelia (*Phacelia tanacetifolia*), and sage (*S. oficinalis*) were consistently preferred due to factors such as good forage availability, honey value, and honeybee colony health benefits. These results suggest that beekeepers weigh both ecological factors (e.g., floral resources, safety, colony health) and economic considerations (e.g., honey yield, payment for services, easy logistics) when deciding where to place their hives. The aggregated data reveal that beekeepers most frequently select non-crop plants on the basis of their availability during peak forage periods, the top reason being "it is the most widely available forage at the time of the year it flowers" (64 mentions). Other dominant reasons, as expected, include "it produces good yields of honey" (59), "I have easy access to it/it just happens to be there" (56), and "it is good for colony growth and survival" (50). Similar to crops, the importance of honeybee colony sustainability, reliable honey yields, and high honey value were also among the most common drivers of plant preference. Avoidance of certain plants was much less common but still notable. The most commonly mentioned concerns were related to pesticide or chemical exposure (8 mentions), toxins in nectar or pollen (6 mentions), and low honey quality (5 mentions). There were only a few isolated comments about poor or unreliable yields, and competition from superior floral resources.

Breaking the responses down by plant species provided more insights for black locust (*R. pseudoacacia*) stood out as the most frequently preferred plant overall, associated with a broad range of beneficial traits, including high honey yield (51 mentions), honeybee colony strength (31), forage availability (42), and reliable production (36). It was also noted for easy access and frequent recommendations from fellow beekeepers. Sweet chestnut (*C. sativa*) was another highly preferred plant, valued for its contribution to honeybee colony health, high-value honey, and sustainability. Respondents also cited it as widely available and easy to access. Small-leaved lime (*T. cordata*) was mentioned for its early-season forage, good honey production, and importance for bee colony development. Favored plants such as *A. fruticosa, S. caprea, B. napus var. oleifera,* and *P. avium* were commonly linked to desirable attributes such as seasonal forage, high honey production, and benefits for colony growth and sustainability. On the avoidance side, a few plant species such as *V. vinifera, B. napus var. oleifera,* and *Z. mays* appeared. These were mainly avoided due to possible pesticide exposure, low-quality honey production, or toxic pollen or nectar.

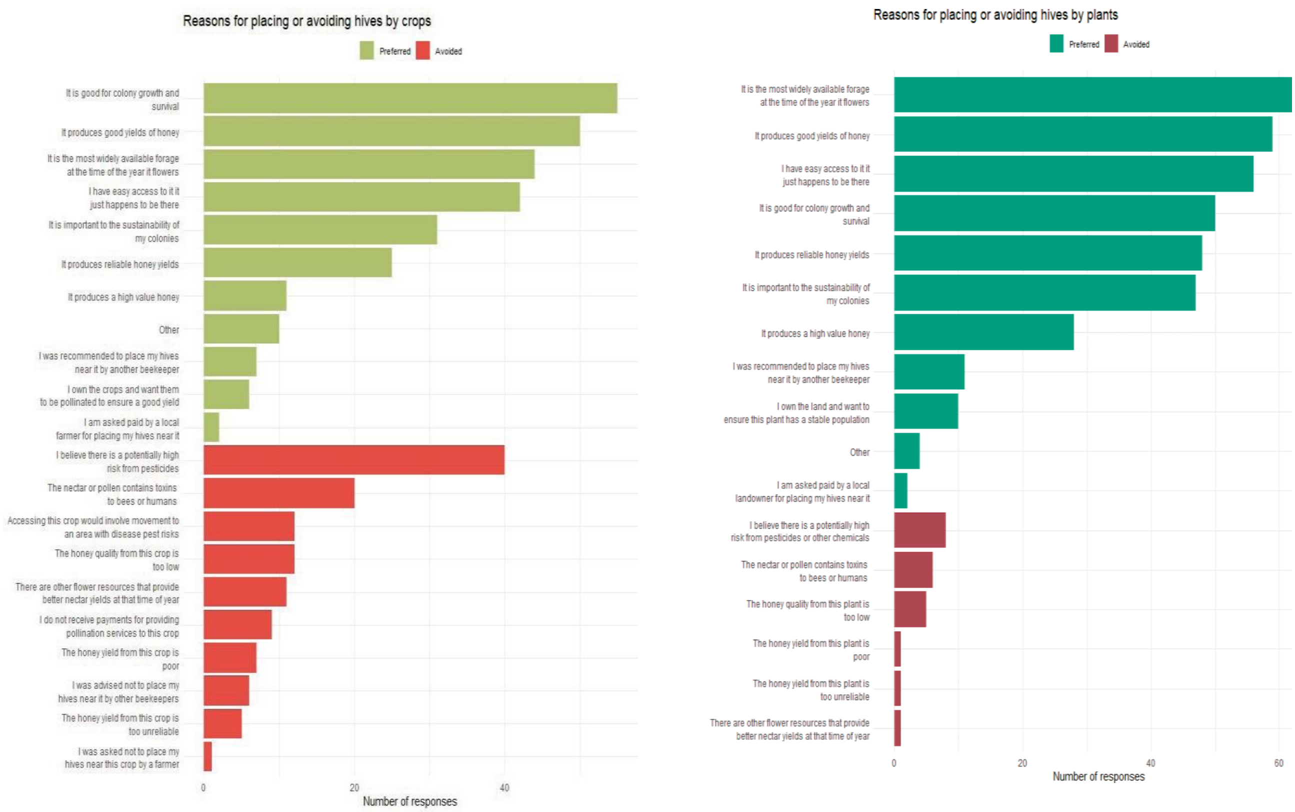

Fig. 7. The most frequently mentioned reasons for placing or avoiding hives near specific crop plants
Reasons are grouped by category (preferred vs. avoided) and ordered from the most to the least commonly selected within each group

The final section of the survey provided insight into how beekeepers envision the future of their activities and the broader agricultural environment. Respondents were invited to reflect on changes that would encourage hive expansion, increase the provision of pollination services, and support better collaboration between beekeepers, farmers, and policymakers. When asked what might encourage them to expand the number of their hives, the factors most frequently mentioned were higher honey prices, increased demand, or better profits (13 respondents). Other key motivations included more available time (8 responses), financial support or subsidies (7), and access to paid pollination service work (4). A smaller number also mentioned the need for better beekeeping equipment, more available forage, or reduced regulatory burdens. Several participants noted that age or lack of available staff limited their capacity to expand. Beekeepers emphasized the importance of cooperation with local farmers. The most prominent subject was the need for payments or compensation for services, which was mentioned 34 times. Additionally, better pesticide-using practices, such as more selective or informed spraying, were also frequently cited (15 mentions). Other suggestions included enhancing available forage, improving awareness and communication between beekeepers and farmers, and providing direct support for moving hives when necessary. Policy-level actions were seen as essential in creating an enabling environment. The top recommendation was to provide subsidies for beekeeping, mentioned by 43 respondents. There was also strong support for banning or reducing pesticide use, improving access to suitable apiary locations, and creating incentives for alternative pest control methods. Beekeepers expressed a desire for better market support for honey, increased promotion of beekeeping, and the creation of forums to link beekeepers with farmers more effectively. In the open-ended comments, beekeepers raised broader concerns about the risk of honeybee poisoning from pesticides, and the lack of awareness among farmers about the impacts of their actions. Several respondents highlighted a lack of forage, especially in tourism-heavy regions, and insufficient education about beekeeping, both for farmers and the general public. Others noted that pollination services remain underdeveloped or poorly understood.

Here, we present the analysis of responses provided by farmers. As previously mentioned, a total of 18 responses were included in the final dataset. Among these, 7 respondents (38.9 %) indicated that they were organic farmers, while the remaining 11 (61.1 %) stated they were not. The respondents who answered "yes" described their farming practices in the following ways: ecological agriculture (2 respondents), ecological production (1 respondent), integrated apple cultivation (1 respondent), fruit and vegetable production (1 respondent), and fruit growing (1 respondent). One respondent left the description field blank. Regarding participation in Agri-Environmental Schemes (AES), 5 farmers (27.8 %) reported participation, while 13 (72.2 %) did not. The participants in AES provided the following types of schemes or focus areas: measures of rural development in agriculture, environment, and climatic change (1 respondent); biodiversity (1); Green Osijek (1); ecological agriculture (1), as well as protection of waters and sources of freshwater (1).

When asked which crops they cultivate are the most important, farmers listed a diverse range of species. The most frequently mentioned crop was *M. domestica*, reported by 14 respondents. Other commonly grown crops included peach (*Prunus persica*) and tomato (*Solanum lycopersicum*), each cultivated by 3 farmers, as well as wild strawberry (*Fragaria vesca*), apricot (*Prunus armeniaca*), and pear (*Pyrus communis*), each reported by 2 respondents. A single farmer, including *B. napus* var. *oleifera*, *F. esculentum*, *H. annuus*, raspberry (*Rubus idaeus*), and *V. vinifera*, mentioned some other fruit and crop species. In response to the question "How much do you believe the yields of these crops would decrease without any animal pollination?", farmers provided estimates ranging from 10 % to 100 %, with a median of 42.5 %. Eight farmers did not respond. No clear correlation was observed between the specific crop types and the estimated yield loss. When asked whether they believe the yields of any of their crops are currently lower than they could be due to insufficient insect pollination on their land, 16 farmers responded "Yes", while only 2 farmers responded "No". This highlights the perceived importance of insect pollination in maintaining crop productivity.

Next, we analyzed the responses to two key questions: (1) whether farmers hire or purchase managed insects for pollination, and (2) whether they own and manage honeybee hives for pollination of their crops. It is important to note that the figures presented below do not reflect the number of individual farmers, but rather the total number of crop entries associated with each pollination method. Each respondent could list up to three different crops for which they use or manage pollinators. Due to the relatively small number of complete responses and variable response quality, we aggregated the data across all crop types. Overall, 17 responses stated they do not hire any managed pollinators ("HireNone"); 5 responses regarding hiring honeybee hives ("HireHB"); 7 responses about owning honeybee hives ("OwnHB"); 6 responses about using solitary bee cocoons ("UseSB"), and only 1 response about hiring one-season bumblebee colonies ("HireBB"). These results suggest that most farmers either rely on their own honeybee hives, or on natural/wild pollination. The use of solitary bees was mentioned occasionally, while the hiring of bumblebee colonies was rare. As each pollination strategy could be reported for up to three different crops, the crop-specific breakdown reflects mentions per crop, not the number of farmers. For example, one farmer managing honeybee hives for three crops would contribute three mentions to the "OwnHB" category. In terms of pollinator use by crop for "HireNone," *M. domestica* was most frequently mentioned (6), followed by *S. lycopersicum* (3), and *P. armeniaca* (2). Other crops, each mentioned once, included *F. esculentum*, garden strawberry (*Fragaria ananassa*), Leguminosae, *P. domestica*, *P. dulcis*, and *V. vinifera*. For "HireHB," *M. domestica* was again the most common (3), followed by one mention each for *B. napus, F. vesca, H. annuus*, and *P. avium*; for "UseSB," *M. domestica* was mentioned twice, while *P. persica, P. communis,* blackcurrant (*Ribes nigrum*), and *R. idaeus* were each reported once, while in the "OwnHB" group, *M. domestica* also dominated (3 mentions), with additional single mentions for *B. napus, F. vesca, H. annuus*, and *P. avium*. While managed honeybee colonies, either owned or hired, appear to be the most frequently used strategy, the use of solitary bees is crop-specific and relatively rare.

Only a small number of participants provided information on the number of managed pollinators they rent, further emphasizing the limited scope of the dataset. Specifically, five respondents reported hiring honeybee colonies, with the number of hives ranging from 2 to 100 (values: 2, 5, 8, 10, and 100). For solitary bee cocoons, four respondents gave numbers between 20 and 1000 (values: 20, 67, 800, and 1000). Rental costs were scarcely reported, only one participant indicated a rental price, which was about 40 EUR for 800 solitary bee cocoons.

The responses to the question "Why do you use bees to pollinate your crops?" provide insights into farmers' motivations for utilizing different types of managed pollinators, including honeybees, solitary bees, and bumblebees (Fig. 8). It is essential to note that each pollination strategy could be reported for up to three different crops, meaning the figures below reflect the number of crop-specific mentions, not the number of individual farmers. For example, if one farmer reported using honeybees on three different crops, this would result in three entries in the "Honeybees" category. Honeybees were cited most frequently. The leading reason for their use was that they are "effective pollinators of the crop" (7 mentions). Other common reasons included: "My fields are too big for wild pollinators alone" (6 mentions), "I like seeing them on my farm" (6), "I can get them at little or no cost" (5), "I find them easy to use" (4), and "Recommended by an agronomist" (3). Managed solitary bees were also reported with

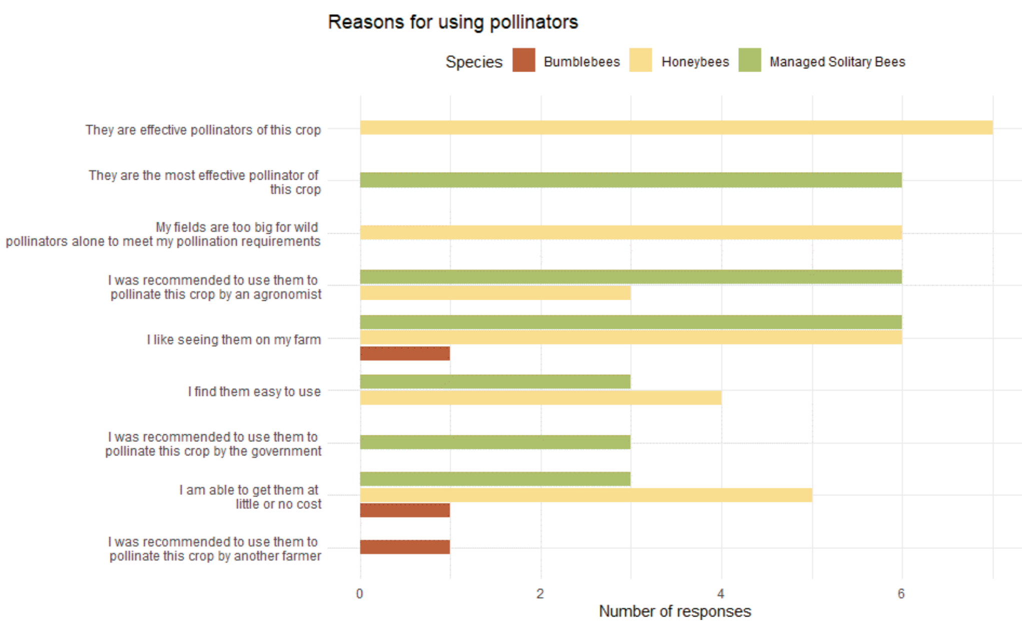

Fig. 8. Specific reasons for using different types of pollinators: honeybees, bumblebees, and solitary bees, categorized by each pollinator species

high frequency, particularly for their "effectiveness as pollinators" (6 mentions), "I like seeing them on my farm" (6), and "recommendation by an agronomist" (6). Additionally, they were noted as "easy to use" and "affordable" (3 mentions each), and some respondents mentioned a "recommendation by the government" (3). Bumblebees were much less frequently used. Only one crop mention was recorded for each of three reasons: "low or no cost," "liking their presence," and "recommendation by another farmer." Overall, the results indicate that farmers' decisions are influenced by a combination of perceived effectiveness, accessibility, aesthetics, and expert recommendations. Honeybees and solitary bees are both widely used and appreciated for their practical benefits and pollination performance.

Participants provided a range of reasons for implementing habitat management practices, such as avoiding insecticide spraying near margins, maintaining flower-rich field margins, and preserving hedgerows. Avoiding the use of insecticides near field margins was the most frequently justified by its ecological benefits. The most common reason given was that it encourages wild pollinators, which in turn benefit crop yields (8 responses). A significant number of farmers (7) also noted that it helps them meet greening objectives. Other commonly cited motivations included encouraging broader wildlife on the farm (5), enhancing crop productivity in other ways (5), and having little or no associated cost (4). A few respondents stated they are required to follow this practice as part of organic or agri-environmental schemes (4), or that it was recommended by the government (3), agronomists (2), or fellow farmers (1). Maintaining flower-rich field margins was similarly valued for its benefits to biodiversity and pollination. The most frequently cited reasons were that it encourages wild pollinators (8 responses), supports greening objectives (7), and attracts wildlife (6). Several respondents highlighted productivity benefits (5), affordability (4), and external recommendations, particularly from agronomists (2), the government (2), and other farmers (1). One farmer reported implementing this practice simply because the land had no other use. Additionally, two farmers noted that this practice helps them obtain agri-environmental funding. One response also mentioned compliance with organic or environmental schemes. Maintaining hedgerows was also implemented primarily for ecological and regulatory reasons. Six farmers said it helps support wild pollinators, while 5 linked it to greening objectives, and 5 emphasized the broader benefit to wildlife. Other reasons included fulfilling requirements from organic or agri-environmental schemes (2), low cost (2), lack of alternative land use (2), and recommendations by agronomists (1) or the government (1). A single farmer also indicated that hedgerows help improve crop productivity.

On the basis of the farmers' responses, we assessed the perceived usefulness of different pollination strategies such as managed honeybees, managed bumblebees, managed solitary bees, and field management to support wild pollinators. Using a 0 to 5 scale, where 5 indicates "very useful" and 0 "not useful at all" (Fig. 10). Managed honeybees received the highest ratings overall. Over half of the responses (53.3 %) rated them as very useful (score 5), and an additional 26.7% rated them 4. This shows a strong consensus among respondents that honeybee hives are a valuable pollination service. Managed solitary bees also received high ratings, with 48.1 % giving the maximum score of 5 and another 29.6 % assigning a score of 4. This indicates growing recognition of their role in effective pollination, though fewer respondents rated them than honeybees. Managed bumblebees had slightly more varied opinions. While 45.8 % of responses rated them as very useful, the remaining responses were more evenly distributed across scores 2 to 4, suggesting some uncertainty or variation in experience among farmers. Field management to encourage wild pollinators was not rated as high as others: 35.7 % of respondents rated it as very useful, and 42.9 % gave it a 4. In summary, all four strategies were perceived as valuable, with managed honeybees and solitary bees being rated the most consistently useful, followed closely by wild pollinator habitat management, and slightly more varied views on bumblebees.

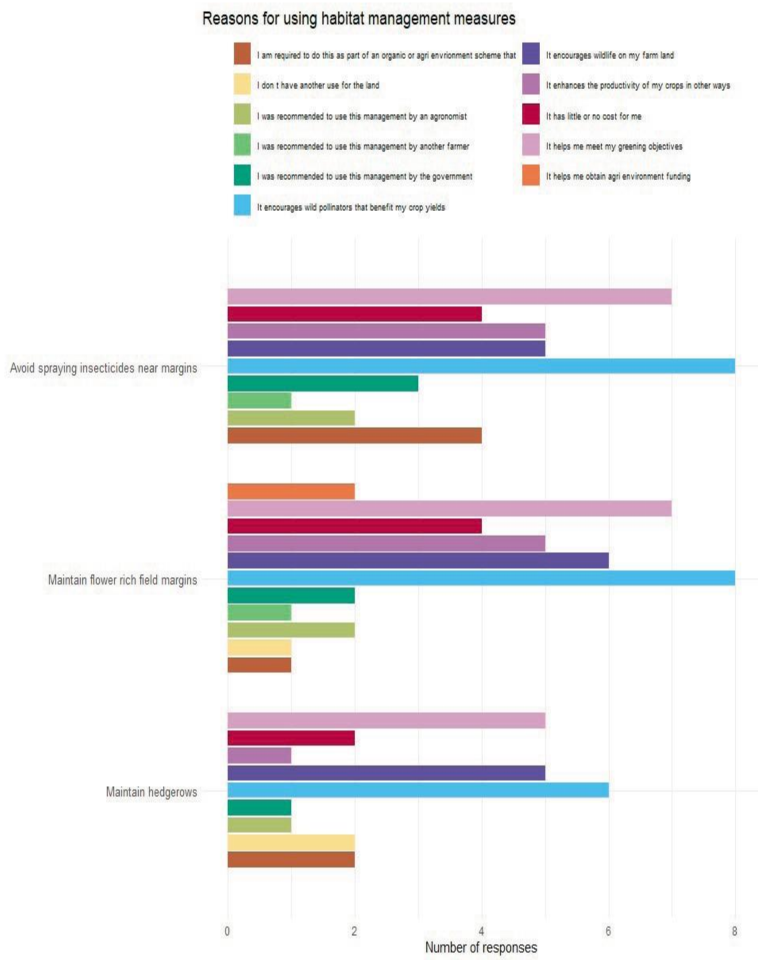

Fig. 9. The number of respondents who selected specific reasons for using habitat management measure

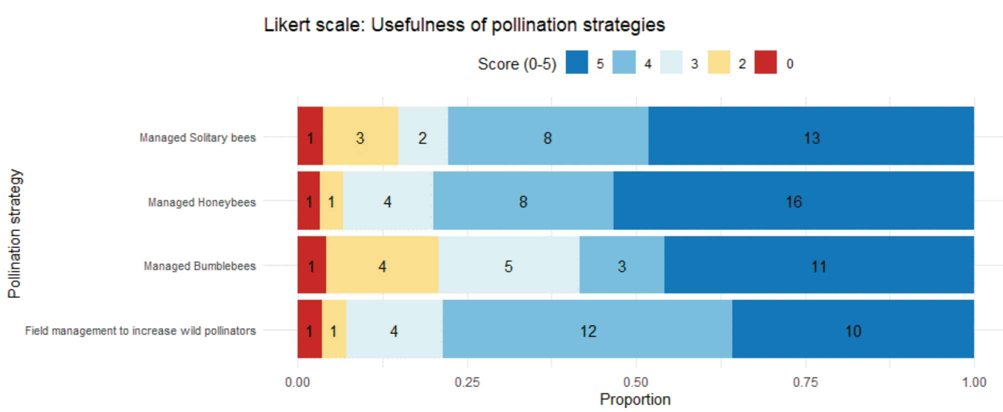

Fig. 10. The perceived usefulness of different pollination strategies, as rated by farmers on a scale from 0 (not useful at all) to 5 (very useful). Each bar in the graph is proportionally divided to represent the number of responses for each rating category

This section examines farmers' views on enhancing pollination services, as well as the challenges they encounter. However, the data quality for this part of the survey is relatively poor and fragmented. Only two respondents indicated that they would like to take measures to enhance pollination on their farms, one simply responded "yes", while the other specified "honeybees and solitary bees." When asked which crops these measures would apply to, the first respondent mentioned strawberries and apples, and the second listed almonds, apples and apricots. Despite limited responses regarding desired actions, there were slightly more replies to the question "What barriers are preventing you from using these measures?", although this imbalance is somewhat illogical. The most reported barriers were a lack of knowledge about how to manage pollination measures (6 responses) and insufficient access to necessary expertise or equipment (5 responses). Other individual responses cited a lack of space, prohibitive costs, and the unavailability of resources. Two types of support were mentioned that could help overcome these barriers: greater access to training, and more funding or initiatives to support pollination-related practices. Finally, in response to the question about which crops farmers do not want visited by pollinators, most respondents replied "None" indicating no concerns. However, one respondent mentioned maize, specifically because its seed is treated with neonicotinoids, implying concerns about chemical exposure. It should be noted that the number of farmer responses was substantially lower than the number of beekeeper responses, limiting the ability to draw fully balanced comparisons between the two groups.

Discussion

The findings of BREEZE et al. (2019) point to the importance of aligning farmer and beekeeper practices with ecological knowledge to optimize crop pollination. Their study found that mismatches between farmers' needs and beekeepers' offerings, along with an overall underutilization of ecological principles, pose significant barriers to effective pollination services. They emphasize the importance of trust-building, shared incentives, and knowledge exchange to foster more effective collaboration. Similarly, they found that managed honeybee colonies were often preferred for their predictability and availability, while the ecological benefits of wild pollinators and diverse habitats were frequently undervalued. These insights offer a valuable comparative perspective for interpreting our study's results, which reveal that Croatian beekeepers and farmers have overlapping yet often uncoordinated views on pollination needs and practices. The results of this and previous studies highlight the diversity of beekeeping practices in Croatia (MANARA et al., 2026) and underscore the need for targeted ecological knowledge to enhance pollination services through strengthened apicultural-agricultural partnerships. These findings underscore the urgent need for targeted policy measures that facilitate cooperation between beekeepers and farmers, such as coordinated advisory programs and incentive structures to support pollinator-friendly practices. A dominant proportion of the respondents identified as part-time beekeepers (83.8%), which aligns with broader European trends where small-scale, non-professional beekeepers constitute the majority of the sector (POTTS et al., 2016). Despite this, the experience levels varied considerably, with some individuals reporting over 50 years of practice. The moderate Spearman correlation (ρ=0.55) between years of experience and number of honeybee colonies managed suggests that while experience influences scale, other factors, such as financial investment, land access, or motivations (hobby vs. commercial), may be equally or more important (JACQUES et al., 2017).

Income distribution data emphasize that honey remains the primary economic driver for most Croatian beekeepers, which is consistent with global trends (BREEZE et al., 2019). However, the marginal role of pollination services in Croatian beekeeping, as reflected in both the low median income share (23.5%) and the limited uptake of hive relocation practices, indicates untapped potential. In contrast, in contexts where apicultural and agricultural sectors are closely integrated, pollination services contribute substantially to beekeeper revenues. For example, in the United States, pollination fees (especially from almond pollination) account for approximately two-fifths of beekeepers' income (USDA ERS, 2025). In Europe, institutional shortfalls hinder wider adoption: a Special Report by the European Court of Auditors concluded that the EU Pollinators Initiative lacked legal enforceability, clear stakeholder roles, and effective monitoring, and that the Common Agricultural Policy (CAP) did not include provisions tailored to wild pollinators (EUROPEAN COURT OF AUDITORS, 2020). The 2023 European Parliament "New Deal for Pollinators" resolution calls for national strategies, stronger CAP alignment, and improved governance mechanisms to address these gaps (EUROPEAN PARLIAMENT, 2023). Foundational ecological economic assessments demonstrate the vast, often-unpriced, benefits of insect pollination globally and in Europe (GALLAI et al., 2009; IEEP, 2025), and landscape-scale analyses show that a small subset of bee species provides the bulk of crop pollination services, suggesting that targeted coordination and incentives could yield disproportionately large returns (KLEIJN et al., 2015). In Croatia, the national CAP Strategic Plan interventions for apiculture focus on supporting equipment, disease control, education, and the rationalization of migratory beekeeping. However, they do not include specific measures for developing a market for pollination services (APPRRR, 2023; APPRRR, 2024). Together, these findings suggest that Croatia's limited engagement with pollination services may stem from a combination of weak governance, limited market incentives, and low awareness.

Apiaries' placement data showed a strong seasonal preference for grasslands, which remained dominant throughout the year. Forests gained relative importance in summer, likely due to their provision of floral resources such as chestnut and lime during nectar dearth periods, a pattern consistent with ecological foraging behavior observed elsewhere in Europe (REQUIER et al., 2015). The avoidance of hive relocation, primarily due to logistical constraints, disease concerns, or insufficient forage on owned property, reveals a significant operational bottleneck for expanding pollination services. These constraints echo findings from European beekeeping surveys where mobility is limited by similar practical and economic considerations (GRAY et al., 2019).

The results on crop and plant preferences reinforce the complexity of beekeepers' ecological decision-making. Preferences for *R. pseudoacacia*, *C. sativa*, and *T. cordata* correspond well with their documented floral reliability, high nectar productivity, and strong honey market value (BOGDANOV et al., 2004; BÜCHLER et al., 2014). In contrast, the ambivalent views expressed toward mass-flowering crops, such as *B. napus var. oleifera*, *Z. mays*, and, to a lesser extent wheat (*T. aestivum*), illustrate the dual role of arable landscapes in beekeeping strategies. Maize can provide substantial quantities of pollen during summer dearth periods, but its nutritional quality is relatively poor, and concerns about pesticide seed treatments (notably neonicotinoid coatings) and fungicidal sprays have contributed to perceptions of risk (ALBURAKI et al., 2015; TSVETKOV et al., 2017; SAMSON-ROBERT et al., 2017). Wheat, by contrast, is wind-pollinated and generally offers negligible nectar or pollen, yet bees foraging in wheat-dominated areas may still face elevated exposure to agrochemicals and habitat simplification, making such landscapes unattractive from a beekeeper's perspective (REETZ et al., 2011). These findings highlight that crop preferences are shaped not only by floral resource availability but also by the perceived trade-off between forage potential and pesticide-mediated honeybee colony health risks. Avoidance of certain crops due to toxicity or low honey quality further emphasizes the need for collaborative communication between farmers and beekeepers to align planting and protection practices with pollinator health. The study by BREEZE et al. (2019) importantly contextualizes these findings within a broader policy and market framework. They argue that despite the theoretical value of pollination services, beekeepers across Europe often derive little income from them, largely due to the absence of structured markets and recognition mechanisms. This disconnect was reflected in our results, where some beekeepers reported not receiving any compensation for pollination, leading to deliberate hive placement away from crops such as maize and oilseed rape, which are otherwise significant agricultural commodities.

Lastly, ecological motivations behind plant preference, such as promoting colony growth, forage availability, and honey yield, appear central to beekeepers' decision-making. These findings emphasize the necessity for policy strategies based on ecosystem services that encourage landscape diversification, crop rotations with flowering plants, and a reduction in agrochemical use. Encouragingly, plant species such as *A. fruticosa, S. oficinalis,* and *P. tanacetifolia*, which are associated with both ecological and economic benefits, offer promising models for designing pollinator-friendly agroecosystems. Overall, our findings support the argument that enhancing crop pollination in Croatia is not solely a matter of increasing hive numbers or beekeeper engagement, but requires the systemic integration of ecological knowledge, economic incentives, and land-use planning. Promoting training, regional cooperation, and policy incentives to reward pollination contributions, particularly among hobbyist beekeepers, could strengthen the resilience and sustainability of both apicultural and agricultural systems. BREEZE et al. (2019) argue that despite the theoretical value of pollination services, their practical economic role in Europe remains minimal due to insufficient policy support and missing market infrastructure. Our findings confirm this disconnect: the majority of Croatian beekeepers rely solely on honey sales, with minimal compensation or coordination with agriculture. This underlines the urgent need for improved institutional frameworks and incentive schemes that recognize and reward pollination contributions. Also, the results support the development of evidence-based recommendations for practice, including the adoption of regionally adapted training for stakeholders, and financial mechanisms to incentivize sustainable pollination strategies at the farm level.

In conclusion, enhancing pollination services in Croatia goes beyond simply increasing the number of hives or engaging more beekeepers. It requires a systemic change that includes better integration of ecological knowledge into agricultural planning, policy support for mobile beekeeping, and improved collaboration between farmers and beekeepers. With the right incentives, even part-time beekeepers, who currently dominate the landscape, could play a meaningful role in enhancing pollination services and ensuring agricultural sustainability. The results reveal several key insights into farmers' knowledge, practices, and attitudes toward pollination services and pollinator support, with clear parallels to recent European studies. A significant proportion of farmers (27.8%) reported participating in Agri-Environmental Schemes (AES), aligning with broader European trends of increasing but often indirect engagement in pollinator conservation. For instance, BREEZE et al. (2016) found that while many farmers are involved in AES, only a minority manage land specifically with pollinators in mind. Similarly, EERAERTS et al. (2020) noted that even in high-value crops such as cherries, growers often prioritize managed honeybees over wild pollinator support.

The estimated median crop yield loss without animal pollination (42.5%) and the widespread belief that yields are currently limited due to insufficient pollination, confirm farmers' strong awareness of pollination dependence. This is consistent with the findings of KLEIN et al. (2007), who estimated that 75% of leading global food crops depend to some extent on animal pollination, and with BRITTAIN et al. (2013), who highlighted pollination shortfalls as a critical constraint in production systems.

Despite this awareness, most farmers in the study stated they relied on managed honeybees, either through ownership or hiring. The occasional use of solitary bees and very limited use of bumblebees reflect prevailing patterns in European agriculture. EERAERTS et al. (2020) reported similar trends, with honeybees dominating despite evidence that solitary bees and bumblebees can provide equal or superior pollination services for some crops. Furthermore, research by GARIBALDI et al. (2013) demonstrated that wild pollinators often enhance fruit set more effectively than honeybees, especially under conditions where honeybee populations are limited or environmental conditions are suboptimal.

Farmers' motivations for using pollinators extended beyond yield, encompassing ease of use, cost, aesthetics, and expert recommendations. These multi-faceted drivers have been documented in previous studies (SCHEPER et al., 2013; EERAERTS et al., 2020), reinforcing the need to integrate both agronomic and perceptual factors in pollinator-related extension programs. Habitat management practices were also frequently mentioned. Avoiding insecticides near field margins, maintaining flower-rich margins, and preserving hedgerows were motivated by their ecological value and minimal cost. These results are consistent with the conclusions of SCHEP-

ER et al. (2013) and KLEIJN et al. (2015), who emphasized that simple, low-cost interventions, such as field margin enhancement, can significantly support pollinator populations and improve ecosystem services.

Despite the farmers' willingness, their responses highlighted multiple barriers to enhancing pollination services: the lack of technical knowledge, limited access to equipment, and financial constraints. These align with findings from BREEZE et al. (2016) and DICKS et al. (2016), who advocate for more accessible technical support and targeted incentives within AES and broader agricultural policy. The lower number of farmer respondents in this study constitutes a key limitation affecting the representativeness of the data provided, and the interpretation of comparative results. Future studies should incorporate tailored recruitment strategies to engage more farmers and ensure greater sample size equity, allowing for robust and unbiased comparison.

In terms of perceived usefulness, managed honeybees and semi-reared solitary bees were rated highest, followed by wild pollinator habitat management and bumblebees. This rating hierarchy corresponds with both economic accessibility and knowledge, reinforcing the call from GARIBALDI et al. (2013) to promote diversified pollinator strategies through informed extension, cost-sharing, and demonstration projects. By highlighting gaps in farmer engagement and the underutilization of wild pollinators, this study points to the value of integrating ecological knowledge into national agricultural policy and extension services. Such policy actions could help unlock the ecological and economic potential of crop pollination services, thereby contributing to the long-term sustainability of agricultural production systems.

Conclusions

This study highlights the critical role of insect pollination in securing agricultural productivity, with farmers estimating median yield losses of more than 40% in its absence. While honeybees remain the dominant managed pollinators, wild pollinators contribute substantially to yields and ecosystem resilience, yet their potential remains underutilized. Promoting wild pollinators through environmental restoration, establishment of floral resources such as hedgerows and flower strips, diversified cropping systems, and reduced pesticide risks, offers considerable room for improvement. Barriers, including limited awareness, insufficient technical support, and a lack of financial incentives, continue to restrict broader adoption of pollinator-friendly practices. Overcoming these challenges through targeted training, advisory services, and policy incentives could greatly enhance both pollination services and farm productivity. For beekeepers, strong demand for honeybee pollination provides opportunities for diversification and closer collaboration with farmers. However, true progress will only be achieved when the majority of farmers recognize the importance of pollinators and actively incorporate their protection into daily management. Strengthened cooperation between farmers, beekeepers, and policymakers, underpinned by coherent agri-environmental strategies, will be essential to safeguard pollinator health and ensure sustainable food production in the years ahead.

Declaration of competing interests

The authors declare that there is no conflict of interest.

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SAŽETAK

Učinkovito oprašivanje usjeva ovisi o usklađivanju poljoprivrednih i pčelarskih praksi s ekološkim znanjem. Ovim istraživanjem analizirana je dinamika odnosa između hrvatskih pčelara i poljoprivrednika, otkrivajući preklapajuće, ali često nekoordinirane pristupe oprašivanju. Podaci dobiveni upitnikom pokazali su da je 83,8% pčelara zaposleno na dio radnog vremena, što je u skladu sa širim trendovima uočenim diljem Europe. Iako proizvodnja meda ostaje glavni izvor prihoda, usluge oprašivanja tom prihodu doprinose minimalno, dijelom zbog logističkih prepreka, slabih institucionalnih okvira i ograničenih tržišnih poticaja. Postavljanje pčelinjaka pod jakim je utjecajem sezonskih medonosnih paša, s preferencijom za travnjake i selektivnim izbjegavanjem određenih usjeva zbog rizika od izlaganja pesticidima ili slabog medenja. Poljoprivrednici su prijavili značajnu ovisnost o oprašivanju kukcima (medijan 42,5%) i jaku ovisnost o uzgajanim zajednicama medonosnih pčela, no slobodno živući kukci oprašivači i mjere poboljšanja njihovih staništa i dalje su nedovoljno iskorišteni. Unatoč raširenoj svijesti, ograničenja poput tehničkih i financijskih nedostataka otežavaju daljnju angažiranost proizvođača. Istraživanje naglašava hitnu potrebu za integracijom ekološkog znanja u politike i prakse. Promicanje suradničkih odnosa, poticaji temeljeni na uslugama ekosustava i regionalno prilagođene obuke moglo bi poboljšati rezultate oprašivanja pčelama. Pčelari djelomičnim radnim vremenom mogu biti ključni resurs za proširenje usluga oprašivanja kukcima ako dobiju bolju podršku. S ciljem jačanja partnerstva između pčelara i poljoprivrednika u Hrvatskoj, potrebno je koordinirati napore u politici, obrazovanju i planiranju korištenja zemljišta kako bi se u potpunosti pokrenuo ekološki i ekonomski potencijal oprašivanja.

Ključne riječi: pčelarske prakse; oprašivanje kukcima; pčelinje zajednice; bumbarske zajednice; slobodno živuće pčele