



Effect of *Apis cerana himalaya* Fab. pollination on siliqua formation, seed set, seed quality, seed yield and oil content of rapeseed-mustard (*Brassica rapa* var. *toria*)

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Summary

Crop pollination by honey bees plays a vital role in improving the yield and quality of rapeseed-mustard. The present study was conducted to evaluate the influence of *Apis cerana himalaya* Fab. pollination on siliqua formation, seed set, seed quality, seed yield, and oil content in rapeseed-mustard under three pollination treatments: bee pollination (BP), pollination without insects (PWI), and open pollination (OP). The results revealed that bee pollination significantly enhanced all yield and quality parameters compared to PWI and OP treatments. Under BP, the maximum siliqua length (5.81 cm), highest number of seeds per siliqua (14.96), and greater seed yield (0.33 q/ha) were recorded, indicating the positive impact of efficient pollination on crop productivity. Seed quality parameters were also markedly improved under bee pollination, with higher germination percentage (89.57%) and 1000-seed weight (0.19 g). In addition, oil content was highest under BP (77.00%), demonstrating the beneficial effect of honey bee pollination on seed quality and economic value of the crop. The improved performance under bee pollination may be attributed to effective pollen transfer and better fertilization, leading to enhanced seed development and maturation. The findings highlight the significant role of *Apis cerana himalaya* in enhancing rapeseed-mustard productivity and emphasize the importance of pollinator conservation for sustainable agricultural production.

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Keywords: *Apis cerana himalaya* Fab., rapeseed-mustard, siliqua, pollination efficiency

Introduction

Pollination is a vital biological process that plays a key role in maintaining healthy and biodiverse ecosystems. Insects constitute one of the primary groups of pollinating agents, and the association between insects and flowering plants is well established. Insect pollination is essential for the reproduction and persistence of many wild plant species (Ollerton et al. 2011). Pollinators provide important ecosystem services, and animal-mediated pollination contributes approximately 15–30% of global food production, with bees recognized as the most important group (Atmowidi et al. 2008). Pollination is an essential process in the sexual reproduction of plants, involving the transfer of pollen grains from the male reproductive organ (anther) to the female reproductive organ (stigma), thereby enabling fertilization (Buchmann & Nabhan 1996). Pollinators thus support both natural and agricultural ecosystems. Agricultural productivity depends, in part, on pollinator populations present in surrounding semi-natural habitats (Atmowidi et al. 2007; Nidhi and Haldhar 2026). Globally, bees contribute significantly to crop pollination (Gallai et al. 2009; Singh et al. 2022). In Brassica crops, including rapeseed-mustard, pollination is particularly dependent on insects because the pollen

grains are sticky and require external agents for effective transfer. This highlights the close mutual relationship between bees and Brassica species, where bees act as efficient pollen vectors (Challa et al. 2019; Haldhar et al. 2021a&b). Among pollinators, members of the order Hymenoptera—especially honey bees—are considered highly efficient and economically important due to their foraging behaviour and ability to collect nectar and pollen for brood rearing. *Apis cerana* Fabricius, commonly known as the Asiatic honey bee, is widely distributed across Asia and has been used for honey production and pollination services for centuries (Koetz, 2013; Haldhar et al. 2025; Nidhi et al. 2025). Honey bees play a crucial role in enhancing crop productivity, contributing to 15–30% of the global food supply through pollination (Greenleaf & Kremen 2006). The efficiency of apiculture largely depends on bee species, management practices, and the availability of floral resources such as nectar and pollen (Shruthi et al. 2009; Haldhar et al. 2024). During foraging, honey bees facilitate the transfer of pollen between flowers, thereby improving pollination efficiency, fertilization success, seed set, fruit development, and overall crop productivity. Recent studies have highlighted that managed honey bee pollination significantly enhances both the quantity and quality of agricultural produce, particularly in insect-pollinated crops (Klein et al. 2007; Potts et al. 2016). Hence, honey bees remain among the most important pollinators contributing to global food security and sustainable agricultural production.

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Materials and Methods

The field experiments were conducted for two consecutive years in 2022 and 2023 during the *rabi* season on the mustard-rapeseed variety TS-38 at College of Agriculture, Central Agriculture University, Imphal, Manipur, India. Sowing was done during November in the two years. The land was prepared with farm yard manure at 5 tonnes /ha, was thoroughly incorporated into the soil, and levelled properly with other recommended agronomic practices. Various parameters were computed using various pollination methods.

Setting of the net: Nylon net was erected on the standing crop of Bee Pollination (BP) and Pollination Without Insects (PWI) treatments just before the flowering of rapeseed. In BP treatment the plot was caged with nylon net forming a large single cage. In PWI treatment, a separate individual net was erected on each of the three plots forming a compartment so as to prevent the entry of insect pollinators. The cages were removed when florets in almost all the flowers withered in BP and PWI. In case of Open Pollination (OP) treatment, plants were not caged.

Release of bee: When the crop bloom reaches 10 per cent *A. cerana himalaya* Fab. with a strong colony was placed inside the cage, and thus entry of other insects should be avoided in the plot with net of Bee Pollination (BP) treatment until the end of the flowering.

Ten plants were selected randomly during harvest from each plot and the comparative effectiveness of the different pollination treatments was judged based on the following parameters:

1. **Siliqua length (cm):** Five siliqua were selected from ten plants, each from top, middle and bottom at random and the average length of siliqua was calculated.
2. **No. of seed per siliqua:** Five siliqua from selected ten plants were collected randomly from the top, middle and bottom, the average number of seed content per siliqua was worked out.
3. **Seed yield (q/ha):** Ten healthy plants were sundried thoroughly from each replication, and the weight of the seed was recorded after sun drying thoroughly. The weight of seeds of each replication was recorded in grams and converted into quintals per hectare.
4. **Seed germination (%):** Twenty seeds from each replication of different treatments were placed on moist blotting paper in a petri dish. These were kept at room temperature and the germination counts were made at 24-hour intervals (Li Y., 2008). The observation was calculated as

$$\text{Germination (\%)} = \frac{\text{Number of seed germinated}}{\text{Number of seeds tested}} \times 100$$

5. **1000 seed count (q/ha):** One thousand healthy seeds from each replication of all the treatments were selected at random, sun-dried properly, then weight of seeds of

each replication was recorded in grams and converted into quintals per hectare.

6. Seed oil content (%): The seed oil was extracted with the help of a Soxhlet apparatus and the percentage of oil content is calculated. (AOAC, 2000)

$$\text{Oil per cent} = \frac{W_2 - W_1}{X} \times 100$$

W2: Weight of extraction flask with oil after Soxhlet extraction

W1: Weight of empty extraction flask (before extraction)

X: Weight of seed sample used for extraction

Statistical analysis

The experimental data obtained from different pollination treatments were analysed using IBM SPSS Statistics. The experiment was conducted in a Randomized Block Design (RBD) with three treatments. The Data recorded was subjected to analysis of variance (ANOVA) to test the significance of treatment effects. Before analysis, the data were examined for normality and homogeneity of variance to ensure the validity of ANOVA assumptions. When the F-test indicated significant differences among treatments, the means were separated using the Least Significant Difference (LSD) test at the 5% level of significance ($p \leq 0.05$). The standard error of difference (SEd $\pm$) and critical difference (CD) values were calculated to compare treatment means. Year-wise analysis was carried out separately for each season (2022–2023 and 2023–2024), followed by pooled analysis across years to determine the overall effect of treatment results.

Results

The effects of bee pollination on the quantity and quality of rapeseed-mustard production during the year in 2022–2023 are summarised in Table 1.

During 2022–2023, bee pollination (BP) recorded the highest performance across all parameters. The siliqua length was maximum under BP (5.90 cm), followed by pollination without insects (PWI) (3.79 cm), while the lowest was observed under open pollination (OP) (3.18 cm). Similarly, the number of seeds per siliqua was highest in BP (14.66), compared to OP (9.18) and PWI (7.27). Seed yield was also maximum under BP (0.16 q/ha), followed by OP (0.07 q/ha) and PWI (0.04 q/ha). Seed germination percentage was highest in BP (89.79%), followed by PWI (83.87%) and OP (83.87%). The 1000-seed weight was greater in BP (0.09 q/ha) compared to PWI (0.06 q/ha) and OP (0.04 q/ha). Seed oil content was also highest under BP (76.95%), followed by OP (75.55%) and PWI (75.39%).

Bee pollination (BP) showed a marked increase over both pollination without insects (PWI) and open pollination (OP) across all parameters. The increase over PWI was 55.40% in siliqua length, 101.65% in number of seeds per siliqua, 286.66% in seed yield, 7.05% in seed germination, 77.29% in 1000-seed weight, and 2.06% in seed oil content. Similarly, when compared to OP, bee pollination recorded greater improvements of 71.13% in siliqua length, 59.69% in number of seeds per siliqua, 114.82% in seed yield, 7.05% in seed germination, 130.98% in 1000-seed weight, and 1.85% in seed oil content.

Table 1. The effects of mode of pollination on the quantity and quality of rapeseed-mustard during the year in 2022-2023

Mode of pollination	Siliqua length (cm)	No. of seeds per siliqua	Seed yield (q/ha)	Seed germination (%)	1000 seed count (q/ha)	Seed oil content (%)
Bee pollination (BP)	5.90	14.66	0.16	89.79	0.09	76.95
Control (PWI)	3.79	7.27	0.04	83.87	0.06	75.39
Open Pollination (OP)	3.18	9.18	0.07	83.87	0.04	75.55
SE(d)±	0.25	1.15	0.19	1.87	0.34	1.86
CD	0.54	2.45	0.43	4.13	0.75	N/A
% increase over PWI	55.40	101.65	286.66	7.05	77.29	2.06
% increase over OP	71.13	59.69	114.82	7.05	130.98	1.85

Means were compared using LSD at 5% level of significance ($p \leq 0.05$)

SE(d): Standard Error of Difference, CD: Critical difference

The effects of mode of pollination on the quantity and quality of rapeseed-mustard production during the year in 2022-2023 are summarised in Table 2.

The effects of bee pollination on the quantity and quality parameters of rapeseed-mustard during 2022–2023 are presented in Table 2. A similar trend was observed during 2023–2024, where bee pollination (BP) consistently recorded superior performance compared to pollination without insects (PWI) and open pollination (OP). Under BP, the maximum siliqua length (5.72 cm), highest number of seeds per siliqua (15.26), and greater seed yield (0.16 q/ha) were recorded. In contrast, lower values were observed under OP and PWI treatments. Seed quality parameters were also significantly enhanced under BP, with the highest seed germination

(89.35%), 1000-seed weight (0.09 g), and oil content (77.06%).

Bee pollination markedly improved crop performance over both PWI and OP treatments. Compared with PWI, BP increased siliqua length by 48.18%, number of seeds per siliqua by 134.76%, seed yield by 346.15%, seed germination by 10.93%, 1000-seed weight by 91.08%, and oil content by 5.47%. Similarly, compared with OP, BP increased siliqua length by 93.25%, number of seeds per siliqua by 59.95%, seed yield by 107.15%, seed germination by 8.94%, 1000-seed weight by 106.89%, and oil content by 1.82%. These findings clearly demonstrate the significant role of *Apis cerana himalaya* pollination in improving both yield and quality attributes of rapeseed-mustard.

Table 2. The effects of mode of pollination on the quantity and quality of rapeseed-mustard production during the year in 2023-2024

Mode of pollination	Siliqua length (cm)	No. of seeds per siliqua	Seed yield (q/ha)	Seed germination (%)	1000 seed count (q/ha)	Seed oil content (%)
Bee pollination (BP)	5.72	15.26	0.16	89.35	0.09	77.06
Control (PWI)	3.86	6.50	0.03	80.55	0.06	73.06
Open Pollination (OP)	2.96	9.54	0.08	82.02	0.04	75.68
SE(d)±	0.20	1.13	0.19	1.64	0.28	2.95
CD	0.43	2.48	0.43	3.62	0.62	N/A
% increase over PWI	48.18	134.76	346.15	10.93	91.08	5.47
% increase over OP	93.25	59.95	107.15	8.94	106.89	1.82

Means were compared using LSD at 5% level of significance ($p \leq 0.05$)

SE(d): Standard Error of Difference, CD: Critical difference

The pooled effects of mode of pollination on the quantity and quality of rapeseed-mustard production during the year in 2022-2024 are summarised in Table 3.

The pooled effects of bee pollination on the quantity and quality parameters of rapeseed-mustard during 2022–2024 are presented in Table 3. The pooled analysis clearly demonstrated the superiority of bee pollination (BP) over pollination without insects (PWI) and open pollination (OP). Under BP, the maximum siliqua length (5.81 cm), highest number of seeds per siliqua (14.96), and greater seed yield (0.16 q/ha) were recorded. In

comparison, lower values were observed under OP and PWI treatments. Seed quality parameters were also significantly improved under bee pollination, with the highest seed germination (89.57%), 1000-seed weight (0.09 g), and oil content (77.00%).

The pooled analysis further indicated substantial improvement in crop performance under bee pollination. Compared with PWI, BP increased siliqua length by 52.09%, number of seeds per siliqua by 117.44%, seed yield by 314.28%, seed germination by 8.95%, 1000-seed weight by 82.35%, and oil content by 3.73%. Similarly,

compared with OP, bee pollination increased siliqua length by 89.25%, number of seeds per siliqua by 59.82%, seed yield by 114.81%, seed germination by 7.99%, 1000-seed weight by 121.42%, and oil content by 1.82%. These

findings clearly highlight the important role of *Apis cerana himalaya* pollination in enhancing both yield and quality attributes of rapeseed-mustard.

Table 3. The pooled effects of mode of pollination on the quantity and quality of rapeseed-mustard production during the year in 2022-2024

Mode of pollination	Siliqua length (cm)	No. of seeds per siliqua	Seed yield (q/ha)	Seed germination (%)	1000 seed count (q/ha)	Seed oil content (%)
Bee pollination (BP)	5.81	14.96	0.16	89.57	0.09	77.00
Control (PWI)	3.82	6.88	0.04	82.21	0.06	74.23
Open Pollination (OP)	3.07	9.36	0.08	82.94	0.04	75.62
SE(d)±	0.10	0.55	0.01	1.60	0.15	1.45
CD	0.22	1.14	0.02	3.28	0.30	N/A
% increase over PWI	52.09	117.44	314.28	8.95	82.35	3.73
% increase over OP	89.25	59.82	114.81	7.99	121.42	1.82

Means were compared using LSD at 5% level of significance ($p \leq 0.05$)

SE(d): Standard Error of Difference, CD: Critical difference

Discussion

The present investigation revealed that bee pollination (BP) significantly enhanced yield and yield-attributing parameters of rapeseed-mustard compared to pollination without insects (PWI) and open pollination (OP). These improvements can be attributed to the efficient foraging behaviour of *A. cerana himalaya* Fab., which ensures effective pollen transfer and promotes cross-pollination.

The results of the present investigation showed that bee pollination significantly increased siliqua length. The enhancement in siliqua length under bee pollination may be attributed to efficient transfer of pollen grains, improved hormonal activity within the developing pod leading to successful fertilization and better pod development. In contrast, limited pollination often causes incomplete fertilization and poor pod development. Similar observations have been reported by Free (1993), Patidar et al. (2017), Stanley et al. (2017), Nagpal et al. (2017), Singh et al. (2000), and Sekhon (2020), who observed that insect pollination significantly improved pod characteristics in oilseed crops. Likewise, Abrol (2012) stated that honey bee pollination enhances reproductive growth and siliqua development through efficient pollen transfer.

Bee pollination significantly increased the number of seeds per siliqua compared with open pollination and pollinator exclusion treatments, which indicated better fertilization efficiency, honey bees particularly *A. cerana*, visit a large number of flowers and facilitate uniform pollen deposition on the stigma. The higher seed number may be due to effective cross-pollination and improved fertilization of ovules facilitated by bee visitation. These findings are in agreement with the observations of Klein et al. (2007), who highlighted the essential role of

pollinators in enhancing seed set and reproductive success in agricultural crops. Similar findings were reported by Free (1993), Klein et al. (2007), Patidar et al. (2017), Stanley et al. (2017), Nagpal et al. (2017), Sekhon (2020), who emphasized the critical role of insect pollinators in improving reproductive success in flowering crops.

The significant improvement in seed yield under BP may be due to enhanced pollination leading to a greater number of fertilized ovules and well-developed siliqua. Honey bees are considered highly efficient pollinators because of their floral fidelity and active foraging behaviour, which facilitate effective transfer of pollen among flowers. Enhanced fertilization ultimately results in greater reproductive success and higher economic yield. The findings are in close conformity with those of Abrol (2012), who reported substantial yield enhancement in bee-pollinated oilseed crops. These results are in agreement with Sihag (1997), Abrol (2012), Hossain (2016), Patidar et al. (2017), Nagpal et al. (2017), Stanley et al. (2017) and Yadav et al. (2021) who reported that bee pollination substantially increases yield in mustard and other oilseed crops.

The present study revealed that bee pollination significantly improved seed germination percentage. Enhanced germination under bee pollination may be attributed to effective pollen transfer, complete fertilization, and the development of well-filled and physiologically mature seeds which ultimately enhances seed viability and germination potential. Similar findings were reported by Delaplane & Mayer (2000), who observed that bee-mediated pollination improved seed quality and germination in several agricultural crops. Likewise, Free (1993), Pudasaini et al. (2014), Neha et al.

(2016) and Nagpal et al. (2017) also give the influence of insect pollination on seed germination.

A significantly higher 1000-seed weight was recorded under the bee. The improvement in seed weight may be due to efficient pollination and fertilization, bee activity promotes uniform pollen deposition and better fertilization of ovules, which results in the production of bold and heavier seeds. Reduced seed weight under pollinator exclusion might be associated with incomplete fertilization and poor seed development. The findings are in accordance with the observations of Abrol (2012), who reported that bee pollination significantly increased seed size and seed weight in oilseed crops. Similar observations were made by Partap & Verma (1994), Hossain (2016), Nagpal et al. (2017), Devi and Sharma (2018) and Delaplane & Mayer (2000) who highlighted the positive impact of honey bee pollination on both seed quantity and quality.

Bee-pollinated plants recorded higher oil content compared to control and open-pollinated treatments, indicating the positive effect. Adequate pollination enhances fertilization efficiency and seed maturity, which may promote better synthesis and accumulation of oil in seeds. Lower oil percentage under pollinator exclusion may result from incomplete seed development and poor physiological maturity. Similar observations were reported by Sihag (1997), who found higher oil content in insect-pollinated oilseed crops than in pollinator-excluded treatments. Furthermore, Partap (2011), Nagpal et al. (2017), Yadav et al. (2021) and Sekhon (2020) highlighted that bee pollination not only increases crop yield but also improves qualitative parameters, including oil recovery and seed composition.

These findings further strengthen the importance of managed pollination using *Apis cerana*, particularly under conditions where natural pollinator populations are limited. Klein et al. (2007) reported that insect pollinators significantly enhance fruit and seed set in many crops, thereby improving the development of reproductive structures such as siliqua. Similarly, Sihag (1997) observed increased siliqua length in mustard due to honey bee pollination, attributing the improvement to efficient pollen transfer and better fertilization. The present findings clearly demonstrate that enhanced pollination by honey bees improves fertilization efficiency, promotes better seed development, and ultimately increases siliqua length and overall crop productivity in rapeseed-mustard.

Conclusion

Bee pollination (BP) significantly improved yield and yield-attributing parameters compared to pollination without insects (PWI) and open pollination (OP) during both years as well as in pooled analysis. Higher seed yield, increased seeds per siliqua, and greater siliqua length under BP indicated superior pollination efficiency under bee-mediated conditions. Seed quality parameters, including germination percentage, 1000-seed weight, and oil content, were also enhanced under bee pollination. The consistency of results across years confirms that managed pollination with *Apis cerana himalaya* is an

effective and reliable strategy for improving rapeseed-mustard productivity and seed quality.

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Declarations of interests

All authors of this manuscript declare that they have no conflict of interest.

Data sharing

All relevant data are within the manuscript.

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