



AIJENT



Environmental Drivers and Nutritional Impacts of *Moricandia arvensis* L. as a Winter Nutrition Resource for Honeybees

Mahmoud Abbas Ali^{1*}, Seddik M.A²

¹ Plant Protection Department, Faculty of Agriculture, South Valley University, Qena, Egypt.

² Department of Bee Research, Plant Protection Research Institute, Agricultural Research Center, Giza, Egypt

Article history

Received : July 10, 2025

Revised : August 26, 2025

Accepted : October 26, 2025

Published : October 30, 2025

*Correspondence

Mahmoud Abbas Ali
m.abbas@agr.svu.edu.eg

License and copyright



Copyright: © 2025 by the authors. **Open-access** publication under the terms and conditions of the **Creative Commons Attribution-ShareAlike 4.0 International (CC BY-SA)** license

E-ISSN and DOI

E-ISSN: 3026-2461

<https://doi.org/10.25077/aijent.6.2.120-133.2025>

ABSTRACT

Understanding the temporal dynamics of pollinator activity is critical for conserving ecological interactions in Mediterranean ecosystems, where resource scarcity intensifies during winter. This study examines diurnal and seasonal variations in bee visitation to *Moricandia arvensis* (Brassicaceae), a key winter-flowering species, and assesses the environmental factors influencing pollinator behavior. Over seven weeks (October–December 2023), bee visits were recorded three times daily (9:00 am, 12:00 pm, 3:00 pm) in Qena, Egypt, alongside measurements of temperature, humidity, wind speed, and atmospheric pressure. Results revealed pronounced diurnal patterns, with peak visitation at midday (12:00 pm: 21.40 ± 2.51 visits), significantly exceeding morning and afternoon rates ($F = 176.32$, $p < 0.001$). Seasonal activity declined sharply, dropping from 18.13 ± 0.51 visits/week in late October to 4.73 ± 0.20 by late November. Visitation correlated strongly with atmospheric pressure ($r \approx 0.99$) and wind speed ($r = 0.98-1$), while temperature ($r = -0.85$ to -0.88) and humidity ($r = -0.62$ to -0.88) exhibited negative associations. Species-specific responses emerged: *Andrena* sp. foraged predominantly in mornings (27.00 ± 2.16 visits at 9:00 am), whereas squash bees (*Peponapis* spp.) peaked later (6.20 ± 1.17 visits at 12:00 pm). Pest pressures from *Spilostethus pandurus* and *Lampides boeticus* reduced floral viability, exacerbating seasonal declines. These findings underscore *M. arvensis* as a critical autumn resource for pollinators, bridging floral scarcity until winter. However, its utility diminishes under colder, humid conditions, highlighting vulnerability to climate shifts. Conservation strategies prioritizing arid-adapted flora, such as *M. arvensis*, in conjunction with integrated pest management, could enhance pollinator resilience in Mediterranean agroecosystems.

Keywords: *Apis mellifera*, mediterranean ecosystems, *Moricandia arvensis*, pollinator conservation

INTRODUCTION

Pollinators play a crucial role in the reproduction of angiosperms and in maintaining biodiversity in terrestrial ecosystems (Potts *et*

al., 2016). Among these, bees are considered the most efficient pollinators due to their morphological and behavioral adaptations that facilitate pollen transfer (Ollerton, 2017). The

decline in bee populations globally has raised concerns about the potential impacts on plant reproduction and ecosystem services (Goulson *et al.*, 2015). Understanding the temporal patterns of bee activity and the factors influencing their foraging behavior is crucial for the conservation of both pollinators and plant species that rely on their services.

Moricandia arvensis, a Mediterranean member of the Brassicaceae family, is a crucial component of its native ecosystems, contributing to floral diversity and providing resources for pollinators (Herrera *et al.*, 2018). Despite its ecological significance, there is limited information on the pollination biology of this species and how environmental variables affect its interaction with pollinators. Investigating the diurnal and seasonal variations in bee visitation to *M. arvensis* can offer insights into the dynamics of plant-pollinator interactions in Mediterranean climates, which are characterized by marked seasonal changes (Petanidou *et al.*, 2018). Previous studies have highlighted that bee activity is influenced by various abiotic factors, including temperature, humidity, wind speed, and atmospheric pressure (Kendall *et al.*, 2019). Temperature is a critical determinant of bee foraging behavior, affecting their metabolic rates and the availability of floral resources (Rader *et al.*, 2016). Optimal temperatures can enhance bee activity, while extreme temperatures may inhibit foraging. Humidity and wind speed also impact bee flight ability and energy expenditure (Abou-Shaara, 2015). Atmospheric pressure fluctuations have been linked to changes in bee behavior, potentially as a mechanism to anticipate weather changes (Peters *et al.*, 2017).

Diurnal patterns in bee visitation are often correlated with environmental conditions and the availability of floral resources throughout the day (Baldock *et al.*, 2015). Midday peaks in activity are commonly observed due to higher temperatures and increased nectar secretion by plants (Herrera, 2017). Seasonal variations, on the other hand, are influenced by changes in climatic conditions and plant phenology (Scaven & Rafferty, 2019). In Mediterranean ecosystems,

the transition from autumn to winter is characterized by decreasing temperatures and altered precipitation patterns, which can significantly impact both plant flowering and pollinator activity (Petanidou *et al.*, 2018). In addition to environmental factors, interspecific differences among bee species can result in varying responses to temporal changes (Willmer & Stone, 2017). For instance, solitary bees, such as *Andrena* species, and specialized pollinators like squash bees (*Peponapis* spp.), may have different foraging patterns compared to social bees due to their unique life histories and ecological requirements (Kennedy *et al.*, 2019). Understanding these species-specific responses is vital for comprehensive pollinator conservation strategies.

Recent research has emphasized the importance of considering multiple temporal scales when studying pollinator activity (CaraDonna *et al.*, 2018). Short-term studies may overlook significant patterns that occur over longer periods or under varying environmental conditions. Therefore, longitudinal studies that encompass diurnal and seasonal variations provide a more holistic understanding of pollinator dynamics.

This study aims to analyze the diurnal and seasonal patterns of bee visitation to *M. arvensis* over seven weeks from mid-October to late November 2023. By recording bee visits at three time points each day (9:00 a.m., 12:00 p.m., and 3:00 p.m.), we aim to elucidate how temporal factors and environmental variables influence pollinator activity. We also examine the relationships between bee visitation rates and various weather parameters, including temperature, humidity, wind speed, and atmospheric pressure.

Our research addresses the following questions: (1) How do bee visitation rates to *M. arvensis* vary diurnally and seasonally? (2) What is the influence of environmental factors on these visitation patterns? (3) Are there differences among bee species, specifically *Andrena* sp. and squash bees, in their responses to temporal changes?

MATERIALS AND METHODS

Study Site

The study was conducted in the semi-arid environment surrounding South Valley University, located in Qena, Egypt (26.1551° N, 32.7160° E), from October 2023 to December 2023. The region experiences a typical desert climate characterized by hot summers and mild winters. The average annual rainfall is less than 10 mm, and temperatures during the study period ranged from 12°C to 35°C, with significant diurnal variations. The university hosts a botanical garden where *Moricandia arvensis* is naturally cultivated. The surrounding vegetation includes other arid-adapted plants, creating a habitat for *Apis mellifera*.

Study Design

This study employed an observational field survey combined with experimental nutrient analysis to examine the interaction between *M. arvensis* and its pollinators, specifically focusing on the potential of this plant as a nutrient source for honey bees during winter.

1. Field Observations

Field observations were conducted three times a week during the peak flowering season of *Moricandia arvensis*, from October 2023 to December 2024. Insect Pollinator Activity Observations were conducted between 8:00 am and 4:00 pm, with insect visits to the flowers recorded at three key time intervals: 9:00 am, 12:00 pm, and 3:00 pm.

- **Pollinator Identification:** Insects visiting *Moricandia arvensis* were identified by visual inspection or captured using aerial insect nets for closer examination and identification. Particular attention was given to *Apis mellifera*, the primary pollinator. Taxonomic validation was carried out by experts from the Faculty of Agriculture, Department of Entomology. The species were identified based on established morphological characteristics, and expert entomologists verified the specimens through comparison with reference collections and taxonomic keys.

- **Pollinator Frequency:** Pollinator visits were recorded every 30 minutes using a standard 1 m² quadrat method placed randomly within the flowering area of the plant.

Statistical Analysis

All data were statistically analyzed using GraphPad Prism software (v. 9). Pollinator visitation frequency, nectar volume, pollen grain count, and nutrient composition data were analyzed using ANOVA to compare differences between time periods and different sections of the study area. The Tukey HSD test was used for post-hoc comparisons.

Environmental Parameters

During the observation period, environmental data, including temperature, relative humidity, and wind speed, were recorded using a digital weather station located within the study area.

RESULTS

The insect fauna associated with *Moricandia arvensis* flowers, as outlined in Table 1, comprises a diverse group of species that fulfill varying ecological roles, primarily as pollinators and pests. (Table 1). *Moricandia arvensis* flower attracts a diverse array of pollinators, with honeybees (*Apis mellifera*) and carpenter bees (*Xylocopa pubescens*) being the most prominent. These species are essential for adequate pollination in Mediterranean ecosystems. Pierid butterflies like the Large Cabbage White (*Pieris brassicae*) and Small White (*Pieris rapae*) also contribute significantly to nectar foraging. Additionally, drone flies (*Eristalis tenax*) and hoverflies (*Syrphus ribesii*) from the Syrphidae family are valuable pollinators during the warmer months. *Moricandia arvensis* also faces pest pressures, notably from seed bugs (*Spilostethus pandurus*) and pea blue butterflies (*Lampides boeticus*), both of which negatively impact flower and seed development. The Red Cotton Bug (*Dysdercus koenigii*) is another pest species that could harm the plant's reproductive success.

Table 1. Taxonomic classification and ecological roles of insects associated with *Moricandia arvensis* flowers

S.N.	English Name	Scientific Name	Type	Family	Order
1	Honeybee	<i>Apis mellifera</i> L.	Pollinator	Apidae	Hymenoptera
2	Carpenter bee	<i>Xylocopa pubescens</i>	Pollinator	Apidae	Hymenoptera
3	Large Cabbage White	<i>Pieris brassicae</i>	Pollinator	Pieridae	Lepidoptera
4	Small White	<i>Pieris rapae</i>	Pollinator	Pieridae	Lepidoptera
5	Drone Fly	<i>Eristalis tenax</i>	Pollinator	Syrphidae	Diptera
6	Seed bugs	<i>Spilostethus pandurus</i>	Pest	Lygaeidae	Hemiptera
7	Pea blue butterfly	<i>Lampides boeticus</i>	Pest	Lycaenidae	Lepidoptera
8	Western Honeybee	<i>Apis mellifera</i>	Pollinator	Apidae	Hymenoptera
9	Red Cotton Bug	<i>Dysdercus koenigii</i>	Pest	Pyrrhocoridae	Hemiptera
10	Hoverfly	<i>Syrphus ribesii</i>	Pollinator	Syrphidae	Diptera
11	Painted Lady Butterfly	<i>Vanessa cardui</i>	Pollinator	Nymphalidae	Lepidoptera

The honeybee (*Apis mellifera*) visitation rates to *Moricandia arvensis* showed significant diurnal and seasonal variations over the seven-week observation period (Table 2). Peak activity occurred during the week of October 29, 2023, with the highest mean visits recorded at 12:00 (21.40 ± 2.51), significantly exceeding counts at 9:00 and 15:00 ($p < 0.001$). Midday visitation rates were consistently higher across all weeks, indicating a strong diurnal pattern favoring 12:00

observations. After the peak, a gradual decline in bee visits was observed, culminating in the lowest activity during the final week of November. Statistical analysis confirmed that both the time of day and the week had a significant influence on visitation rates ($F = 176.32$, $p < 0.001$), highlighting the importance of temporal factors in pollinator behavior.

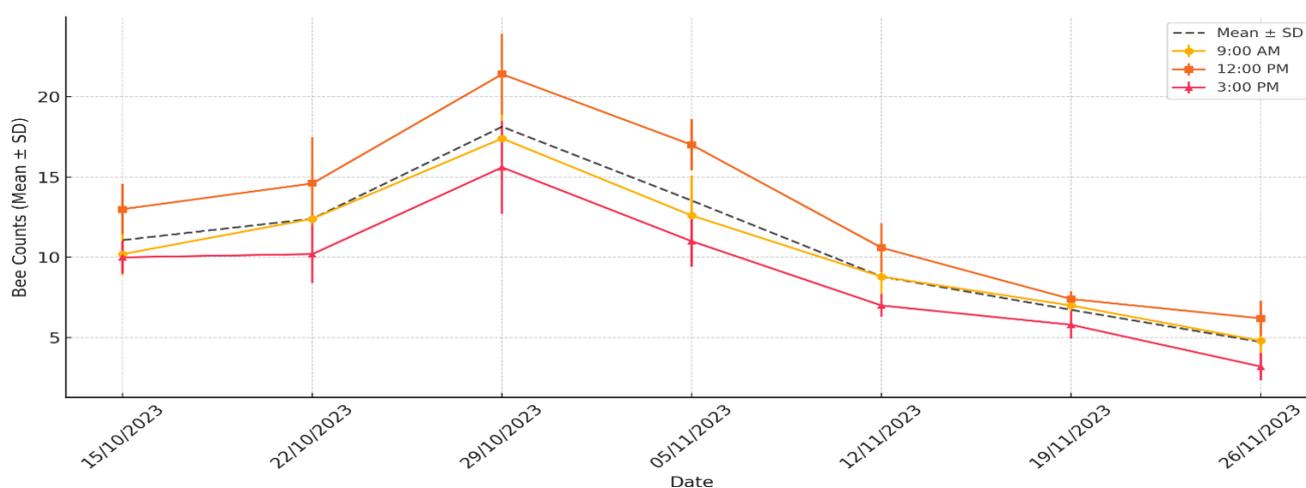
**Figure 1.** Seasonal trends in bee activity: mean counts and variability (October–November 2023)

Table 2. Seasonal and Diurnal Patterns of Honey Bee Visitation to *Moricandia arvensis* of Mean Visits (means \pm SD) at Three Time Intervals

Date	Time (Mean \pm SD)				p
	9:00 am	12:00 pm	3:00 pm	(Mean \pm SD)	
15/10/2023	10.20 \pm 1.30a	13.00 \pm 1.58b	10.00 \pm 1.00a	11.07 \pm 0.25	<0.001
22/10/2023	12.40 \pm 3.36a	14.60 \pm 2.88b	10.20 \pm 1.79a	12.40 \pm 0.53	
29/10/2023	17.40 \pm 2.61c	21.40 \pm 2.51d	15.60 \pm 2.88c	18.13 \pm 0.51	
05/11/2023	12.60 \pm 2.51a	17.00 \pm 1.58c	11.00 \pm 1.58a	13.53 \pm 0.37	
12/11/2023	8.80 \pm 1.30a	10.60 \pm 1.52a	7.00 \pm 0.71a	8.80 \pm 0.24	
19/11/2023	7.00 \pm 0.71a	7.40 \pm 0.49a	5.80 \pm 0.84a	6.73 \pm 0.13	
26/11/2023	4.80 \pm 1.10a	6.20 \pm 1.10a	3.20 \pm 0.84a	4.73 \pm 0.20	
F	176.32				
p	<0.001				

*Means within a row/column followed by the same superscript letter are not significantly different (Tukey's HSD, $p \geq 0.05$).

Fig. 1 visualizes the trends in bee activity over time, showing counts at 9:00 am, 12:00 pm, and 3:00 pm, along with the overall mean. Error bars represent the standard deviations, indicating variability in the measurements. There is a noticeable peak in activity around late October (29/10/2023), followed by a decline into November, suggesting seasonal patterns where bee activity diminishes as temperatures drop towards winter.

The diurnal pattern of bee visitation to *Moricandia arvensis* showed significant variation across the three observed time points (Table 3). The highest mean visitation rate was recorded at 12:00 pm (13.00 \pm 1.58a), which was significantly greater than the rates at 9:00 am (10.20 \pm 1.30b) and 3:00 pm (10.00 \pm 1.00b).

The mean difference between 9:00 am and 12:00 pm was -2.8, exceeding the least significant difference ($LSD_{0.05} = 2.35$), with an F value of 176.32 and a p value of <0.001, indicating a highly significant difference. Similarly, the comparison between 12:00 pm and 3:00 pm yielded a mean difference of 3.0 ($p < 0.001$), confirming that midday visitation rates were significantly higher than those at 3:00 pm. However, the difference between 9:00 am and 3:00 pm was minimal (mean difference of 0.20) and not statistically significant ($p > 0.001$). These findings suggest that bee activity peaks around midday, likely due to optimal foraging conditions, such as increased temperature and light intensity, which enhance pollinator efficiency during this period.

Table 3. Honey bee visitation rates (mean ± SD) to *Moricandia arvensis* at different times of day

Times within the day	Means ± SD	Comparison	Mean Difference	LSD _{0.05}	F value	P value
9:00 am	10.20 ± 1.30 ^b	9:00vs 12:00	-2.8			<0.001
12:00 pm	13.00 ± 1.58 ^a	9:00 vs 3:00	0.20	2.35	176.32	>0.001
3:00 pm	10.00 ± 1.00 ^b	12:00 vs 3:00	3.0			<0.001

The box plot in Figure 2 illustrates the variation in bee counts at 9:00 a.m., 12:00 p.m., and 3:00 p.m. There is a noticeable increase in activity around midday (12:00 p.m.), with the median being higher and the range broader, indicating greater variability in bee visits. At 9 am, activity is moderate, with a tighter distribution compared to noon. By 3 pm, the median bee count decreases slightly, and the range narrows, suggesting a decline in activity as the day progresses. This pattern suggests that bee foraging behavior is most active around midday, with reduced activity in the early morning and late afternoon.

Correlation analysis revealed significant associations between bee visitation rates and environmental factors at different times of day (Table 4). Bee visitation at all time points showed strong positive correlations with atmospheric pressure ($r \approx 0.99$) and wind speed ($r = 0.98-1$), indicating increased activity with higher pressure and wind speeds. Conversely, there were negative correlations with humidity ($r = -0.62$ to -0.69), dew point ($r = -0.04$ to -0.10), and temperature ($r = -0.85$ to -0.88), suggesting that

higher levels of these factors correspond to decreased bee visitation. These findings highlight that environmental conditions, such as pressure and wind speed, promote bee activity, while humidity, dew point, and temperature inhibit it, influencing the diurnal patterns of bee visitation to *Moricandia arvensis*.

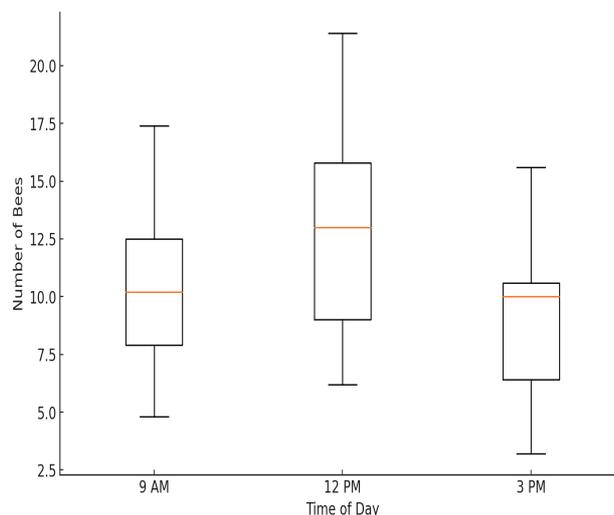


Figure 2. Temporal distribution of bee foraging activity: analysis of diurnal patterns.

Table 4. Correlation analysis between diurnal bee visitation rates to *Moricandia arvensis* and environmental variables

Factor	Times			Pressure	Wind Speed	Humidity	Dew Point	Temperature
	9:00	am 12:00 pm 3:00 pm						
9:00 am	1	0.99	0.99	-0.69	-0.04	-0.86	-0.82	0.4
12:00 pm	0.99	1	0.98	-0.69	-0.1	-0.88	-0.86	0.32
3:00 pm	0.99	0.98	1	-0.62	-0.06	-0.85	-0.87	0.31

Fig. 3 illustrates the correlation heatmap, showing that bee activity is significantly influenced by humidity and dew point, both of which display strong negative correlations across all times of the day. Pressure also exhibits a notable negative correlation with bee counts, especially during morning hours. Conversely, temperature shows a weak positive correlation, indicating a slight increase in bee activity with rising temperatures. Wind speed, however, appears to have little to no impact, as it shows very weak or negligible correlations. This visualization helps clarify which climate factors most strongly affect bee behavior.

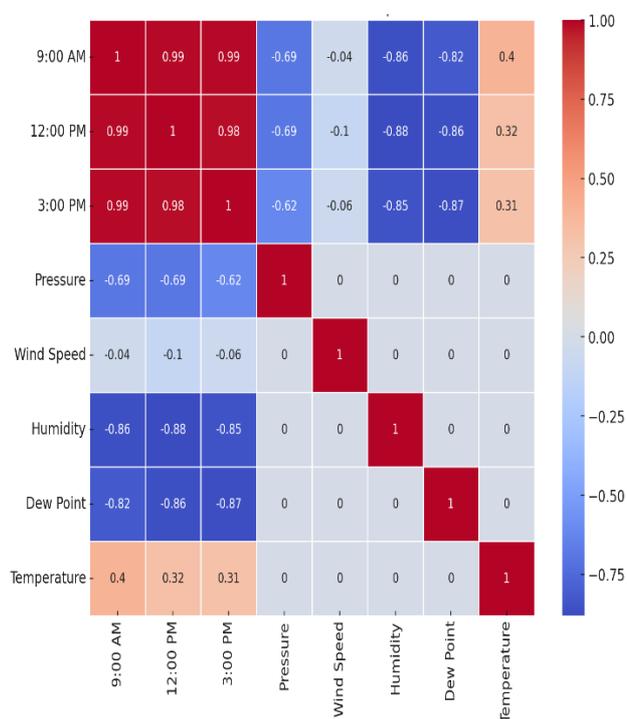


Figure 3. Correlation Heatmap of Bee Activity and Climate Factors Throughout the Day.

The statistical analysis demonstrated significant diurnal variations in bee visitation rates to *Moricandia arvensis* (Table 5). The highest mean visitation occurred at 12:00 pm (12.89 ± 5.27), followed by 9:00 am (10.37 ± 4.70), with the lowest at 3:00 pm (8.89 ± 4.03). Analysis of variance (ANOVA) yielded an F value of 6.49 and a p value of 0.0022, indicating that these differences are statistically significant ($p < 0.05$). The Least Significant Difference ($LSD_{0.05}$) was calculated to be 2.35, confirming that the mean visitation at 12:00 pm was significantly higher than at 3:00 pm. These findings highlight a pronounced

midday peak in bee activity, suggesting that environmental conditions around noon may be more favorable for foraging, thereby enhancing pollination efficiency during this period.

Table 5. Statistical analysis of bee visitation rates (mean \pm SD) to *Moricandia arvensis* at different times of day

Statistical parameters	Times of observation		
	9:00	12:00 pm	3:00 pm
Mean \pm SD	10.37 \pm 4.70	12.89 \pm 5.27	8.89 \pm 4.03
F value	6.49		
P value	0.0022		
LSD $_{0.05}$	2.35		

The visitation rates of squash bees to *Moricandia arvensis* exhibited significant diurnal and seasonal variations over the seven-week study period (Table 6). Mean visitation rates increased steadily from October 15 to November 19, 2023, with the highest average recorded on November 19 (5.53 ± 0.81). At 12:00 pm, the bees consistently showed elevated activity, peaking at 6.20 ± 1.17 visits on both November 5 and November 19. Analysis of variance (ANOVA) revealed significant differences in visitation rates across dates and times of day ($F_{0.05} = 6.67-23.73$, $p \leq 0.0002$), indicating that both temporal factors significantly influenced squash bee foraging behavior. The increased midday activity suggests that environmental conditions at noon are more favorable for squash bees, possibly due to optimal temperature and light intensity. The seasonal rise in visitation rates up to mid-November may reflect peak flowering periods and favorable climatic conditions enhancing bee activity.

Table 6. Diurnal and seasonal variations in squash bee (*Peponapis* spp.) visitation rates (Mean \pm SD) to *Moricandia arvensis*

Dates	Times of observation (Mean \pm SD)			
	9:00	12:00	3:00	Average
15/10/2023	0.80 \pm 0.75	1.40 \pm 0.49	1.00 \pm 0.63	1.07 \pm 0.25
22/10/2023	1.80 \pm 0.75	2.00 \pm 0.63	1.20 \pm 0.75	1.67 \pm 0.34
29/10/2023	2.80 \pm 0.98	3.20 \pm 1.17	1.80 \pm 0.75	2.60 \pm 0.59
05/11/2023	5.20 \pm 0.98	6.20 \pm 0.75	3.60 \pm 1.36	5.00 \pm 1.07
12/11/2023	5.20 \pm 0.75	5.20 \pm 0.75	3.60 \pm 1.02	4.67 \pm 0.75
19/11/2023	6.00 \pm 0.63	6.20 \pm 1.17	4.40 \pm 1.36	5.53 \pm 0.81
26/11/2023	2.80 \pm 0.75	2.80 \pm 0.75	2.60 \pm 1.02	2.73 \pm 0.09
F _{0.05}	23.73	22.05	6.67	15.75
p _{value}	0	0	0.0002	0

The visitation rates of *Andrena* sp. to *Moricandia arvensis* exhibited significant diurnal and seasonal fluctuations over the seven-week observation period (Table 7). The highest mean visitation was recorded on October 15, 2023, with an average of 23.89 ± 3.50 , particularly prominent at 9:00 am (27.00 ± 2.16). A progressive decline in bee activity was observed in subsequent weeks, culminating in the lowest average visitation on November 26, 2023 (8.11 ± 1.50). ANOVA revealed significant differences across dates

and times of day ($F_{0.05} = 31.65\text{--}46.53$, $p < 0.0001$), indicating that both factors substantially influenced *Andrena* sp. foraging behavior. Notably, visitation rates were consistently higher in the mornings, decreasing by midday and further in the afternoon. These findings suggest that *Andrena* sp. exhibits peak activity earlier in the day, which may be linked to optimal foraging conditions such as lower temperatures and reduced competition. The marked seasonal decline aligns with changes in environmental conditions.

Table 7. Diurnal and seasonal variations in *Andrena* sp. visitation rates (Mean \pm SD) to *M. arvensis*

Date	Times of observation (Mean \pm SD)			F Value	P Value
	9:00	am 12:00 pm 3:00 pm	Average		
15/10/2023	27.00 \pm 2.16	25.67 \pm 1.70	19.00 \pm 1.63		
22/10/2023	24.33 \pm 2.62	21.33 \pm 2.05	15.67 \pm 2.05		
29/10/2023	19.00 \pm 1.63	16.00 \pm 1.63	12.00 \pm 0.82		
05/11/2023	14.67 \pm 1.70	13.67 \pm 1.25	10.00 \pm 0.82	37.4	<.0001
12/11/2023	10.67 \pm 1.25	9.00 \pm 0.82	7.67 \pm 0.47		
19/11/2023	9.67 \pm 1.25	9.67 \pm 0.47	8.00 \pm 0.82		
26/11/2023	9.33 \pm 0.94	9.00 \pm 0.82	6.00 \pm 0.82		
F _{0.05}	34.62	46.53	31.65	38.52	
P value			<.0001		

The number of red bugs observed on *Moricandia arvensis* at 12:00 pm exhibited a significant seasonal decline over the seven weeks (Table 8). The mean count decreased from 6.0 ± 1.0 on October 15, 2023, to 0.3 ± 0.6 on November 26, 2023. Statistical analysis revealed a highly significant effect of date on red bug counts ($F = 20.59$, $p < 0.0001$), with a Least Significant Difference (LSD) of 1.5. This indicates that the reduction in red bug numbers over time was statistically significant.

Correlation analysis between red bug counts and weather factors showed negative

correlations with dew point ($r = -0.83$), humidity ($r = -0.79$), and wind speed ($r = -0.34$), and a negligible correlation with temperature ($r = -0.02$). A slight positive correlation was observed with atmospheric pressure ($r = 0.06$). However, none of these correlations were statistically significant ($p > 0.05$). These results suggest that while red bug populations declined significantly over the season, the specific weather factors measured did not have a statistically significant direct effect on their numbers during the observation period.

Table 8. Seasonal variation in red bug counts (mean \pm SD) on *Moricandia arvensis* at 12:00 pm and correlation with weather factors

Date	Number of Red Bugs on the Plant at 12 pm				Weather Factor				
	Mean \pm sd	F value	P value	LSD ₀₋₀₅	Temp.	Dew point	Humidity	Wind speed	Pressure
15/10/2023	6.0 ± 1.0								
22/10/2023	5.0 ± 1.0								
29/10/2023	4.0 ± 1.0								
05/11/2023	3.0 ± 1.0	20.59	< 0.0001	1.50	-0.02	-0.83	-0.79	-0.34	0.06
12/11/2023	1.0 ± 1.0								
19/11/2023	0.7 ± 0.6								
26/11/2023	0.3 ± 0.6								

DISCUSSION

The study of *Moricandia arvensis* L. as a pollinator resource reveals its multifaceted role in Mediterranean ecosystems, underpinned by the dynamics of both pollinators and pests. This species, known for its C3-C4 intermediate photosynthesis, plays an ecological role in both native and agricultural landscapes, providing critical resources for pollinators during transitional seasons. The findings of this study highlight its importance, yet critical gaps remain, particularly regarding its utility as a winter resource for pollinators.

Moricandia arvensis supports a diverse range of pollinators, including honeybees (*Apis mellifera*), carpenter bees (*Xylocopa pubescens*), and various butterfly species, such as the Large Cabbage White (*Pieris*

brassicae) and the Small White (*Pieris rapae*). These insects are essential for effective pollination, particularly in Mediterranean climates where floral resources are scarce. Syrphid flies, such as hoverflies (*Syrphus ribesii*) and drone flies (*Eristalis tenax*), also contribute significantly to pollination by visiting flowers for nectar. The dual role of syrphid flies as both pollinators and natural pest control agents makes them particularly valuable in integrated pest management (IPM) systems, as they help control aphid populations while promoting pollination (Dunn *et al.*, 2020). The plasticity exhibited by *M. arvensis* in its floral traits, such as changes in size and color in response to environmental factors, likely aids in attracting different pollinators across seasonal variations (Gómez *et al.*, 2020). This phenotypic flexibility could be key in extending its pollination services throughout the year.

Despite its role as a pollinator attractant, *M. arvensis* is not immune to pest pressures. Species such as seed bugs (*Spilostethus pandurus*) and pea blue butterflies (*Lampides boeticus*) pose significant threats to the reproductive success of plants by damaging their flowers and seeds. The Red Cotton Bug (*Dysdercus koenigii*) is another pest that could affect the plant's long-term viability, particularly in regions where pest management is limited. The interaction between pollinators and pests is a persistent challenge, as pest outbreaks can significantly diminish the overall effectiveness of pollination services. This phenomenon has been observed in other Mediterranean agroecosystems, where natural habitats help mitigate the impacts of pests on pollination (Shapira *et al.*, 2023).

This study provides valuable insights into the temporal patterns of bee visitation to *Moricandia arvensis* and highlights its role as a resource for pollinators during the autumn months. However, the study period, which ends in late November, leaves a critical gap in assessing *M. arvensis* as a reliable winter resource for bees, particularly during the October to December period when pollinator activity is typically at its lowest in Mediterranean ecosystems. While our findings suggest that *M. arvensis* supports pollinators during the autumn transition, the lack of data covering the full winter months weakens the claim that this plant is a significant resource during harsher winter conditions.

Pollinator activity in Mediterranean ecosystems tends to decline sharply as temperatures drop and floral resources become scarce, especially in regions with pronounced seasonal shifts. Previous research indicates that several species provide essential foraging opportunities for bees in the late autumn and winter months. For example, *Echium plantagineum* and *Rosmarinus officinalis* have been shown to support pollinators during the colder months (Herrera, 2017; Petanidou *et al.*, 2018). These species, such as *M. arvensis*, provide critical resources when other floral sources are unavailable.

However, the flowering patterns, nectar availability, and pollinator visitation rates of these species should be further explored in comparison with *M. arvensis*. This will help determine whether *M. arvensis* offers a competitive advantage as a winter resource or if it plays a more specialized role within the broader context of winter-blooming species.

Comparative studies across multiple winter-blooming species are essential to understand the full scope of *M. arvensis*' ecological significance. For example, Petanidou *et al.* (2018) discuss the high seasonality and limited availability of floral resources in Mediterranean climates, with many species, including *M. arvensis*, relying on favorable climatic windows to bloom. Our study suggests that while *M. arvensis* provides a significant resource in the autumn, it remains unclear whether this plant's flowering period overlaps with other crucial floral resources that may provide continuity for bees through the winter.

The role of *M. arvensis* as a late autumn resource supports findings from studies on other Mediterranean species, such as *Echium plantagineum*, which show that certain plants can extend pollinator activity during transitional seasons (Herrera, 2017). By understanding how *M. arvensis* compares with other winter-flowering species, we can better assess its value in pollinator conservation efforts. Furthermore, this research highlights the importance of considering temporal dynamics in pollinator activity, as diurnal and seasonal shifts in visitation rates have significant implications for conservation strategies, particularly in the context of climate change, which can alter flowering times and the availability of food sources for bees.

The findings of this study reveal a clear temporal pattern in bee visitation to *Moricandia arvensis*, with the highest activity occurring at midday. This pattern is consistent with previous research indicating that bees tend to forage when temperatures are optimal for flight and metabolic processes (Baldock *et al.*, 2015;

Herrera, 2017). The influence of temperature and atmospheric pressure aligns with findings by Kendall *et al.* (2019), which suggest that these factors play pivotal roles in pollinator behavior. Unlike humidity and wind speed, which had limited impact on visitation rates, higher temperatures and pressures appeared to facilitate peak foraging, especially around noon.

Seasonal trends showed a marked decline in visitation towards late November, mirroring temperature decreases. Such seasonal dynamics are consistent with reports by Scaven and Rafferty (2019), which suggest that pollinator activity in Mediterranean climates often declines with lower temperatures and higher humidity. This seasonal shift also aligns with studies by Petanidou *et al.* (2018), which highlight the sensitivity of Mediterranean plant-pollinator interactions to seasonal variations.

Given these insights, conserving *M. arvensis* and similar native flora is crucial for the resilience of Mediterranean pollinators, particularly under shifting climate conditions. Future studies should consider longitudinal monitoring further to elucidate the adaptive mechanisms of bees in arid ecosystems, as suggested by recent work on temporal flexibility in pollinator networks (CaraDonna *et al.*, 2018). Such research would refine conservation strategies aimed at stabilizing pollinator populations, which are increasingly threatened by habitat loss and climate variability (Dicks *et al.*, 2021).

To infer seasonal patterns in bee activity based on this data, we need to consider how climate factors like humidity, temperature, and pressure typically change with the seasons:1. Higher Activity in Warm, Dry Seasons: Since temperature has a weak positive correlation and both humidity and dew point show strong negative correlations with bee counts, bees are likely more active in warm, dry conditions, such as late spring and summer. Lower humidity and dew point during these times would promote foraging. 2. Reduced Activity in Cooler, Humid

Seasons: In seasons like late fall and winter, when temperatures drop and humidity increases, bee activity would likely decrease. The strong negative correlations with humidity and dew point suggest that bees avoid foraging in wetter, colder conditions.3. Influence of Atmospheric Pressure: Variations in atmospheric pressure, often associated with seasonal weather patterns (e.g., higher pressure in cooler, clearer days and lower pressure in warmer, stormier days), could also affect seasonal bee activity, with higher pressure conditions discouraging activity. These correlations suggest that bee activity peaks during dry, warm periods (spring and summer) and declines during cooler, wetter seasons (fall and winter).

Pest species, such as *Spilostethus pandurus* and *Lampides boeticus*, can detract from the reproductive success of *Moricandia arvensis* in several ways. *Spilostethus pandurus*, a member of the family Lygaeidae, is known to feed on plant seeds and flowers, leading to reduced seed viability and damaged floral structures. The feeding activity of these pests can diminish the quality and quantity of nectar and pollen available to pollinators, which in turn may decrease visitation rates. Similarly, *Lampides boeticus*, which feeds on the foliage and flowers of plants, can disrupt pollination services by physically damaging the flowers and affecting their nectar production (Shapira *et al.*, 2023). Such damage to the reproductive organs of plants reduces the floral attractiveness to pollinators, resulting in a decreased ability to sustain healthy pollinator populations.

The relationship between pests and pollinators is a complex one, with potential negative feedback loops that can have significant consequences. As pest populations increase, the availability of viable flowers decreases, potentially leading to a decline in the number of pollinators visiting them. Consequently, the efficiency of pollination can decline, and the plant's ability to reproduce effectively may be compromised. This phenomenon is particularly important in

Mediterranean ecosystems, where floral resources are already limited during transitional seasons, and any reduction in floral abundance can have serious repercussions for pollinator populations (Petanidou *et al.*, 2018).

The dynamics between pests and pollinators often go beyond direct interference with plant-pollinator interactions; pests may also influence pollinator behavior indirectly. For example, the presence of pests such as *Dysdercus koenigii* (Red Cotton Bug) or *Spilostethus pandurus* can alter the habitat quality by affecting plant health, which in turn may reduce the attractiveness of plants to pollinators (Dunn *et al.*, 2020). The declining health of plants can lead to a decrease in nectar and pollen quality, both of which are crucial for sustaining bee populations, particularly during periods of seasonal scarcity.

Moreover, certain pest species, such as syrphid flies (e.g., *Syrphus ribesii*) and drone flies (*Eristalis tenax*), which primarily act as pollinators, can also function as natural predators of pest insects, particularly aphids, in a balanced ecosystem. These dual roles of pest species highlight the intricate relationships in ecosystems, where some "pests" may play beneficial roles by controlling herbivorous pest populations (Dunn *et al.*, 2020). This dual role of specific insect species complicates the assessment of their overall impact on pollinator dynamics.

The seasonal fluctuation in pest populations, especially in Mediterranean ecosystems, further underscores the importance of understanding pest-pollinator interactions. The increased presence of pests during specific periods, such as the autumn-to-winter transition when *Moricandia arvensis* blooms, can severely alter the temporal patterns of pollinator visitation. Studies by Shapira *et al.* (2023) and Scaven and Rafferty (2019) illustrate how such seasonal changes in pest activity can disrupt the natural balance between pollinators and pests, particularly when climate-induced shifts in pest dynamics occur.

To mitigate the detrimental effects of pests on pollination success, it is important to consider integrated pest management (IPM) strategies that maintain a balance between pest control and pollinator health. IPM practices can involve the use of natural predators, such as the aforementioned syrphid flies, alongside biological controls and the selective use of pesticides that target specific pest species without harming pollinators (Goulson *et al.*, 2015). Furthermore, habitat diversification that includes the planting of both pollinator-friendly and pest-repellent plants can help reduce the incidence of pest outbreaks, while still supporting diverse pollinator populations.

Longitudinal studies that investigate the co-evolution of pest and pollinator populations are also essential to understanding the broader impacts of pests on pollination success. By examining these dynamics over extended periods, especially across varying climatic conditions, researchers can develop a more comprehensive understanding of how pest populations impact plant-pollinator interactions (CaraDonna *et al.*, 2018).

CONCLUSION

This research highlights the significance of *Moricandia arvensis* as a seasonal food source for honeybees and other pollinators, particularly during periods of winter scarcity. Diurnal peaks in bee activity were closely linked to midday temperature and atmospheric pressure, while seasonal declines aligned with colder, more humid conditions. The study demonstrates that Mediterranean ecosystems, though challenging due to extreme seasonal shifts, support critical pollinator resources. Conservation of *M. arvensis* and similar arid-adapted species could mitigate pollinator declines, particularly as climate change intensifies seasonal extremes. Future studies should further examine the resilience of Mediterranean plant-pollinator interactions under projected climate scenarios.

ACKNOWLEDGEMENTS

The authors would like to express their sincere gratitude to all individuals and institutions that contributed to this research—special thanks to the South Valley University Meteorological Station for supplying the essential weather data.

Conflict of interest: The authors hereby declare that no competing interests or conflicts exist.

Ethical Considerations and permissions:

The study adheres to ethical guidelines for the treatment of honeybee colonies and the handling of bees. As the authors of the manuscript, we affirm that all necessary permissions and licenses for the collection of plant and seed specimens were duly obtained in accordance with applicable regulations and ethical guidelines.

Author Contributions: Mahmoud Abbas Ali contributed to the conceptualization, methodology, data analysis, investigation, writing of the original draft, writing review and editing, visualization, and project administration. Seddik M.A. was involved in conceptualization, methodology, formal analysis, investigation, writing, review, editing, supervision, and project administration. Both authors contributed equally to the study's design and execution, ensuring its successful completion.

REFERENCES

Abou-Shaara, H. F. (2015). The foraging behaviour of honey bees, *Apis mellifera*: A review. *Veterinary Medicine (Praha)*, 60(1), 1–10. <https://doi.org/10.17221/7988-VETMED>

Baldock, K. C. R., Goddard, M. A., Hicks, D. M., *et al.* (2015). Where is the UK's pollinator biodiversity? The importance of urban areas for flower-visiting insects. *Proceedings of the Royal Society B: Biological Sciences*, 282(1803), 20142849. <https://doi.org/10.1098/rspb.2014.2849>

CaraDonna, P. J., Burkle, L. A., and Waser, N. M. (2018). Temporal flexibility in the structure of plant–pollinator interaction networks. *Oikos*, 127(10), 1551–1561. <https://doi.org/10.1111/oik.05227>

CaraDonna, P. J., Burkle, L. A., and Waser, N. M. (2018). Temporal flexibility in the structure of plant–pollinator interaction networks. *Oikos*, 127(10), 1551–1561. <https://doi.org/10.1111/oik.05227>

Dicks, L. V., Breeze, T. D., Ngo, H. T., *et al.* (2021). A global assessment of drivers and risks associated with pollinator decline. *Nature Ecology and Evolution*, 5(2), 145–154. <https://doi.org/10.1038/s41559-020-1262-y>

Dunn, L., Lequerica T, M., Reid, C., Latty, T. (2020). Dual ecosystem services of syrphid flies (Diptera: Syrphidae): pollinators and biological control agents. *Pest Management Science*. <https://doi.org/10.1002/ps.5807>

Dunn, L., Lequerica T., M., Reid, C., Latty, T. (2020). Dual ecosystem services of syrphid flies (Diptera: Syrphidae): pollinators and biological control agents. *Pest Management Science*. <https://doi.org/10.1002/ps.5807>

Gómez, J., Perfectti, F., Armas, C., Narbona, E., González-Megías, A., Navarro, L., DeSoto, L., Torices, R. (2020). Within-individual phenotypic plasticity in flowers fosters pollination niche shift. *Nature Communications*, 11, 3785. <https://doi.org/10.1038/s41467-020-17875-1>

Goulson, D., Nicholls, E., Botías, C., and Rotheray, E. L. (2015). Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. *Science*, 347(6229), 1255957. <https://doi.org/10.1126/science.1255957>

Goulson, D., Nicholls, E., Botías, C., and Rotheray, E. L. (2015). Bee declines driven by combined stress from parasites, pesticides, and lack of flowers.

- Science*, 347(6229), 1255957.
<https://doi.org/10.1126/science.1255957>
- Herrera, C. M. (2017). Flower traits, habitat, and phylogeny as predictors of pollinator service: A plant community perspective. *Ecological Monographs*, 87(1), 35–50.
<https://doi.org/10.1002/ecm.1231>
- Herrera, J., Pozo, M. I., Medrano, M., and Arroyo, J. (2018). Flower size variation and pollination effectiveness in *Moricandia arvensis* (Brassicaceae). *Plant Biology*, 20(1), 177–184.
<https://doi.org/10.1111/plb.12649>
- Kendall, L. K., Ward, K. L., and Moretto, G. (2019). Environmental drivers of bumble bee foraging behavior and abundance in a high elevation ecosystem. *Environmental Entomology*, 48(3), 685–693. <https://doi.org/10.1093/ee/nvz052>
- Kennedy, C. M., Lonsdorf, E., Neel, M. C., et al. (2019). A global quantitative synthesis of local and landscape effects on wild bee pollinators in agroecosystems. *Ecology Letters*, 22(9), 1485–1498.
<https://doi.org/10.1111/ele.13331>
- Ollerton, J. (2017). Pollinator diversity: Distribution, ecological function, and conservation. *Annual Review of Ecology, Evolution, and Systematics*, 48, 353–376. <https://doi.org/10.1146/annurev-ecolsys-110316-022919>
- Petanidou, T., Kallimanis, A. S., Sotiropoulou, S., and Sgardelis, S. P. (2018). Long-term observation of pollinator community dynamics in Mediterranean shrublands. *Oikos*, 127(3), 346–357.
<https://doi.org/10.1111/oik.04558>
- Petanidou, T., Kallimanis, A. S., Sotiropoulou, S., and Sgardelis, S. P. (2018). Long-term observation of pollinator community dynamics in Mediterranean shrublands. *Oikos*, 127(3), 346–357.
<https://doi.org/10.1111/oik.04558>
- Peters, M. K., Peisker, J., Steffan-Dewenter, I., and Hoiss, B. (2017). Morphological traits are linked to the cold performance and distribution of bees along elevational gradients. *Journal of Biogeography*, 44(4), 994–1005.
<https://doi.org/10.1111/jbi.12912>
- Potts, S. G., Imperatriz-Fonseca, V., Ngo, H. T., et al. (2016). Safeguarding pollinators and their values to human well-being. *Nature*, 540(7632), 220–229.
<https://doi.org/10.1038/nature20588>
- Rader, R., Bartomeus, I., Garibaldi, L. A., et al. (2016). Non-bee insects are important contributors to global crop pollination. *Proceedings of the National Academy of Sciences*, 113(1), 146–151.
<https://doi.org/10.1073/pnas.1517092112>
- Scaven, V. L., and Rafferty, N. E. (2019). Physiological effects of climate warming on flowering plants and insect pollinators and potential consequences for their interactions. *Current Zoology*, 65(3), 418–426.
<https://doi.org/10.1093/cz/zoz024>
- Shapira, T., Roth, T., Bar, A., Coll, M., Mandelik, Y. (2023). Complex Effects of a Land-Use Gradient on Pollinators and Natural Enemies: Natural Habitats Mitigate the Effects of Aphid Infestation on Pollination Services. *Insects*, 14(11), 872.
<https://doi.org/10.3390/insects14110872>
- Shapira, T., Roth, T., Bar, A., Coll, M., Mandelik, Y. (2023). Complex Effects of a Land-Use Gradient on Pollinators and Natural Enemies: Natural Habitats Mitigate the Effects of Aphid Infestation on Pollination Services. *Insects*, 14(11), 872.
<https://doi.org/10.3390/insects14110872>
- Willmer, P. G., and Stone, G. N. (2017). Behavioral, ecological, and physiological determinants of the activity patterns of bees. *Advances in Insect Physiology*, 53, 109–180.
<https://doi.org/10.1016/bs.aiip.2017.07.001>