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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

The Beneficial Effects of Honey Bees (*Apis mellifera* L.) as a Potential Pollinator on Quantitative and Qualitative Yield Parameters of Sunflower (*Helianthus annuus* L.)

Abdulraouf AMRO[1]*, Mostafa SEDDIK[2]

Abstract

A field study was conducted at the experimental station of the Bee Research Department, Naqada region, Qena Governorate, Egypt, during the 2024 sunflower (*Helianthus annuus* L.) flowering season. This research aimed to identify the insect pollinator community associated with sunflower plants, particularly honey bees (*Apis mellifera* L.), to evaluate their foraging ecology and quantify their effects on *H. annuus* yield parameters. The study implemented three pollination scenarios: open pollination (OP), allowing full insect pollinator access; managed honey bee-only (MHO), providing exclusive *A. mellifera* pollination within an isolated netted plot containing one colony; and non-pollinated (NP) plants, where pollinators were excluded using insect-proof mesh cages. Hymenoptera included the main pollinators (90%) especially *A. mellifera*, which recorded the most abundant pollinator (78%). The peak foraging activity of *A. mellifera* on sunflowers recorded at 9 am (excluding January 18), declined by midday (12 pm), and was lowest in the afternoon (3 pm). *A. mellifera* foragers exhibited significantly longer mean visitation durations (seconds capitulum) during mid-February compared to late February under OP conditions. Sunflowers under OP condition yielded the most seeds per plant head (565.67 head^{-1}), surpassing MHO (450.67 head^{-1}) and NP (241.33 head^{-1}). The NP group had statistically significant lower yield parameters (head weight per plant, number of seeds per head, 100-seed weight (g.), seed yield (t ha^{-1}), seed set, oil content % and seed germination %) than the OP and/or MHO. The difference in seed yield, weight, oil content% and germination% between OP and MHO pollination conditions was statistically non-significant ($p > 0.05$). However, MHO exhibited superior seed setting compared to OP and NP, recording 93.78%, 89.00 and 26%, respectively. Our results concluded that MHO plays a significant role in sunflower pollination, leading to substantial improvements in yield parameters compared to NP. However, they might not fully compensate for the absence of other pollinators in terms of the number of seeds per head and head weight.

Keywords: Sunflower, Pollination, Foraging behavior, Seed set, Oil content

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1. Introduction

Pollination is a vital ecosystem service that enhances the reproductive success of flowering plants and supports global biodiversity (Kevan and Viana, 2003). Among the various pollinators, honey bees (*Apis mellifera* L.) play a crucial role in the pollination of many crops (Amro, 2021), including sunflowers (*Helianthus annuus* L.) (Ali et al., 2024). *H. annuus* is a significant oilseed crop worldwide, and its production heavily relies on effective pollination services (Moustafa et al., 2008). While some degree of self-pollination is possible (Abdelsatar et al., 2020), the role of pollinators, particularly *A. mellifera*, is crucial for maximizing seed yield and quality (Ferguson et al., 2024). This is due to the fact that insect pollinators enhance the productivity of sunflowers by increasing seed set (Muhammad et al., 2021).

Both quantitative and qualitative yield parameters in sunflower were positively influenced by open pollination. Number of seeds setting (Altayeb and Nagi, 2015; Abbasi, et al., 2021), weight of plant heads (Idrees et al., 2023), head diameter (Ali et al., 2024), weight of 100 seeds (Kendarini et al., 2025), yield per plant t ha^{-1} (Karso et al., 2023), seed germination (Muhammad et al., 2021) and oil content of seed and oil yield (Jilo et al., 2025). However, Jilo et al. (2025) stated that the overall oil yield and oil content are not consistent across different pollination treatments, even though the area percentage and retention time of linoleic acid, oleic acid, palmitic acid, and stearic acid remain statistically unchanged.

The interaction between sunflowers and their pollinators is complex, involving the provision of floral rewards such as nectar and pollen, which attract a diverse array of pollinators (Mallinger and Prasifka, 2017). So, understanding the dynamics between pollination services, pollinator behavior, and floral traits is essential for optimizing sunflower productivity, maintaining healthy ecosystems and ensuring ecological sustainability. Pollination by honey bees and wild bee populations is essential for sunflower production (Ferguson et al., 2024), encompassing two critical stages. The first stage, hybrid seed development, depends on bees for pollen movement between male-fertile and male-sterile lines (Greenleaf and Kremen, 2006). Secondly, bee visitation during the cultivation of hybrid varieties, even self-compatible ones, significantly enhances yields by 25–45% (Mallinger et al., 2019). Hence, under typical field conditions for hybrid sunflowers, the pollination services provided by wild bees significantly enhance those of honey bees, effectively doubling the overall pollination rate (Kevan, 2001).

In Egypt, sunflower pollination appears to be heavily reliant on bees in many regions, particularly the European honey bees and the wild bees. In the Assiut region, Upper Egypt, honey bee comprised about 96% of all pollinators of sunflowers (Moustafa et al., 2008). However, in an early scanning study by Hussein and Abdel-Aal (1982), they documented 12 genera of wild and honey bees belonging to 7 families were identified on sunflowers (Apidae, Andrenidae, Anthophoridae, Halictidae, Megachilidae, Colletidae and Xylocopidae). While other insect visitors and occasional pollinators are present on sunflower plant heads during the growing season in different plots in Egypt, their contribution to pollination seems to be minor based on their low abundance or primary forage source. The high abundance of honey bees suggests they are a crucial pollinator for sunflowers in this agricultural system (Al Naggar et al., 2018). The significant presence of carpenter bees indicates the importance of wild or non-managed bee species as well (Moustafa et al., 2008). The low abundance of other potential pollinators might suggest a need to understand factors that could enhance their populations or the potential risks of over-reliance on a single or two dominant pollinator species.

Open pollination consistently resulted in slightly better outcomes than pollination restricted to managed honey bees, hinting that a diverse pollinator community or other factors present in an open environment might offer additional benefits for sunflower production (Said et al., 2017; Nene et al., 2024; Jilo et al., 2025). Perrot et al., (2019) recorded that pollinators enhanced field yield by up to 40% (0.7 t ha^{-1}) and plant yield by 31.3%, showing a similar impact across scales. The degree of pollinator dependence is highly dependent on sunflower variety, with impacts on production and productivity outcomes, e.g. individual plant yield values varied between 0.188 and 0.692 (Mota et al., 2024). While multiple varieties demonstrated autonomous self-fertilization capacity, outcrossing pollination significantly enhanced seed production in most genotypes, with yield increases reaching 300% in certain cultivars (Karso et al., 2023; Nene et al., 2024; Jilo et al., 2025)

A significant knowledge gap exists regarding pollinator species and their foraging activity on sunflowers in Qena, Upper Egypt. Furthermore, the influence of these pollinators on sunflower yield has not been adequately documented. Consequently, this research seeks to: identify insect pollinator and visitor species, assess their foraging activities especially honey bees. Finally, quantify the impact of three different pollination conditions (OP, MHO and NP) on quantity and quality of sunflower yield parameters within the Qena region of Upper Egypt.

2. Materials and Methods

2.1. Site description

The experiment was conducted at the research farm of the Bee Research Department, Plant Protection Research Institute, in the Naqada region, Qena governorate, Egypt (25.9° 50.8´11´´N, 32.7° 56.9´04´´E) during the semidried winter growing season of 2023/2024. Near the department's apiary (comprising 20 colonies) and at a distance of 600 meters, the experimental plots were located. The soil profile of the experimental area was determined to be light clay, and the climate was observed to be moderate with low humidity and cold temperatures. This site was deemed appropriate due to its established record of uniform farming practices and relative isolation from external factors, thereby supporting the reliability of experimental outcomes.

2.2. Experimental design

A nested, complete block design with four replicates was employed for this experiment. An area of about 1.5 ha (hectares) was divided into plots; each plot was 0.5 ha (6 rows plot^{-1}). Each plot was divided into three blocks, each containing three subplots. The blocks were spaced 4 meters apart by alleys, and a 1.5-meter path separated the plots. Each growth plot had a size of 25 square meters. Treatments were implemented to assess different pollination scenarios: open pollination (OP) allowed full access for all insect pollinators to sunflower plants; managed honey bee only (MHO) provided exclusive *A. mellifera* pollination within an isolated netted plot containing one *A. mellifera* colony; and non-pollinated (NP) plants where pollinators were excluded using insect-proof mesh cages deployed pre-anthesis. For the dual purpose of preventing insect pollinator entry and ensuring adequate ventilation, the isolated plants were covered with 2 mm mesh insect-proof nets. To ensure that sunflower plants were pollinated only by bees, they were isolated alongside a honey bee colony using wooden-framed cages (4 m long, 6 m wide, and 2.5 m high) covered with a white nylon cloth with a 1 mm mesh.

2.3. Cultivated Plants and Field Practices

The experiment consisted of 4 replicates per pollination condition, with each replicate containing 25 plants (100 plants total per condition). The study utilized the Fedowk sunflower cultivar, an agronomically recommended variety (Moustafa et al., 2008), during the peak anthesis period (15 January till 29 February). Seeds were sourced from the Agricultural Research Center in Giza, Egypt. In early December 2023, sunflower seeds were hand-sown on ridges, maintaining a 60 cm inter-row distance and a 30 cm intra-row distance. Thinning was performed 15 days after sowing to ensure one plant remained per hill. Standard conventional agricultural practices were implemented (Ali et al., 2004), and insecticide treatments were not applied.

2.4. Data Collection

2.4.1. Species and abundance

Weekly observations of insect pollinators and visitors on uncaged sunflower plants were conducted from January 18 to February 29, 2024, during the flowering season. Insects were collected using a standard aerial net with a 35 cm diameter (Borror et al.,1989). Insects were collected and killed using 70% chloroform applied to cotton in polyethylene bags within killing jars before being brought to the lab. Once there, they were pinned or pointed, labeled, and curated. Final identification was performed by taxonomists at the Agricultural Research Center (Giza, Egypt). Using Facylate's (1971) formula, we calculated the abundance percentages of the collected insect pollinators for each species as follows:

$$A = \frac{n}{N} * 100 \quad \text{(Eq. 1)}$$

Where:

A =Abundance percentage

n =Total number of samples in which each species appeared

N =Total number of samples taken all over the season

2.4.2. Temporal Dynamics of A. mellifera Foraging Activity

The diurnal activity patterns of insect pollinators were evaluated on uncaged sunflower plants throughout the 2024 flowering season. Observations conducted daily at 9 am, 12 pm, and 3 pm recorded their temporal foraging behavior. A 1 m² wooden frame was used to count pollinators visiting each square meter area for five-minute intervals per replicate (recorded as insects m² min^{-5}) as described by Amro (2021).

2.4.3. Floral Visit Duration of A. mellifera

Individual foraging bout durations were measured for *A. mellifera* using calibrated digital stopwatches, with timing initiated at capitulum contact and terminated upon bee departure (OP plots only). The mean duration of individual bee visits to a sunflower capitulum is expressed in seconds per capitulum.

2.4.4. Yield variations in sunflowers under different pollination conditions

2.4.4.1. Seed yield

For yield and yield attribute analysis, ten guarded plants from each plot per treatment were randomly chosen from the 3rd and 6th ridges at harvest. The selected plants were then harvested, bundled, and subjected to an air-drying process to determine the total number of seeds per head, 100-seed weight (g), seed yield (t ha^{-1}), and head weight per plant (g.).

2.4.4.2. Seed set, germination and oil content percentage

The seed set percent was calculated by the formula given by Roath and Miller (1982) as follows:

$$\text{Seed setting percentage} = \frac{\text{(Number of filled seed)}}{\text{(Total seeds)}} * 100 \qquad \text{(Eq. 2)}$$

To assess seed germination, 50 seeds from each treatment were placed in plastic Petri dishes lined with two layers of Whatman No. 1 filter paper. The Petri dishes were incubated in a growth chamber set at 20 ± 2 °C. The filter paper was initially saturated with double-distilled water on the sowing date and subsequently kept moist for a duration of five days. Successful germination was defined by the observation of fully developed cotyledons (Kevan and Eisikowitch, 1990). The percentage of oilseed content was recorded. Subsequently, the crude oil percentage in the seeds was quantified based on the AOCS – American Oil Chemists' Society (1985) method, which involved extraction using a Soxhlet apparatus with petroleum ether in the 40–60 °C boiling range as the solvent.

2.5. Statistical analysis

The data presented no deviation from normality according to Shapiro-Wilk's W test (Shapiro and Wilk, 1965). Data were rigorously analyzed using R version 4.1.2 (R Core Team 2021) and SPSS version 27 (IBM Corp. 2020). Analysis of Variance (ANOVA): One-way ANOVA was conducted to determine the temporal dynamics of honey bee visitation rates on sunflower plants. Post-hoc comparisons were performed using Tukey's Honest Significant Difference (HSD) test with a significance level of $\alpha = 0.05$. For data that violated assumptions of normality or homogeneity of variance, Kruskal-Wallis tests were used, followed by Dunn's test for pairwise comparisons with Bonferroni correction for multiple testing. Spearman's rank correlation was used for non-normally distributed data. Linear regression employed has been assessed to model the influence of pollinator visits on yield components.

3. Results and Discussion

3.1. Species and abundance

Table 1 presents a snapshot of the insect pollinators visiting sunflowers during the 2024 growing season in the Qena region of Egypt, detailing their abundance percentage and primary forage source. The order Hymenoptera constituted a staggering 90% of the observed insect visitors to sunflowers. This strongly indicates that bees are the primary pollinators of sunflowers in this region. Within Hymenoptera, the family Apidae is the only one listed, further emphasizing the crucial role of bees in sunflower pollination in the region. The order Coleoptera represented by *Coccinella undecimpunctata* (eleven-spotted lady beetle) is observed at a minimal abundance of 1%. Lady beetles, being predominantly predatory and feeding on other insects, are likely incidental visitors to sunflowers, not primarily engaged in pollination. Finally, the order Diptera constituted 9% of sunflower visitors. *Syrphus corolla* (hover fly) comprises 4% and, as a nectar feeder, contributes to pollination, though less effectively than bees. *Musca domestica* (house fly), at 5%, also feeds on nectar but is not considered a significant pollinator due to its limited capacity for efficient pollen transfer.

Table 1. Sunflower-visiting insect pollinators and their relative abundance in the Qena region, Upper Egypt, during the successive growing seasons of 2024

Order	Family	Species	Common name	Abundance (%)	Forage source*
Hymenoptera 90%	Apidae	*Apis mellifera* L.	Honey bee	78	N+P
		Xylocopa aestuans L.	Carpenter bee	12	N+P
Coleoptera 1%	Coccinellidae	*Coccinella undecimpunctata* L.	Eleven spotted lady beetle	1	C
Diptera 9%	Syrphidae	*Syrphus corolla* Fabricius	Hover fly	4	N
	Muscidae	*Musca domestica* L.	House fly	5	N

*N - Nectar forager; PN - Pollen and nectar forager; C - Casual

3.2. Foraging dynamics of A. mellifera on sunflower plants

The obtained results in *Figure 1* documented the average number of honey bees buzzing around sunflowers each minute across different observation dates in early 2024. The bars are broken down by the time of day the observations were made: 9 am, 12 pm, and 3 pm. From the initial glance, it appears that the time of day has a significant impact. Across almost all observation dates, the 9 am readings consistently show the highest average number of bee visits per minute, except for January 18. It seems like morning activity is the peak activity time for these pollinators on sunflowers during this period in our plots. However, afternoon activity (3 pm) observations generally have the lowest average bee visits. Meanwhile, at midday (12 pm), the bee visits tend to decrease compared to the morning peak, although they are often still higher than the afternoon counts.

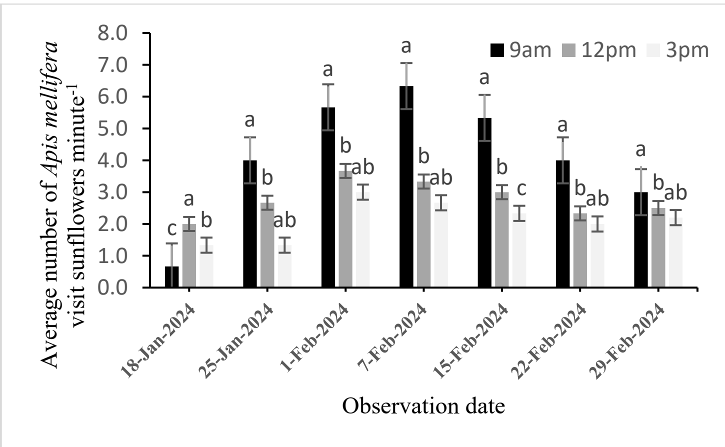

Figure 1. Diurnal foraging patterns of Apis mellifera visiting sunflower field at 9 am, 12 pm and 3 pm in the Qena region, Upper Egypt, during flowering seasons of 2024. Bars with different letters within each month indicate statistically significant differences (P < 0.05)

Apis mellifera is by far the most abundant visitor in our plots, making up 78% of all recorded insects. This highlights the significant contribution of honey bees to sunflower pollination in the Qena region. Their high numbers suggest they are either actively managed in the area or are thriving in the local environment with access to sunflower resources. Several studies have also shown honey bees as the most important pollinator for sunflowers (Abbasi et al., 2021; Karso et al., 2023; Ali et al., 2024). In contrast, in the same study area, in a recent alarming study, Abdel-Rahman and

Moustafa (2012), demonstrated a significant decline in honey bee colonies due to the colony collapse disorder (CCD). They attributed this to several factors, including the spread of the red Oriental hornet (*Vespa orientalis*), poor queens, the spread of American foulbrood disease, and the decline of good genetic traits in the region's bees. The absence of *V. orientalis* in our plots results is noteworthy. This absence indicates a potential for temporal shifts in the pollinator insect community within the same geographical location (McCabe and Cobb, 2021), emphasizing the necessity of monitoring pollinator populations in sunflower cultivation zones. However, *X. aestuans* represents a notable 12% of the visitors. Carpenter bees are known to be effective pollinators due to their large size and buzzing behavior (Greenleaf and Kremen, 2006; Goras et al., 2016), which can efficiently release pollen. Their substantial presence suggests they also play a vital role in sunflower pollination, even though their numbers are lower than honey bees in this study.

The results in *Figure 2* show the mean time (in seconds) bees spent on the sunflower plant capitulum across different observation dates in early 2024, measured at three times: 9 am (morning activity), 12 pm (midday activity), and 3 pm (afternoon activity). From January 18 to February 15, the mean time bees spent on the sunflower plant capitulum generally increases across all time points, peaking on February 15 with significant differences within observation date (F = 14.74, df = 31.24, P ≤ 0.05). After this peak, the time decreases sharply by February 22 and continues to decline slightly by February 29, with highly significant differences between observation dates (F = 67.75, df = 41.31, P <0.01). At 9 am (morning activity), the bees spend 83 seconds on sunflower capitulum on January 18, rising to 293 seconds by February 15, then dropping to 110 seconds by February 29. At 12 pm (midday activity), the time follows a similar pattern, starting at 94 seconds, peaking at 272 seconds on February 15, and falling to 131 seconds by February 29. The same trend has been shown at 3pm (afternoon activity), the time also starts at 77 seconds, peaks at 267 seconds on February 15, and drops to 117 seconds by February 29 with highly significant differences between morning, midday, and afternoon activities (F = 114.78, df = 97.74, P <0.001).

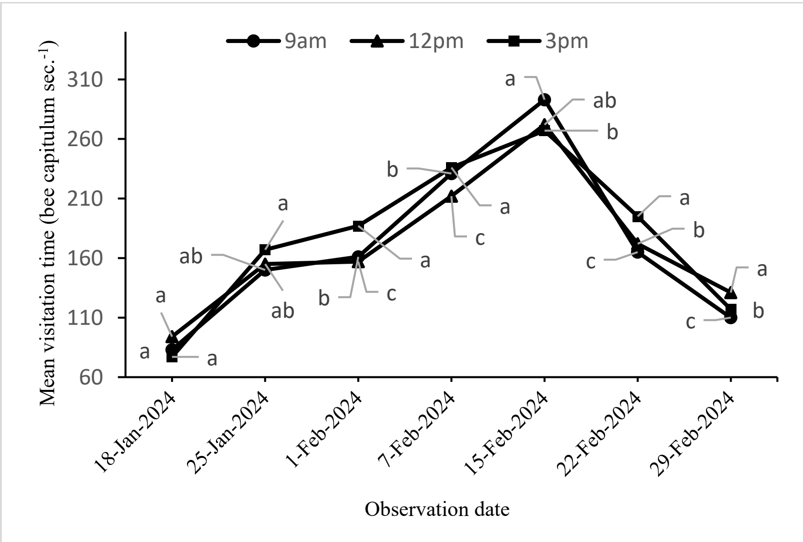

Figure 2. The mean time spent by A. mellifera per sunflower capitulum (bee capitulum sec^{-1}) in the Qena region, Upper Egypt, during flowering seasons of 2024. Bars with different letters within each month indicate statistically significant differences (P < 0.05).

Our results highlighted that bees spend more time on the *H. annuus* flower as the season progresses from mid-January to mid-February 2024, possibly due to increasing temperatures or changing flower availability (DeGrandi-Hoffman and Watkins, 2000). The peak on February 15 suggests optimal conditions for this behavior. The sharp decline afterward might indicate a shift in environmental conditions or bee behavior. Our results documented that the 9 am measurements often show the most extreme values, suggesting morning conditions may have a stronger influence on this behavior. However, by late February, the time of day has less impact, as the values converge. Following a similar trend in a comparable geographic area, Moustafa et al. (2008) and Muhammad et al. (2021) observed peak pollinator visitation activity between 08:00 and 10:00 hours. However, afternoon activity is lower and the 3 am observations generally have the lowest average bee visits, suggesting that the bees might take a bit to get going in the morning, or perhaps the flowers aren't as attractive to them earlier in the day (Roch et al., 2023). The obtained results showed date-to-date variations in the number of bee visits with no constant over time. For example, February 7th shows a particularly high number of morning visits, while January 18th has the lowest overall activity. This could be due to various factors like weather conditions (Cojocari, 2023), sunlight (Idrees et al., 2023), wind (Perrot et al., 2019), the sunflower variety (Mota et al., 2024), climate changes (Debaeke et al., 2017; Gürkan, 2023) or even changes in the local bee population (Roch et al., 2023).

3.3. Yield variations in sunflowers under different pollination conditions

3.3.1. Seed yield

Figure 3 compares three sunflower yield parameters - number of seeds per head, weight of head per plant (g.), 100-seed weight (g.), and seed yield (t ha^{-1}) across three pollination conditions: open pollination (OP), managed honey bees only (MHO), and non-pollinated plants (NP). OP yields the highest number of seeds per sunflower plant head (565.67 $head^{-1}$), significantly more than plants pollinated only by honey bees (450.67 $head^{-1}$) (F = 64.73, df = 37.54, P <0.01), which in turn is significantly higher than NP sunflower plants (241.33 $head^{-1}$) (F = 104.63, df = 97.53, P <0.01). OP again shows the highest weight of sunflower plant heads (142.58 g. $head^{-1}$), significantly greater than MHO (94.70 g. $head^{-1}$) (F = 126.41, df = 77.34, P <0.001), which is significantly higher than NP plants (49.88 g. $head^{-1}$) (F = 24.33, df = 17.14, P <0.01). Regarding the seed weight of the tested sunflower plants as an important parameter for testing the effect of different pollination conditions on sunflower yield parameter, OP has the highest 100-seed weight (18.36 g/ 100 seeds), not significantly different from MHO (12.61 g/ 100 seeds) (F = 9.17, df = 3.52, P > 0.05), but both are significantly higher than NP (5.86 g/ 100 seeds) (F = 7.33, df = 5.23, P <0.01). The difference in seed yield (t ha^{-1}) between OP and MHO pollination conditions was statistically non-significant (P > 0.05) recording 7.14, 6.86 t ha^{-1}, respectively. However, both previous pollination methods considered significantly higher than the NP sunflower plants (F = 2.61, df = 0.51, P <0.01) recording 3.24 t ha^{-1}.

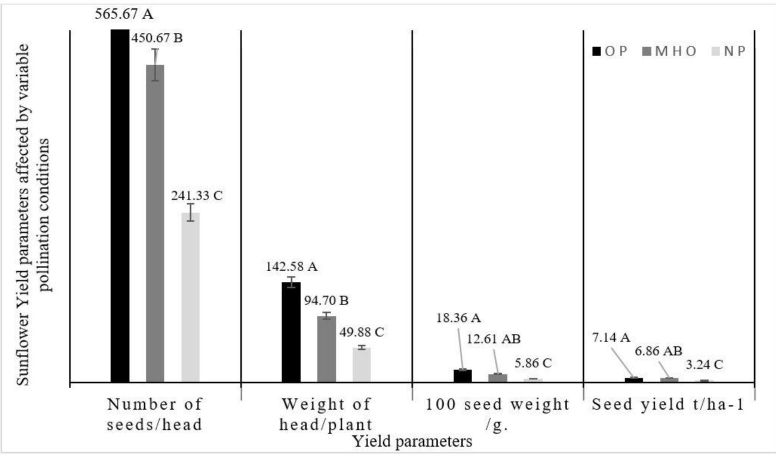

Figure 3. Impacts of different pollination conditions, open pollination (OP), managed honey bee only (MHO) and non-pollinated plants (NP) on sunflower quantitative parameters (Number of seeds $head^{-1}$; weight of head $plant^{-1}$; 100 seed weight g^{-1}.; seed yield t ha^{-1}) in the Qena region, Upper Egypt, during flowering seasons of 2024. Bars with different letters within each yield parameter indicate statistically significant differences (P < 0.05)

Although capable of both autonomous and insect-assisted pollination, sunflower populations exhibit optimal yield and genetic diversity when cross-pollinated by bees (Moustafa et al., 2008; Goras et al., 2016; Abbasi et al., 2021 and Karso et al., 2023). In our plots, OP yields the highest sunflower seed production and plant vigor may be due to a diverse pollinator community (Jilo et al., 2025). In accordance with the same previous authors, MHO improves yield compared to NP plants but is less effective than OP, suggesting wild bees and other insects play a significant role (Hussein and Abdel-Aal 1982; Greenleaf and Kremen, 2006; Goras et al. 2016). NP plants have the lowest yield, underscoring the importance of pollination. While honey bees contribute to seed production, they are less effective than a natural pollinator mix. The NP group shows a substantial reduction in seed set, indicating the crucial role of pollinators in sunflower reproduction. Our findings are consistent with the documented observations of Mota et al. (2024) and Nene et al. (2024), which indicate that although some sunflower varieties can produce seeds without pollinators, insect pollination significantly boosts seed productivity. Nevertheless, the performance of cultivated varieties should be considered. Önemli and Önemli (2023) reported substantial difficulties in obtaining seeds from some species, likely stemming from their limited adaptability to local field conditions. This challenge may be linked to the genetic centers of these species being located in specialized environments like deserts.

In this study, the weight of the sunflower head is directly influenced by the number of filled seeds. Higher seed set in the OP and MHO treatments leads to heavier heads compared to the NP (control). This further emphasizes the importance of pollination for overall yield. In the same line, Goras et al., (2016) and Nene et al. (2024) found that under standard field conditions for hybrid sunflowers, wild bees contribute pollination services that significantly increase the overall pollination rate, achieving approximately twice the level provided by honey bees alone. The weight of individual seeds also appears to be influenced by the pollination conditions. Our results documented that, OP might lead to better fertilization and resource allocation, resulting in heavier seeds. While MHO contributes to seed weight, the NP group shows a drastic reduction, likely due to poor or incomplete fertilization leading to smaller and lighter seeds (Charrière et al., 2010; Jilo et al., 2025). Also, this study highlights the lack of significant difference in 100-seed weight between OP and MHO suggesting that seed size may be less affected by pollinator diversity compared to seed number and head weight. In contrast, Nene et al. (2024) reported that honey bee-colonized plots produced sunflower seed heads weighing 3.5 times more than those in pollinator-excluded plots. The overlap in statistical significance between OP and MHO for this parameter suggests that the presence of MHO might be sufficient to achieve a seed weight comparable to OP, although this needs further investigation.

3.3.2. Seed set, germination and oil content percentage

Our plots result strongly demonstrate the importance of pollination for both the quality (oil content), viability (germination rate) and seed setting of sunflower plants. *Figure 4* illustrated the effects of three different pollination conditions on two key characteristics of sunflower plants: oil content and seed germination percentages. Both MHO and OP significantly outperform the NP control group. NP plants show the lowest oil content percentage (16.67%), while sunflower plants pollinated by MHO have a significantly higher oil content (26%), whereas OP in sunflower plants exhibits the highest oil content (33.67%). Regarding the germination rate percentages, the seeds from NP plants have a very low germination rate (28.33%). Pollination by MHO dramatically increases the germination rate (89%). OP shows the highest germination rate, approaching 100% (97.67%). In respect to seed setting, the overall views were different. Sunflower plants caged with a honey bee colony exhibited superior seed setting compared to OP and NP plants, recording 93.78%, 89.00 and 26%, respectively.

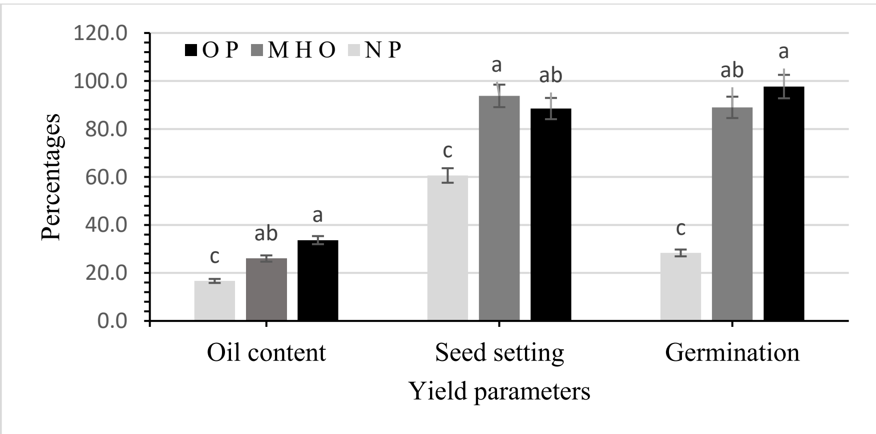

Figure 4. Impacts of different pollination conditions, open pollination (OP), managed honey bee only (MHO) and non-pollinated plants (NP) on sunflower qualitative parameters (oil content, seed set and germination %) in the Qena region, Upper Egypt, during flowering seasons of 2024. Bars with different letters within each yield parameter indicate statistically significant differences (P < 0.05)

The results indicate that, pollination significantly increased oil content, with no statistically significant (P <0.001) difference observed between the OP and MHO treatments. Also, Jilo et al., (2025) reported that sunflowers pollinated only by honey bees show significantly higher oil content and oil yield compared with self-pollinated ones (*P* <0.001). OP appears slightly more effective than pollination solely by MHO, suggesting that either a diversity of pollinators or other environmental factors in the open setting contribute to maximizing oil production (Said et al., 2017). Statistically the differences were significant, meaning the oil content percentage and germination percent in each group are significantly different from the others (P <0.01). Our findings were harmonized with those of Nene et al. (2024), who found that seeds derived from sunflower plots with MHO exhibited significantly higher germination rates (P < 0.05) compared to those from pollinator-excluded plots. No significant difference in germination was observed between seeds from wild pollinator-visited plots and MHO. As with oil content, OP yields the best results, although pollination by MHO also provides a massive improvement over non-pollinated plants. The significantly enhanced seed set in bee-accessible isolated plants (F = 34.56, df = 15, P < 0.001) compared to both OP and NP (controls) provides empirical evidence for the indispensable role of bees in sunflower agroecosystems. Pollinator activity significantly enhanced yield through increased seed set per plant (P < 0.05), while demonstrating no measurable impact on individual seed mass. This positive effect on fecundity occurred despite an observed inverse relationship between seed number and unit mass (Perrot et al., 2019).

4. Conclusions

This study demonstrates that open pollination (with a diverse pollinator community) consistently produces the highest sunflower yield in terms of seed production and plant vigor, outperforming managed honey bees alone. While honey bees improve yield compared to non-pollinated plants, they are less effective than open pollination, suggesting that wild bees and other insects play a key role. Non-pollinated plants had the lowest yield, confirming that pollinators are essential for sunflower reproduction. Interestingly, individual seed weight (100-seed weight) did not differ significantly between open pollination and honey bee pollination, indicating that pollinator diversity mainly affects seed number and head weight rather than seed size.

Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

There is no conflict of interest between the article authors.

Authorship Contribution Statement

Concept: Amro, A., Seddik, M.; Design: Amro, A., Seddik, M.; Data Collection or Processing: Seddik, M.; Statistical Analyses: Amro, A.; Literature Search: Amro, A., Seddik, M.; Writing, Review and Editing: Amro, A., Seddik, M.

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