EGYPTIAN ACADEMIC JOURNAL OF
BIOLOGICAL SCIENCES
ENTOMOLOGY

A

ISSN
1687-8809

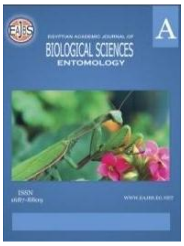
WWW.EAJBS.EG.NET

Vol. 18 No. 2 (2025)

Citation: *Egypt. Acad. J. Biolog. Sci. (A. Entomology) Vol. 18(2) pp.133-143 (2025)*
DOI: 10.21608/EAJBSA.2025.432101

Egypt. Acad. J. Biolog. Sci., 18(2):133-143 (2025)

Egyptian Academic Journal of Biological Sciences
A. Entomology
Res. Ethics No.: 03-2025-0026
ISSN 1687- 8809
http://eajbsa.journals.ekb.eg/



Influence of Mixed Cropping Systems on Pollinator Diversity and Abundance in Agroecosystems

Wael E.A. El-Sheikh[1], Abdellah S. H. Abdel-Moniem[1], Hasnaa A.S. Sleem[1] and Ahmed H. EL Kenawy[2]

[1]Department of Plant Protection, Faculty of Agriculture, Beni-Suef University, Beni Suef 62511, Egypt.
[2]Biological Control Department, Agricultural Research Centre, Giza 12619, Egypt.
*E-mail: ahmed.elkenawy@arc.sci.eg - wael.elzaher@agr.bsu.edu.eg

ARTICLE INFO
Article History
Received:26/4/2025
Accepted:5/6/2025
Available:9/6/2025

Keywords:
Pollinators, Crop diversity, Pollinator abundance, Agroecosystems, Sustainable agriculture.

ABSTRACT

Pollinators are essential for global agriculture, supporting crop production, nutrition, and economic stability. This study assessed the impact of different crop combinations on the diversity and abundance of *Vespa orientalis* Linnaeus, 1771 (Hymenoptera: Vespidae) and *Apis mellifera* L. (Hymenoptera: Apidae) across four plots during the 2021–2022 and 2022–2023 agricultural seasons (December–April). The experiment included a control plot with bean monoculture (*Vicia faba* L.) and three mixed-crop plots: Plot 1 with lupine (*Lupinus spp*.), peas (*Pisum sativum* L), and beans; Plot 2 with lupine, clover (*Trifolium spp*.), and beans; and Plot 3 with peas, clover, and beans. Pollinators were sampled using sweep netting, shaking, and beating vegetation, with specimens identified in the lab. *V. orientalis* in the control plot showed slight fluctuations, peaking in January and March of the 2021–2022 season (1.05±0.1 indv.), while *A. mellifera* peaked in January (1.2±0.2 indv.). Mixed plots showed higher and more variable pollinator numbers. In Plot 1, *V. orientalis* peaked in January in the first season and increased gradually without peaks in the second season. *A. mellifera* peaked in January in the first season and in January and March in the second season. Plot 2 showed *V. orientalis* peaks in January and March in both seasons, while *A. mellifera* peaked in January and March in the first season and in January, February, and March in the second. Plot 3 had the highest *A. mellifera* abundance in April of both seasons (4.4±1 indv. in 2021–2022 and 4.40±0.8 indv. in 2022–2023), with a peak in January in the second season. *V. orientalis* peaked in January in the first season and in January and March in the second. These results show that mixed cropping enhances pollinator diversity and abundance, promoting sustainable farming and supporting pollinator conservation.

INTRODUCTION

Pollinators are vital to global agriculture, supporting over 75% of major food crops and contributing hundreds of billions of dollars annually (Klein *et al.*, 2007). Key crops like apples, almonds, and cucumbers depend on insect pollinators, especially bees (Garibaldi *et al.*, 2013; Tobajas *et al.*, 2024; Sydenham *et al.*, 2024). Their diversity and abundance

Citation: *Egypt. Acad. J. Biolog. Sci. (A. Entomology) Vol. 18(2) pp.133-143 (2025)*
DOI: 10.21608/EAJBSA.2025.432101

enhance pollination efficiency through varied foraging behaviours and increased flower visits (Blüthgen & Klein, 2011; Klatt *et al.*, 2014). High pollinator densities improve crop yields, such as better nut set in almonds and higher seed set in sunflowers (Brittain *et al.*, 2013; Greenleaf & Kremen, 2006). However, habitat loss, pesticides, climate change, and disease are reducing pollinator populations (Potts *et al.*, 2010). Landscape diversity, farming practices, and floral resources shape pollinator communities and influence pollination potential (Sydenham *et al.,* 2024). Agricultural intensification, characterized by the expansion of monocultures, the removal of natural habitats, and the increased use of agrochemicals, has been identified as a major driver of pollinator decline (Tscharntke *et al*., 2005). Simplified landscapes with limited floral diversity and nesting sites often support fewer pollinator species and lower abundances compared to more diverse landscapes that provide a variety of habitats and resources (Kennedy *et al*., 2013, Sydenham *et al* 2022). For example, studies have shown that fields surrounded by semi-natural habitats, such as hedgerows, grasslands, and forests, tend to have higher pollinator diversity and abundance, leading to better pollination outcomes (Ricketts *et al*., 2008). The impact of pollinators on crop yield and quality depends on their diversity, abundance, and specific interactions with crops. Some crops, like strawberries, benefit significantly from bee pollination, which improves fruit size, shape, and shelf life (Klatt *et al*., 2014, Southern *et al*., 2024). In contrast, wind-pollinated crops like wheat and rice are less affected by pollinators, though their presence still supports ecosystem stability and biodiversity, crucial for sustainable agriculture (Gallai *et al*., 2009, Torvanger *et al*.,2025). Pollinator decline threatens global food security, especially in regions reliant on animal pollination. Reduced yields and higher production costs may result, as farmers turn to less efficient alternatives like hand pollination or managed honeybees (Aizen and Harder, 2009). These methods often fail to match natural pollination and can increase labor demands. Additionally, losing pollinator diversity weakens agricultural resilience, making systems more susceptible to pests, diseases, and climate variability (Kremen *et al*., 2002, Sydenham *et al* 2023). Conserving pollinators is vital for sustaining productivity and food security. Strategies like habitat restoration, agroecological practices, and reduced pesticide use enhance pollinator populations and pollination services (Dicks *et al*., 2016, Sydenham *et al*.,2022). For instance, wildflower strips and hedgerows provide food and nesting sites, boosting pollinator diversity and abundance (Scheper *et al*., 2013). Similarly, integrated pest management (IPM) reduces pesticide exposure, supporting pollinator health (Goulson *et al*., 2015). The study aims to assess the impact of different crop combinations on the diversity and abundance of pollinators to enhance sustainable agricultural practices.

MATERIALS AND METHODS

Studied Area:

The survey was conducted on a farm situated in Qena Governorate - Nag Hammadi Center 26.0502° N - 32.2419° E (Upper Egypt), chosen for its varied topography and accessibility. The plots are in an area with fertile, well-drained soil, typical of field crop production. The experimental area consists of four experimental plots, each approximately [100 m²], situated near one another to ensure uniform environmental exposure while allowing for distinct crop combinations.

Timing and Frequency of Surveys:

Surveys are conducted at key times throughout two successive growing seasons (2021/2022- 2022/ 2023), from December until April,to capture pollinator activity across different stages of crop bloom:

Timing: Surveys are scheduled to coincide with peak flowering times for the crops, typically in the morning and early afternoon when pollinator activity is highest. These times also allow for capturing a broader range of pollinator species as they visit the flowers for nectar and pollen.

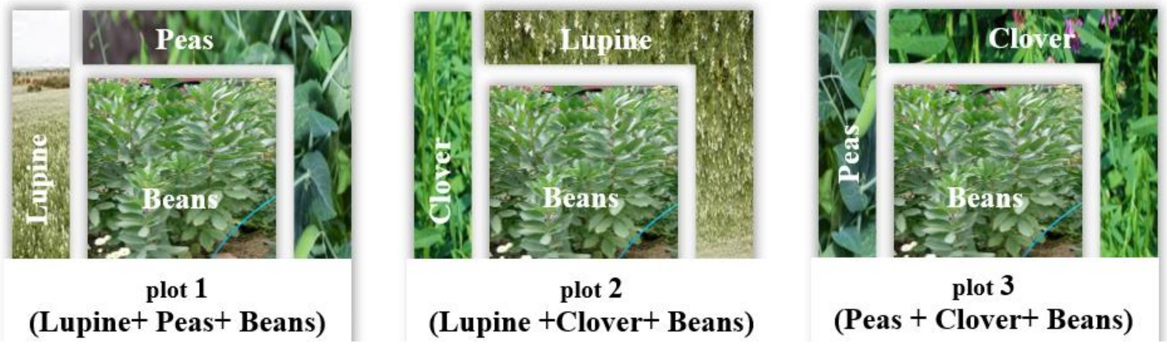
Frequency: Pollinator surveys are performed weekly before and during the peak flowering periods of each crop, with additional surveys conducted during significant weather changes or if there are noticeable fluctuations in pollinator activity.

Selected Crops:

The study focuses on a diverse range of field crops, with beans (*Vicia faba* L.) serving as the principal crop due to their economic importance and role in crop rotation systems. Alongside beans, the selected crops include lupines (*Lupinus polyphyllus* Lindl.), peas (*Pisum sativum* L.), and clover (*Trifolium spp*.). Lupines are valued for their nitrogen-fixing ability, enhancing soil fertility and supporting subsequent crops. Peas, another legume, are cultivated for their nutritional value and as a cover crop, improving soil structure and reducing erosion. Clover, known for its versatility, functions as both a forage crop and a green manure, enriching the soil with organic matter and nitrogen. Together, these crops form an integrated system that promotes biodiversity, soil health, and productivity.

Experimental Design:

The experimental design includes four distinct crop combinations to assess the impact of crop diversity on pollinator activity and crop performance. Plot 1 features a combination of *Lupinus spp.* (lupine), *P. sativum* (peas) and *V. faba* (beans), promoting a mix of flowering times to attract a wide range of pollinators. Plot 2 includes *Lupinus spp.* (lupine), *Trifolium spp.* (clover), and *V. faba* (beans), with clover adding dense floral resources for pollinators. Plot 3 integrates *P. sativum* (peas), *Trifolium spp.* (clover), and *V. faba* (beans), emphasizing legumes known for their pollinator-friendly traits. Plot 4 serves as a control with a monoculture of *V. faba* (beans) to compare pollinator activity and productivity against mixed cropping systems. Regular surveys of pollinators are conducted to identify species diversity, abundance, and visitation rates across the plots, providing insights into how crop combinations influence pollinator dynamics.



Sampling Methods:

Shaking and Beating Vegetation:

The shaking and beating vegetation sampling method was carried out by placing paper or plastic sheets under the shaken and beaten plants. Fifty plants were chosen randomly and wholly inspected in an axial pattern at regular distances (about 5 m). The dislodged arthropods were collected quickly before escaping. The count was timed to sunrise (about 6:30 am), when arthropods were still settled in the plants' canopy. The insects were collected by an aspirator or into a tray containing a killing solution such as chloroform.

Sweeping Net:

Sweep netting has important advantages, including low equipment cost and potentially large yield of specimens per unit (Mccravy and Kenneth, 2018). Once plant stalks became more rigid, this technique was applied in both seasons, respectively, until harvesting.

Fifty double sweep-net strokes were randomly axially taken days apart at 14-day intervals. Collected samples were emptied into labelled collecting glass jars and transferred to the laboratory for examination and identification.

Specimens Identification:

Adult and immature stages of the pollinator's species were killed by chloroform, counted, sorted, bagged, and stored at 10°C. Specimens were then deposited at the Plant Protection Department, Faculty of Agriculture, Beni-Suef University, Egypt and identified using the proper keys (Zalat, *et al*., 1992).

Simpson's Diversity Index (D)

Simpson's Diversity Index (D) is a measure used to quantify the biodiversity of a community by considering both the number of species present (richness) and the relative abundance of each species (evenness). The value of D ranges from 0 to 1, where values closer to 1 indicate higher diversity and more even distribution among species, while values closer to 0 indicate lower diversity with dominance by one or a few species. In the context of our research, D can be calculated for each month or plot by using the abundance data for *V. orientalis* and *A. mellifera* , allowing researchers to compare how insect diversity changes over time or under different cropping systems. A higher Simpson's Index in a particular month or plot suggests a more balanced and diverse insect community, which is often desirable for ecosystem stability and agricultural health.

The Simpson's Diversity Index is calculated as:

$$D = 1 - \sum_{i=1}^{N}(p_i)^2$$

Where:

- S = total number of species (species richness)
- Pi =proportion of individuals belonging to the i the species
  Pi=ni/N
  ni = number of individuals of species ii
  N = total number of individuals of all species
- D ranges from 0 (no diversity) to near 1 (high diversity).

Data Analysis:

ANOVA was used to test the null hypothesis that there are no significant differences between the monthly means. If the ANOVA results were significant ($p < 0.05$), Tukey's Honestly Significant Difference (HSD) post-hoc test was applied to perform pairwise comparisons between the months and assign significance letters to indicate groups that are not significantly different from each other. The F-values and p-values were calculated to determine the strength and significance of the observed differences. All analyses were performed at a significant level of $\alpha = 0.05$, and the results were interpreted to identify statistically significant variations in the data.

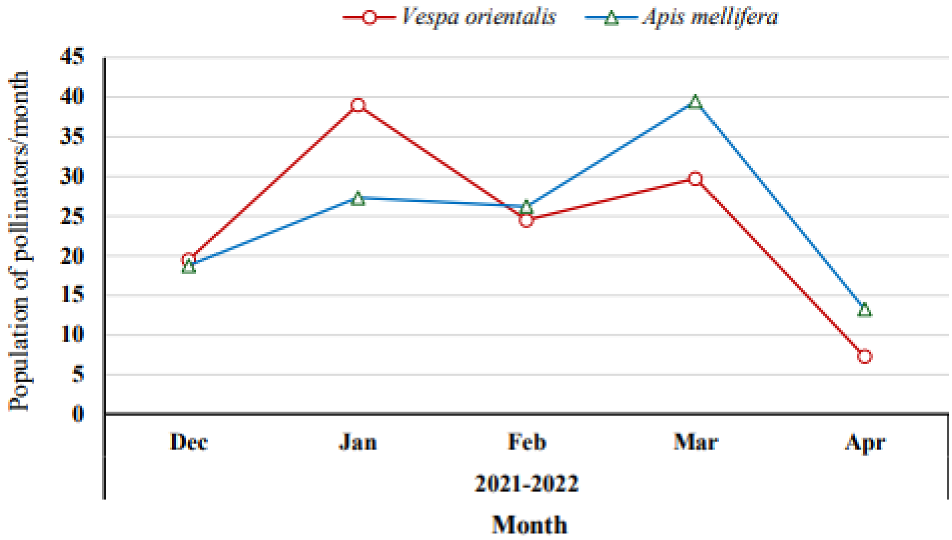
RESULTS

The study recorded two pollinator species: *Vespa orientalis* (Hymenoptera: Vespidae) and *Apis mellifera* (Hymenoptera: Apidae). Among them, *A. mellifera* was the most abundant. While *V. orientalis* is a social wasp, it is occasionally involved in pollination during nectar foraging.

Pollinator Abundance:

Figure 1, shows the total monthly population trends of *V. orientalis* and *A. mellifera* over two consecutive seasons: 2021–2022 and 2022–2023. During the 1st season, *V. orientalis* peaked in January and March (at nearly 39& 30, respectively), followed by a decline, while *A. mellifera* gradually increased and peaked in January and March (at around

27& 45 individuals, resp.). In contrast, the data for the 2nd season shows that both species have increased steadily since December, with *A. mellifera* consistently maintaining slightly higher numbers than *V. orientalis*. Both species reached their highest populations in March (49.75 indv for *A. mellifera* and 45indv. for *V. orientalis*), before experiencing a sharp decline in April.



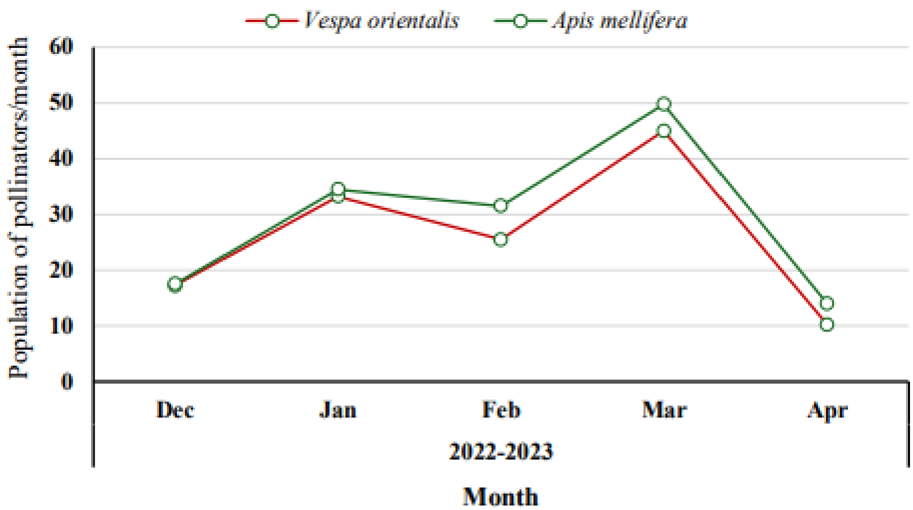


Fig.1: Total monthly fluctuations in the observed populations of *V. orientalis* and *A. mellifera* in both seasons 2021-2022 and 2022-2023.

Pollinators Diversity and Abundance:

Tables (1 & 2), presents the monthly mean abundance of two pollinator species, *V. orientalis* and *A.mellifera*, in various crop combinations during 2021-2022 and 2022-2023 seasons. It examines their presence in control plots (beans only) and three mixed-crop plots.

Control Plot (Beans Only):

In the control plots where Beans only cultivated during the 2021–2022 season (Table 1), *V. orientalis* abundance was relatively consistent across months, with the lowest observed in December (0.8±0.17) and the highest in January and March (1.05±0.1), while *A. mellifera* showed its lowest abundance in December (0.53±0.13) and its highest in January and April (1.2±0.2), with an F-value of 10.56 and a p-value of 0.0012 indicating statistically significant differences in the monthly abundance for *V. orientalis*. In the control plot during the 2022–2023 season (Table 2), *V. orientalis* showed a slight increase in abundance in December (0.67±0.15) with two peaks in Jan. (0.80 ±0.1) and March (1.10±0.1) and slightly declining in April (1.00±0.3), whereas *A. mellifera* had its lowest abundance in December (0.60±0.16) and peaked in Jan. (1.00±0.2), with ANOVA results for both species being statistically significant, showing F-values of 12.45 and 10.89 and p-values of 0.0008 and 0.0015, respectively, confirming variations in monthly abundances.

Plot 1 (Lupine + Peas + Beans):

In Plot 1, (Lupine + Peas + Beans), *V. orientalis* has two peaks in Jan. and March (2.05±0.3 and 1.75±0.3, resp.), with a lowest abundance number in December (1.26±0.2), while *A. mellifera* reached its maximum abundance in April (2.4±0.7) and its minimum in December (1.4±0.21), during the 1st season. Both pollinators showing significant monthly variations, as indicated by F-values of 25.34 and 22.18 and p-values below 0.0001, confirming strong statistical significance. In the 2nd season, *V. orientalis* abundance increased steadily from its lowest abundance in December (1.40±0.2) till reaching April (3.20±0.7) with no peaks , whereas *A. mellifera* had its maximum abundance in March (2.45±0.3) and lower counts in December (1.33±0.2) with two peak in Jan. and March (2.15±0.3 &2.45±0.3, resp.), with significant monthly variations confirmed by F-values of 28.67 and 24.53 and p-values < 0.0001.

Plot 2 (Lupine + Clover + Beans):

In Plot 2, (Lupine + Clover + Beans), *V. orientalis* abundance fluctuated, peaking in January and March (2.1±0.25and 1.65±0.2 , resp.) and the abundance number was dropping in April (1.4±0.2), while *A. mellifera* showed the highest abundance peaks in Jan. and March (2.75±0.34 and 2.75±0.4, resp.) and the lowest in February (1.5±0.2) during the 1st season, with significant F-values (26.78, 23.64) and p-values (<0.0001) highlighting meaningful variations in monthly counts. In the 2nd season, *V. orientalis* abundance number peaked in Jan. and March (1.55±0.1 and 2.50±0.2, resp.), followed by a decrease in April (2.20±0.2), with its lowest count in December (1.27±0.1), while, *A. mellifera* had one peak in March (3.10±0.3) and its lowest in December (1.33±0.1), with statistical analysis confirming strong significance for monthly changes through F-values of 27.89 and 24.78 and p-values below 0.0001.

Plot 3 (Peas + Clover + Beans):

In Plot 3, (Peas + Clover + Beans), *V. orientalis* abundance was highest in January (2.65±0.34) and lowest in February (1.15±0.1), while *A.mellifera* had two peaks in Jan. (2.6±0.4) and March (2.3±0.3), then the count increased till April (4.4±1), marking the highest recorded value across all plots, with a minimum number observed in February (1.3±0.1) during the 1st season. Statistical analyses confirmed strong monthly differences with F-values of 28.45 and 25.67 and p-values below 0.0001. In the 2nd season, *V. orientalis* showed its highest abundance in March (2.55±0.2), declining slightly by April (1.80±0.3), with the lowest values in December and Feb. (1.27±0.2 and 1.30±0.19, respectively), while the abundance of *A. mellifera* again increased in April with recording the highest count across all plots (4.40±0.8), with the lowest in December (1.40±0.1); significant F-values (27.89 for *V. orientalis* and 24.78 for *A. mellifera*) and p-values < 0.0001 affirmed notable monthly differences.

Table 1: Monthly (Means ±SE) Abundance of Pollinators (*V. orientalis and A. mellifera*) Across Crop Types in Control and Mixed-Crop Plots during 2021-2022 season.

Mon.	**Control (Plot 4)**		**plot 1**		**plot 2**		**plot 3**	
Crop	**Beans only**		**Lupine+ Peas+ Beans**		**Lupine +Clover+ Beans**		**Peas + Clover+ Beans**	
Sp.	*V. orientalis*	*A. mellifera*	*V. orientalis*	*A. mellifera*	*V. orientalis*	*A. mellifera*	*V. orientalis*	*A. mellifera*
Dec.	0.8±0.17^{a}	0.53±0.13^{a}	1.26±0.2^{a}	1.4±0.21^{a}	1.6±0.21^{a}	1.46±0.19^{a}	1.53±0.23^{a}	1.6±0.19^{a}
Jan.	1.05±0.1^{b}	1.2±0.2^{b}	2.05±0.3^{b}	2.25±0.26^{b}	2.1±0.25^{b}	2.75±0.34^{b}	2.65±0.34^{b}	2.6±0.4^{b}
Feb.	0.85±0.1^{ab}	0.95±0.1^{c}	1.4±0.19^{c}	1.5±0.2^{c}	1.5±0.25^{c}	1.5±0.2^{c}	1.15±0.1^{a}	1.3±0.1^{c}
Mar.	1.05±0.1^{b}	0.85±0.2^{c}	1.75±0.3^{d}	2±0.3^{d}	1.65±0.2^{c}	2.75±0.4^{b}	1.5±0.2^{c}	2.3±0.3^{d}
Apr.	0.8±0.2^{c}	1.2±0.5^{a}	2±0.3^{e}	2.4±0.7^{e}	1.4±0.2^{d}	2.6±0.6^{d}	1.6±0.4^{d}	4.4±1^{e}
	F=10.56, P= 0.0012	F=8.72, P= 0.0025	F=25.34, p< 0.0001	F= 22.18, p< 0.0001	F= 26.78, p< 0.0001	F= 23.64, p< 0.0001	F= 28.45, p< 0.0001	F= 25.67, p< 0.0001

Table 2: Monthly (Means ±SE) Abundance of Pollinators (*V. orientalis and A. mellifera*) Across Crop Types in Control and Mixed-Crop Plots during 2022-2023 season.

Month	**Control (Plot 4)**		**Plot 1**		**Plot 2**		**Plot 3**	
Crop	**Beans only**		**Lupine+ Peas+ Beans**		**Lupine +Clover +Beans**		**Peas + Clover +Beans**	
Species	*V. orientalis*	*A. mellifera*	*V. orientalis*	*A. mellifera*	*V. orientalis*	*A. mellifera*	*V. orientalis*	*A. mellifera*
Dec.	0.67±0.15^{a}	0.60±0.16^{a}	1.40±0.2^{a}	1.33±0.2^{a}	1.27±0.1^{a}	1.33±0.1^{a}	1.27±0.2^{a}	1.40±0.1^{a}
Jan.	0.80±0.1^{ab}	1.00±0.2^{b}	1.55±0.1^{b}	2.15±0.3^{b}	1.55±0.1^{b}	1.80±0.2^{b}	1.50±0.1^{b}	1.95±0.2^{b}
Feb.	0.75±0.1^{ab}	0.80±0.1^{c}	1.55±0.1^{b}	1.80±0.2^{c}	1.50±0.1^{b}	1.80±0.2^{b}	1.30±0.19^{c}	1.90±0.2^{b}
Mar.	1.10±0.1^{b}	1.30±0.2^{d}	2.85±0.3^{c}	2.45±0.3^{d}	2.50±0.2^{c}	3.10±0.3^{c}	2.55±0.2^{d}	3.10±0.3^{c}
Apr.	1.00±0.3^{c}	1.40±0.5^{a}	3.20±0.7^{d}	2.40±0.2^{e}	2.20±0.2^{d}	3.00±0.4^{d}	1.80±0.3^{e}	4.40±0.8^{d}
	F=12.45, P= 0.0008	F=10.89, p= 0.0015	F=28.67, p< 0.0001	F=24.53, p< 0.0001	F=27.89, p< 0.0001	F=24.78, p< 0.0001	F=27.89, p< 0.0001	F=24.78, p< 0.0001

Simpson’s Diversity Index:

Vespa orientalis:

In both 2021-2022 and 2022-2023 seasons, the Beans plot exhibited the highest diversity, with Simpson’s Index values of 0.773 and 0.776, respectively, indicating a well-balanced distribution of individuals among the sampled months. The mixed Lupine+ Peas+ Beans and Lupine+ Clover+ Beans- displayed similarly high diversity, with index values ranging from 0.770 to 0.771 in 2021-2022 and slightly lower values of 0.762 to 0.764 in 2022-2023. The Peas+ Clover+ Beans plot consistently showed the lowest diversity among the treatments, with index values of 0.748 and 0.752 for the two seasons, though these values still reflect a relatively diverse community. Overall, the results suggest that all plots maintained robust species diversity across seasons, with only minor fluctuations, and that monoculture (Beans) and mixed cropping systems both supported high levels of diversity according to Simpson’s Index.

Apis mellifera:

In both 2021-2022 and 2022-2023 seasons, the Beans plot exhibited the highest diversity, with Simpson's Index values of 0.773 and 0.776, respectively, indicating a well-balanced distribution of individuals among the sampled months. The mixed plots-Lupine+ Peas+ Beans and Lupine+ Clover+ Beans-displayed similarly high diversity, with index values ranging from 0.770 to 0.771 in 2021-2022 and slightly lower values of 0.762 to 0.764 in 2022-2023. The Peas+ Clover+ Beans plot consistently showed the lowest diversity among the treatments, with index values of 0.748 and 0.752 for the two seasons, though these values still reflect a relatively diverse community. Overall, the results suggest that all plots maintained robust species diversity across seasons, with only minor fluctuations, and that monoculture (Beans) and mixed cropping systems both supported high levels of diversity according to Simpson's Index.

DISCUSSION

The results demonstrate that mixed-crop plots consistently support higher pollinator abundances compared to monoculture plots, reinforcing the importance of crop diversity in enhancing pollinator activity and ecosystem services. The fluctuating pattern of *V. orientalis* abundance, with peaks in late winter and early spring (December to March), is consistent with studies showing that pollinator activity is often influenced by temperature, floral resource availability, and seasonal changes in habitat suitability (Potts *et al*., 2010, Brittain *et al*., 2013). The sharp increase in *V. orientalis* numbers from December to February, followed by a decline in March and partial recovery in April, suggests that this species may be highly responsive to early-season floral resources. Similar patterns have been observed in other hornet species, where population peaks coincide with periods of high resource availability (Matsuura & Yamane, 1990). The higher peak abundance in the 2022–2023 season compared to 2021–2022 may reflect environmental changes, such as variations in temperature or rainfall, which can influence insect population dynamics (Forister *et al*., 2010).The varying trends across plots further emphasize the role of crop diversity in shaping pollinator populations. For instance, the steady increase and higher peak in Plot 1 (Lupine + Peas + Beans) during the second season suggest that this combination provides sustained resources for *V. orientalis*. In contrast, the pronounced fluctuations in Plot 2 (Lupine + Clover + Beans) and the highest peak in Plot 3 (Peas + Clover + Beans) indicate that specific crop combinations may create more favorable conditions for this species. These findings align with studies showing that diverse cropping systems support higher pollinator diversity and abundance by providing a continuous supply of floral resources (Garibaldi *et al*., 2011). The abundance of *A. mellifera* also exhibited seasonal fluctuations, with peaks occurring later than those of *V. orientalis*. This delayed peak may reflect differences in foraging behavior and resource preferences between the two species. Honeybees are known to be highly adaptable and can exploit a wide range of floral resources, but their activity is often influenced by flowering phenology and climatic conditions (Klein *et al*., 2007). The consistent peaks in March across both seasons suggest that *A. mellifera* may rely on late-winter and early-spring blooms, which are abundant in mixed-crop plots.The lower abundance of *A mellifera* in the beans-only plot compared to mixed-crop plots underscores the importance of crop diversity in supporting pollinator populations. Mixed-crop plots, particularly those including lupine, peas, and clover, provided higher and more consistent floral resources, leading to increased bee visitation. This is consistent with previous studies demonstrating that diverse cropping systems enhance pollinator abundance and pollination services (Kennedy *et al*., 2013). The shift in peak activity from April in 2021–2022 to March in 2022–2023 in some plots may reflect changes in flowering patterns or climatic conditions, highlighting the sensitivity of pollinators to environmental variability (Memmott *et al*., 2007).

The results from the control plot (beans only) further emphasize the limitations of monoculture systems in supporting pollinator populations. Both *V. orientalis* and *A mellifera* showed lower and less variable abundances in the beans-only plot compared to mixed-crop plots. This aligns with findings that monocultures often fail to provide the diverse and continuous floral resources needed to sustain pollinator populations (Tscharntke *et al*., 2005). In contrast, mixed-crop plots, particularly those combining legumes (lupine, peas, beans) and clover, consistently supported higher pollinator abundances, highlighting the benefits of crop diversification for pollinator conservation.The statistically significant monthly variations in pollinator abundance, as indicated by high F-values and low p-values, further validate the influence of seasonal and environmental factors on pollinator dynamics. These findings are consistent with studies showing that pollinator populations are highly sensitive to changes in resource availability and environmental conditions (Goulson *et al*., 2015). The higher peaks observed in the second season for both species may reflect cumulative effects of environmental changes, such as increased temperatures or altered precipitation patterns, which can influence floral resource availability and pollinator activity (Forister *et al*., 2010).

Conclusion

The observed patterns in *V. orientalis* and *A. mellifera* abundance underscore the importance of crop diversity and seasonal resource availability in shaping pollinator populations. Mixed-crop plots, particularly those combining legumes and clover, consistently supported higher pollinator abundances compared to monoculture systems, highlighting the benefits of diversified cropping systems for pollinator conservation. The seasonal fluctuations in pollinator activity further emphasize the need to consider environmental and phenological factors in pollinator management strategies. These findings align with previous literature and contribute to a growing body of evidence supporting the role of agroecological practices in enhancing pollinator diversity and ecosystem services.

Declarations:

Ethics Approval and Consent to Participate: Ethical approval for this research was obtained from the appropriate institutional committee, and all necessary permissions were secured prior to conducting fieldwork. No human participants were involved, and thus informed consent was not applicable.

Authors Contributions: I hereby verify that all authors mentioned on the title page have made substantial contributions to the conception and design of the study, have thoroughly reviewed the manuscript, confirm the accuracy and authenticity of the data and its interpretation, and consent to its submission.

Competing Interests: The authors have no competing interests to declare that are relevant to the content of this article.

Availability of Data and Materials: All datasets analysed and described during the present study are available from the corresponding author upon reasonable request.

Funding: This work has received no external funding.

Acknowledgements: The authors would like to thank the staff of the research station and laboratory team for their valuable assistance in field sampling and specimen identification. Appreciation is also extended to all colleagues who provided support throughout the study.

REFERENCES

Aizen, M.A., Harder, L.D. (2009). 'The global stock of domesticated honey bees is growing slower than agricultural demand for pollination'. *Current Biology,* 19(11): 915–918.

Aufy, M.S. (2005). *Survey and taxonomic studies on some species of family Pompilidae (Hymenoptera) in Egypt*. Master’s thesis, Fac. of Sci., Al Azhar Univ., Egypt.PP 120

Blüthgen, N., Klein, A.M. (2011). 'Functional complementarity and specialization: The role of biodiversity in plant–pollinator interactions'. *Basic and Applied Ecology*, 12(4): pp. 282–291.

Brittain, C., Williams, N., Kremen, C., Klein, A.M. (2013). 'Synergistic effects of non-Apis bees and honey bees for pollination services'. *Proceedings of the Royal Society B: Biological Sciences,* 280(1754):, 20122767. doi: 10.1098/rspb.2012.2767

Dicks, L.V. *et al*. (2016). 'Ten policies for pollinators'. *Science*, 354(6315):975–976.

Forister, M.L. *et al*. (2010). 'Compounded effects of climate change and habitat alteration shift patterns of butterfly diversity'. *Proceedings of the National Academy of Sciences,* 107(5): 2088–2092.

Gallai, N., Salles, J.M., Settele, J., Vaissière, B.E. (2009). 'Economic valuation of the vulnerability of world agriculture confronted with pollinator decline'. *Ecological Economics*, 68(3): 810–821.

Garibaldi, L.A. *et al*. (2011). 'Stability of pollination services decreases with isolation from natural areas despite honey bee visits'. *Ecology Letters*, 14(10): 1062–1072.

Garibaldi, L.A. *et al*. (2013). 'Wild pollinators enhance fruit set of crops regardless of honey bee abundance'. *Science*, 339(6127): 1608–1611.

Goulson, D., Nicholls, E., Botías, C., Rotheray, E.L. (2015). 'Bee declines driven by combined stress from parasites, pesticides, and lack of flowers'. *Science*, 347(6229): 1255957.

Greenleaf, S.S., Kremen, C. (2006). 'Wild bees enhance honey bees’ pollination of hybrid sunflower'. *Proceedings of the National Academy of Sciences*, 103(37):13890–13895.

Kennedy, C.M. *et al*. (2013). 'A global quantitative synthesis of local and landscape effects on wild bee pollinators in agroecosystems'. *Ecology Letters*, 16(5): 584–599.

Klatt, B.K. *et al*. (2014). 'Bee pollination improves crop quality, shelf life and commercial value'. *Proceedings of the Royal Society B: Biological Sciences*, 281(1775): 20132440.

Klein, A.M. *et al*. (2007). 'Importance of pollinators in changing landscapes for world crops'. *Proceedings of the Royal Society B: Biological Sciences*, 274(1608): 303–313.

Kremen, C., Williams, N.M., Thorp, R.W. (2002). 'Crop pollination from native bees at risk from agricultural intensification'. *Proceedings of the National Academy of Sciences*, 99(26): 16812–16816.

Matsuura, M., Yamane, S. (1990). *Biology of the Vespine Wasps*. Springer-Verlag.

McCravy, K.W. (2018). 'A review of sampling and monitoring methods for beneficial arthropods in agroecosystems'. *Insects*, 9(4), 170:

Memmott, J., Craze, P.G., Waser, N.M., Price, M.V. (2007). 'Global warming and the disruption of plant-pollinator interactions'. *Ecology Letters*, 10(8): 710–717.

Potts, S.G. *et al*. (2010). 'Global pollinator declines: Trends, impacts and drivers'. *Trends in Ecology & Evolution*, 25(6): 345–353.

Ricketts, T.H. *et al*. (2008). 'Landscape effects on crop pollination services: Are there general patterns?'. *Ecology Letters*, 11(5): 499–515.

Scheper, J. *et al*. (2013). 'Environmental factors driving the effectiveness of European agri-environmental measures in mitigating pollinator loss a meta-analysis'. *Ecology Letters*, 16(7): 912–920.

Souther, S.K. *et al*. (2024). 'Bee and butterfly records indicate diversity losses in western and southern North America, but extensive knowledge gaps remain'. *PLoS ONE*, 19(5), e0289742.

Sydenham, M.A. *et al*. (2024). 'Climatic conditions and landscape diversity predict plant–bee interactions and pollen deposition in bee-pollinated plants'. *Ecography*, 2024(9): e07138.

Sydenham, M.A. *et al*. (2022a). 'Priority maps for pollinator habitat enhancement schemes in semi-natural grasslands'. *Landscape and Urban Planning*, 220, 104354.

Sydenham, M.A. *et al*. (2023). 'The contributions of flower strips to wild bee conservation in agricultural landscapes can be predicted using pollinator habitat suitability models'. *Ecological Solutions and Evidence*, 4(4): e12283.

Sydenham, M.A. *et al*. (2022b). 'Neutral processes related to regional bee commonness and dispersal distances are important predictors of plant–pollinator networks along gradients of climate and landscape conditions'. *Ecography*, 2022(12): e06379.

Sydenham, M.A. *et al*. (2022c). 'MetaComNet: a random forest-based framework for making spatial predictions of plant–pollinator interactions'. *Methods in Ecology and Evolution*, 13(2): 500–513.

Tobajas, E. *et al*. (2024). 'Pollinator asynchrony drives the temporal stability of flower visitation rates, but not of plant reproductive success'. *Journal of Ecology*, 112(1): 4–13.

Torvanger, M.S. *et al*. (2025). 'The distribution of wild bee species along a latitudinal gradient in Northern Europe depends on their flower preferences'. *Diversity and Distributions*, 31(2): e70001.