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Research Article

POLLINATION EFFECTIVENESS OF EXOTIC *APIS MELLIFERA* COMPARED TO NATIVE BEES AND FLIES

[a]Muhammad Jamshad Arshad, [a]Muhammad Waqar Hassan, [a]Asif Sajjad, [a]Muhammad Anjum Aqueel, [b]Asim Abbasi

[a] *Department of Entomology, Faculty of Agriculture & Environment, The Islamia University of Bahawalpur, Bahawalpur, Pakistan.*
[b] *Department of Entomology, University of Agriculture, Faisalabad, Pakistan.*

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ABSTRACT

Growing evidence shows that the exotic honeybee, *Apis mellifera*, disrupts plant-pollinator networks by outcompeting native pollinators for nectar and pollen. Moreover, honeybees are not always the most effective pollinators for all plant species. Therefore, assessing the relative pollination efficiency of *A. mellifera* and native species is crucial when selecting apiary sites in agro-ecosystems. The current study was conducted to assess the relative pollination potential of *A. mellifera* compared to native bees, including solitary bees, native honeybees, and true flies, on *Brassica napus* (canola) and *Sesamum indicum* (sesame) crops. Results showed that in canola, *A. dorsata* and *A. mellifera* collected the highest number of pollen grains; however, neither species transferred as much pollen to the stigma as *Halictus* sp., which resulted in the highest seed count per pod during a single visit. In sesame, *Andrena* sp. and *A. dorsata* collected and deposited the highest number of pollen grains, leading to the greatest number of seeds per capsule and the highest seed weight in a single visit. *A. mellifera* exhibited an intermediate level of pollination potential, along with a few other native pollinators, in both crops. Overall, our findings suggest that solitary bees (*Halictus* sp. and *Andrena* sp.) and the native honeybee (*A. dorsata*) are more effective pollinators of canola and sesame than *A. mellifera* in Southern Punjab, Pakistan. This study provides valuable insights that can inform decisions on hive placement in canola and sesame fields. Future research should extend this comparison to other cross-pollinated crops.

Corresponding Author: Asif Sajjad
Email: asif.sajjad@iub.edu.pk

INTRODUCTION

Pollination is a vital ecosystem service provided by insects and is essential for the sustainability of terrestrial ecosystems and food security (Winfree et al., 2011). Each crop plant species has specific pollination requirements, often relying on certain insect pollinators (Layek et al., 2023). However, the effectiveness of each pollinator species can vary due to its intrinsic behavior on flowers. For example, honeybees may act as efficient pollinators but can also rob nectar without contributing to pollination (Osterman et al., 2021). Therefore, the most frequent floral visitors are not necessarily the most efficient pollinators (Ivey et al., 2003).

It is thus imperative to measure the single visit effectiveness of a pollinator species, that is, its ability to deposit compatible pollen on the stigma and contribute to the reproductive success of plants (Fenster et al., 2004; Ali et al., 2011; Usman et al., 2023).

The managed honeybee (*Apis mellifera* L.) is widely known to enhance agricultural crop yields (Calderone, 2012; Garibaldi et al., 2013). However, large-scale beekeeping is not common in the cotton belt of Southern Punjab, Pakistan, primarily due to extensive pesticide use and extreme summer temperatures (Sajjad et al., 2008). In this region, migratory beekeeping is common, with beekeepers moving from cooler hilly areas to the plains of Punjab during the winter. Recently, efforts have been initiated to maintain *A. mellifera* colonies even during the hot summer months.

Most previous studies in this region have focused on comparing the reproductive performance of native honeybees (*A. dorsata* and *A. florea*) with solitary bees across various crops in terms of single visit effectiveness and crop reproductive outcomes (Sajjad et al., 2008; Ali et al., 2014). Studies by Ali et al. (2014), Akram and Sajjad, 2022), Ali et al. (2022), and Ahmad et al. (2023) found that solitary bees such as *Megachile bicolor*, *Nomia* sp., *Pseudapis oxybeloides*, and *Amegilla* sp. outperformed *A. dorsata* in pollinating *Grewia asiatica*, *Cucurbita pepo*, *Trifolium alexandrinum*, and *Sesamum indicum*, respectively. Conversely, Ali et al. (2011), Saeed et al. (2012), and Anees et al. (2022) reported *A. dorsata* as a more effective pollinator than solitary bees for *Momordica charantia*, *Brassica napus*, *Raphanus sativus*, and strawberry, respectively. To date, *A. mellifera* has been evaluated in only two studies, both of which ranked it lower than the solitary bees *Pseudapis oxybeloides* and *Ceratina smaragdula* for pollination of Egyptian clover and fenugreek, respectively (Ahmad et al., 2023; Usman et al., 2023).

Although *A. mellifera* is the dominant pollinator species in many parts of the world, Garibaldi et al. (2013) found that its visits significantly enhanced the yield of only three out of 22 studied crops. This highlights the need for developing consensus on pollination management strategies to optimize crop pollination (Isaacs et al., 2017; Rollin and Garibaldi, 2019).

To achieve this, it is crucial to assess the relative pollination effectiveness of different pollinator species, along with their nesting habits and ecological roles, in order to integrate them effectively into pollination management strategies (Garibaldi et al., 2014).

In this study, canola (*B. napus*) and sesame (*S. indicum*) were selected as model crops to compare the pollination potential of *A. mellifera* with that of native pollinators. Both crops possess entomophilous flowers and are capable of both self- and cross-pollination. Previous reports have shown that bee-mediated cross-pollination can increase the yields of sesame and canola by up to 59% and 47%, respectively (Becker et al., 1992; Stein et al., 2017). These crops are visited by a range of solitary bees as well as managed honeybees (Ali et al., 2011; Kamel et al., 2013; Parmar et al., 2017).

Earlier studies conducted in South Punjab, Pakistan, have highlighted the role of wild pollinators in enhancing sesame and canola production (Ali et al., 2011, 2022). For instance, *Amegilla* sp. was found to be a more efficient pollinator than *A. dorsata* in sesame, while *A. dorsata* and *A. florea* were more effective than solitary bees like *Halictus* sp. in canola. However, *A. mellifera* has yet to be thoroughly assessed in this context.

Considering the growing interest in optimizing hive placement for *A. mellifera* in canola and sesame fields, this study was conducted to evaluate the relative pollination efficiency of *A. mellifera*, solitary bees, and native honeybees.

MATERIAL AND METHODS

Study area

The study was conducted at the Research Farm of The Islamia University of Bahawalpur, Pakistan (29.370°N; 71.765°E). Canola variety 'Bulbul' was cultivated over one acre from November 2019 to March 2020. Sesame variety 'TH-6' was grown in the same plot from June 2020 to September 2020.

The experimental plot was located 300 m north of a 21-acre planted forest dominated by perennial tree species such as *Eucalyptus camaldulensis*, *Acacia nilotica*, *Capparis decidua*, and *Dalbergia sissoo*, along with numerous weed species including *Spergula arvensis*, *Stellaria media*, and *Alhagi graecorum*. This forest served as a habitat for wild honeybee species such as *A. florea* and *A. dorsata*. Moreover, three beehives of *A. mellifera* were placed near the experimental plot.

During the canola and sesame growing seasons, the experimental plot was surrounded by wheat and cotton fields, respectively. The region experiences cold winters and hot summers, with average daily minimum and maximum temperatures ranging from 15-20 °C and 30-35 °C, respectively. The average annual rainfall is less than 400 mm (PARC, 1980).

Foraging behavior

The foraging behavior of pollinators was assessed based on visitation rate (number of flowers visited per minute), stay time on individual flowers, and nectar robbing behavior (side-feeding without contacting the stigma). Observations were limited to the most frequently visiting pollinator species.

Visitation rate and stay time were recorded throughout the flowering periods of canola (January to March) and sesame (mid-July to late August). Thirty plants of each crop were randomly selected and observed at 09:00, 10:00, 12:00, 14:00, 16:00, and 17:00 hours at weekly intervals during their flowering periods. Specimens of each pollinator species were identified to genus and species level, where possible. Nectar robbing was recorded through visual observation. All observations were conducted on clear, sunny days; rainy and cloudy days were avoided.

Pollination effectiveness

Pollination effectiveness was evaluated based on three parameters: (i) pollen deposition on the stigma from a single visit, (ii) pollen load carried by an individual bee during peak foraging hours, and (iii) reproductive success resulting from a single visit.

To measure pollen deposition, unopened floral buds on different plants were enclosed in nylon mesh bags. After opening, the flowers were uncovered during peak foraging hours (10:00-14:00 h). Once a targeted pollinator visited a flower, the stigma was removed using a sharp blade and stained following the procedure of Dafni (1992). Pollen grains on the stigma were counted under a stereoscopic microscope at 40× magnification (Ali et al., 2011). Ten observations were recorded per pollinator species.

To assess pollen harvest, ten individuals of each pollinator species were captured and euthanized during peak activity hours (10:00-14:00 h). Pollen grains carried by each individual were quantified following the method described by Canto-Aguilar and Parra-Tabla (2000).

For measuring single-visit reproductive success, twenty unopened floral buds were bagged per pollinator species. After opening, the flowers were exposed during peak hours (10:00-14:00 h), and re-bagged and tagged after a single visit by the target pollinator (Dafni, 1992). Flowers remained bagged until pod formation. The following parameters were recorded: pod weight, pod length, number of seeds per pod, and seed weight for each pollinator species.

Data analysis

Data on visitation rate, stay time, number of pollen grains deposited and harvested, pod or capsule weight, pod length, number of seeds per pod or capsule, and seed weight were statistically analyzed using analysis of variance (ANOVA). Means were compared using Tukey's test at $p = 0.05$. All statistical analyses were performed using XLSTAT (2021).

RESULTS

Canola pollination

The six investigated pollinator species showed significant differences in visitation rate ($F = 76.8$, $df = 5$, $P < 0.000$) and stay time ($F = 361$, $df = 5$, $P < 0.000$) (Table 1). *A. dorsata* and *A. mellifera* exhibited the highest visitation rates, whereas *Halictus* sp. had the lowest. In contrast to visitation rate, *A. dorsata* and *A. mellifera* had the shortest stay time per flower, while *Halictus* sp. remained on flowers the longest.

Table 1. Mean (± SE) visitation rate and frequency, number of pollen grains deposited, and number of pollen grains harvested by different pollinator species on canola crop.

Pollinator species	Visitation rate (Number of flowers visited/minute) (N = 100)	Stay time (Seconds/flower/visit) (N = 100)	Number of pollen grains deposited (N = 50)	Pollen grains harvested (N = 10)
Apis mellifera	8.90±0.38 ^{a}	4.80±0.20 ^{d}	214.40±2.84 ^{b}	612.70±3.45 ^{a}
Apis dorsata	9.30±0.47 ^{a}	4.60±0.27 ^{d}	218.70±5.38 ^{b}	619.80±5.98 ^{a}
Apis florea	6.40±0.27 ^{b}	9.40±0.16 ^{c}	131.80±2.44 ^{c}	325.70±2.31 ^{b}
Halictus sp.	2.80±0.20 ^{d}	16.90±0.41 ^{a}	292.60±1.49 ^{a}	149.30±2.72 ^{d}
E. aeneus	4.30±0.21 ^{c}	12.50±0.34 ^{b}	117.70±1.69 ^{d}	128.50±2.06 ^{e}
E. megacephalus	3.90±0.23 ^{cd}	16.40±0.27 ^{a}	143.20±4.03 ^{c}	166.90±3.84 ^{c}

Means sharing the same letter are not significantly different at $P > 0.05$.

Significant differences were also observed in pollen harvest (F = 3981, df = 5, P < 0.000) and pollen deposition (F = 423, df = 5, P < 0.000) among the six pollinator species. Although *A. dorsata* and *A. mellifera* collected the highest number of pollen grains, they deposited fewer grains on the stigma compared to *Halictus* sp. *Eristalinus aeneus* harvested and deposited the fewest pollen grains (Table 1).

All six pollinator species showed significant differences in pod length (F = 21.7, df = 5, P < 0.000), pod weight (F = 10.4, df = 5, P < 0.000), and number of seeds per pod (F = 41.8, df = 5, P < 0.000) resulting from their single visits (Table 2). The greatest pod length was recorded following a single visit by *E. megacephalus*, followed by *A. mellifera*, *A. dorsata*, and *A. florea*, while the shortest pod length was observed with *E. aeneus*. Similarly, the highest pod weight was obtained from a single visit by *E. megacephalus*, followed by *A. florea* and *E. aeneus*. *A. mellifera*, *A. dorsata*, and *Halictus* sp. did not differ significantly from each other in terms of pod weight. The maximum number of seeds per pod was recorded from single visits by *Halictus* sp. and *A. dorsata*, whereas *E. aeneus* resulted in the lowest seed count. *A. mellifera*, *A. florea*, and *E. megacephalus* showed no statistically significant differences in the number of seeds per pod (Table 2).

Table 2. Mean (± SE) pod length (cm), pod weight (g), and number of seeds per pod resulting from a single visit by different pollinators on the canola crop.

Pollinator species	Pod length (cm)	Pod weight (g)	No. of seeds/pod
A. mellifera	7.30±0.21 ^{ab}	0.14±0.00 ^{c}	19.80±0.42 ^{b}
A. dorsata	7.40±0.22 ^{ab}	0.15±0.00 ^{c}	20.20±0.63 ^{ab}
A. florea	7.20±0.20 ^{ab}	0.17±0.00 ^{ab}	19.60±0.50 ^{b}
Halictus sp.	6.40±0.22 ^{b}	0.14±0.01 ^{c}	22.00±0.76 ^{a}
E. aeneus	4.70±0.21 ^{c}	0.15±0.00 ^{bc}	12.50±0.31 ^{c}
E. megacephalus	8.20±0.42 ^{a}	0.18±0.00 ^{a}	18.50±0.22 ^{b}

Means sharing the same letter are not significantly different at P > 0.05.

Sesame pollination

The eight investigated pollinator species differed significantly in visitation rate (F = 59.05, df = 5, P < 0.000) and stay time (F = 50.99, df = 5, P < 0.000) (Table 3). *Andrena* sp. visited the highest number of flowers per minute, followed by *A. dorsata*, whereas *Halictus* sp. visited the fewest. The shortest and statistically non-significant stay times were recorded for *Andrena* sp. and *C. smaragdula*, while the longest, also statistically non-significant, were observed for *Halictus* sp. and *Chrysomya megacephala* (Table 3).

There were significant differences in both pollen harvest (F = 13.98, df = 5, P < 0.000) and pollen deposition (F = 6.92, df = 5, P < 0.000) among the eight pollinator species. The highest numbers of pollen grains harvested and deposited were by *Andrena* sp. and *A. dorsata*, followed by *A. mellifera*. *Halictus* sp. harvested the fewest pollen grains (Table 3).

Table 3. Mean (± SE) visitation rate, visitation frequency, number of pollen grains deposited, and number of pollen grains harvested by different pollinator species on sesame crop.

Pollinator species	Visitation rate (no. of flowers visited/min) (N = 100)	Stay time (S)/flower/visit (N = 100)	Number of pollen grains deposited (N = 50)	Pollen grains harvested (N = 10)
A. mellifera	7.53±0.42^{c}	5.91±0.11^{c}	32.58±10.53 ^{b}	92.02±14.25 ^{b}
A. dorsata	9.43±0.19^{b}	4.53±0.11^{cd}	48.32±15.62 ^{a}	136.46±21.13 ^{a}
A. florea	6.30±0.42^{d}	9.86±0.66^{b}	25.40±8.21 ^{bc}	71.74±11.10 ^{c}
C. smaragdula	8.86±0.42^{c}	4.22±0.11^{d}	22.98±7.42 ^{bc}	64.9±10.04 ^{c}
Halictus sp.	3.00±0.31^{e}	15.15±3.93^{a}	11.56±3.73 ^{d}	32.66±5.05 ^{d}
Andrena sp.	12.13±0.57^{a}	2.10±0.16^{d}	49.49±16.03 ^{a}	139.76±21.64 ^{a}
C.megacephala	6.10±0.78^{de}	14.25±2.35^{a}	13.04±4.21 ^{cd}	36.85±5.70 ^{d}
E. aeneus	7.45±0.67^{c}	9.98±1.61^{b}	13.79±4.45 ^{cd}	38.96±6.03 ^{d}

Means sharing the same letter are not significantly different at P > 0.05.

All eight pollinator species differed significantly in terms of capsule weight (F = 8.04, df = 5, P < 0.000), number of seeds per capsule (F = 44.06, df = 5, P < 0.000), and weight of 1000 seeds (F = 7.06, df = 5, P < 0.000) resulting from their single visits (Table 4). The maximum capsule weight was recorded following single visits by *Andrena* sp. and *A. dorsata*, while the minimum was observed with *Halictus* sp. Single visits by *Andrena* sp. produced the highest number of seeds per capsule, followed by *A. dorsata*, with the lowest seed count recorded for *Halictus* sp. The maximum seed weight was also observed in single visits by *Andrena* sp. and *A. dorsata*, followed by *A. mellifera* (Table 4).

Table 4. Average (mean ± SE) capsule weight (g), number of seeds per capsule, and weight of 1000 seeds (g) resulting from a single visit by different pollinators on sesame crop.

Pollinator species	Capsule weight (g)	No. of seeds/capsule	Weight of 1000 seeds (g)
A. mellifera	2.22±0.07 [a]	61.5±0.48 [b]	4.63±0.10 [a]
A. dorsata	2.17±0.04[ab]	64.6±0.58 [a]	4.58±0.11 [b]
A. florea	2.09±0.04 [b]	61.1±0.45 [bc]	4.44±0.09 [bc]
C. smaragdula	2.03±0.02 [bc]	60.4±0.44 [c]	4.38±0.09 [c]
Halictus sp.	1.97± 0.03[d]	53.6±1.01 [d]	4.12±0.02 [e]
Andrena sp.	2.25± 0.04[a]	64.9±0.67 [a]	4.65±0.08 [a]
C.megacephala	2.00±0.03 [cd]	59.2± 0.39[cd]	4.25±0.04 [de]
E. aeneus	2.01±0.02 [c]	60.1±0.36 [c]	4.29±0.04 [d]

Means sharing the same letter are not significantly different at P > 0.05.

DISCUSSION

The typical entomophilous structure of canola and sesame flowers attracts a large number of insect pollinators, including bees, wasps, flies, butterflies, and beetles, which facilitate successful pollination, seed set, and high yields (Das and Jha, 2019; Ali et al., 2011). In the present study, bees and flies were the most frequent floral visitors of canola and sesame.

Ali et al. (2011) reported 35 insect species visiting canola flowers in Multan (Punjab), with *A. dorsata* being the most abundant. Similarly, Akhtar et al. (2018) documented another 35 species in Chakwal (Punjab), while Shakeel et al. (2015) reported five species from Peshawar (Khyber Pakhtunkhwa), Pakistan. Both of these latter studies found *A. mellifera* to be the most abundant floral visitor of canola.

In similar studies on sesame, Viraktmath et al. (2001) recorded 15 species of Hymenoptera, eight species of Diptera, and six species of Lepidoptera from India, while Mahmoud (2012) reported 11 Hymenopteran, three Dipteran, and three Lepidopteran species from Egypt.

In the current study, the highest visitation rate in canola was recorded for *A. mellifera* and *A. dorsata*. In sesame, *Andrena* sp. and *A. dorsata* had the highest visitation rates. The longest stay time was observed for *Halictus* sp. and *E. megacephalus* in canola, and for *Halictus* sp. and *C. megacephala* in sesame. Visitation rate and frequency vary among pollinator species depending on their energy requirements and the availability of floral rewards (Abrol, 2005). These parameters are also influenced by weather conditions, which change temporally and spatially. For instance, *A. florea* and *A. dorsata* exhibit the highest visitation frequencies between 8:00-10:00 AM in summer vegetables, and between 12:00-2:00 PM in winter vegetables in Southern Punjab, Pakistan (Ali et al., 2011; Saeed et al., 2012).

The amount of nectar or pollen available in flowers can significantly affect pollinator behavior, performance, and pollination efficiency (Adegas and Couto, 1992). Nectar availability in canola flowers declines by 12:00 PM, which may explain why *A. florea* collects nectar more quickly in the afternoon than in the morning, as less effort is required to extract it. *A. mellifera* typically maintains floral constancy and does not frequently revisit blooms, which supports effective pollination. However, depending on nectar availability, it may revisit the same flower multiple times (Mensah and Kudom, 2010; Saeed et al., 2012).

In our study, the highest pollen deposition in canola was observed for *Halictus* sp. Although *A. mellifera* and *A. dorsata* harvested the greatest number of pollen grains, they deposited relatively few. In contrast, in sesame, *Andrena* sp. and *A. dorsata* were both the most efficient at harvesting and depositing pollen. A single visit by *Halictus* sp. and *A. dorsata* yielded the highest seed numbers in canola, while in sesame, the same was true for *Andrena* sp. and *A. dorsata*.

It is generally believed that pollinators with higher foraging rates and visitation frequencies deposit more pollen on stigmas (Singh et al., 2006). However, some studies have shown that high visitation rates do not always correlate with effective pollen deposition (Singh et al., 2006). Pollen deposition is influenced by factors such as stay time, foraging behavior, nectar robbing, sex, and morphology of the pollinator (Ali et al., 2011; Akram and Sajjad, 2022).

In our study, *Halictus* sp. showed a comparatively low visitation rate but a longer stay time on flowers. Despite this, it deposited fewer pollen grains, likely due to its smaller body size, a finding consistent with results reported by Ali et al. (2011). Nectar robbing can also reduce the efficiency of a pollinator in pollen deposition (Ali et al., 2011).

Pollinators generally avoid sesame crops, especially when other, more attractive crops are available nearby (Ashri, 2007). Therefore, in conditions of low insect activity, cross-pollination in sesame may fall below 1%. In contrast, in Moreno, a semi-arid region of California, a high out-crossing rate of 68% was recorded where sesame was the dominant flowering plant, and other vegetation was sparse (Kremen et al., 2004).

A. mellifera is globally considered a major pollinator and is estimated to directly or indirectly contribute to the pollination of more than one-third of the world's crops. However, it is not always the most effective pollinator for every crop species (Geslin et al., 2017). In some crops, syrphid flies (Syrphidae) have proven to be more effective pollinators than honeybees (Ali et al., 2011, 2014). Despite the common perception that *A. mellifera* increases crop yield, once it reaches an optimal visitation rate, further visits may negatively affect productivity (Rollin and Garibaldi, 2019). Both native and managed honeybees are important for sustaining pollination services in agroecosystems (Hristov et al., 2020).

CONCLUSION

Solitary bees such as *Halictus* sp. and *Andrena* sp., along with the native honeybee *A. dorsata*, were found to be more effective pollinators of canola and sesame than *A. mellifera* in Southern Punjab, Pakistan. *A. mellifera* exhibited moderate pollination potential in both crops and can play a supportive role alongside native pollinators. Therefore, while conserving native pollinator populations is crucial, crop-specific recommendations regarding the use of *A. mellifera* should consider the surrounding ecosystem and its ecological dynamics.

AUTHORS' CONTRIBUTIONS

MWH, AS, AA and JA conceptualized the idea; JA and AS designed the methodology and collected the data; MWH and AA analyzed the data; MWH, AS, JA and AA wrote the first draft; AK, KFA, AH and EFA reviewed and edited the draft; AA, AH and EFA acquired the funding; All authors have read and agreed to the published version of the manuscript.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

SUSTAINABLE DEVELOPMENT GOALS TARGETED

SDG 2: Zero Hunger

SDG 12: Responsible Consumption and Production

SDG 15: Life on Land

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