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RESEARCH ARTICLE

Impact of corbicular pollen trapping frequency on pollen yield and colony growth in *Apis mellifera* L. colonies in Indian mustard

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Abstract

Pollen is a nutritionally rich resource collected by bees, providing essential proteins and nutrients required for their growth and development. Effect of varying pollen trapping frequencies on the performance of *Apis mellifera* L. colonies during the Indian mustard flowering were evaluated with the aim of optimizing pollen collection. Maximum pollen collection was recorded under daily pollen trapping (2931.54 g/colony) followed by alternate-day (1338.46 g/colony), every three days (565.13 g/colony) and weekly trapping (214.42 g/colony). In daily trapped colonies, the honey area expanded by 35.03 % compared to 136.52 % in control colonies. Daily pollen trapping severely hindered brood area expansion, resulting in 19.01 % increase compared to the robust growth in control colonies (62.00 %). Alternate day, every three days and weekly trapping resulted in brood area growth rates of 46.12, 60.76 and 68.56 %, respectively. Regarding pollen store area, daily trapping resulted in significantly smaller increase compared to the control. Hence, pollen trapping provides substantial harvests, whereas excessive trapping, particularly daily collection, adversely affects colony strength, highlighting the need for optimized trapping frequencies to balance beekeeper's income with colony health.

Keywords: *Apis mellifera*; colony growth; Indian mustard; pollen; trapping

Introduction

Honeybees play a significant role in our ecosystem and food production through effective pollination (1). They have been commercially utilized for collecting honey and other bee products such as wax, venom, royal jelly, propolis and pollen, which offer tremendous nutritional and health benefits. Pollen is the major food source for bees, containing all the essential vitamins, proteins, minerals, lipids and nutrients that supports the normal growth and development of a bee colony (2). It plays a crucial role in the glandular development of young worker bees, particularly, the hypopharyngeal glands (HGs), which are responsible for producing royal jelly a nutrient-rich substance fed to the queen and young brood. Beyond its nutritional value for honeybees, pollen also plays an important role in bolstering their resistance to diseases and parasites. Additionally, humans consume pollen as a superfood and utilize it in cosmetics and medicine.

Indian mustard [*Brassica juncea* L. (Czern)] is one of the major bee forage crops and is considered as a significant edible oilseed crop in many parts of the world. India is the third largest producer of rapeseed-mustard after Canada and China, contributing around 11 % of the world's total production (3). It is the primary source of canola oil, containing around 38-42 % oil content (4, 5). Traditionally, mustard oil is the primary cooking oil used in Indian subcontinent. Its oil provides balanced levels of saturated and unsaturated fatty acids, omega-6 and omega-3 polyunsaturated fatty acids (PUFAs) and also contains various bioactive substances such as glycosides, flavonoids, phenolic compounds, sterols and triterpene alcohols, which imparts numerous health benefits (4, 6).

Mustard flowers are a rich source of nectar and pollen, attracting many insect pollinators, especially honeybees (7). Although Indian mustard is self-fertile and primarily autogamous, 20-30 % out-crossing has been observed depending on environmental conditions and presence of pollinating insects (8-11). The shape and structure of *Brassica* flowers is ideal for the landing of insect pollinators (12). Their colourful petals, abundant pollen, sweet fragrance and constant nectar supply throughout the flowering period attract insects to visit and feed. Insect pollination plays a crucial role in production of Indian mustard, leading to higher seed yield, larger and more viable seeds and higher oil content (13, 14).

Honeybees are considered primary pollinators because pollen is heavy and sticky, making it unlikely to be carried over long distances by wind. The European honeybee, *A. mellifera,* has emerged as the dominant pollinator species worldwide for a variety of crops. In India, beekeepers commercially utilized *A. mellifera* for both pollination and honey production, while also harvesting other hive products such as pollen, wax and venom to generate additional income. Honeybees' forages and collect floral pollen and nectar during their foraging trips, storing them in the colony for immediate consumption and future survival during dearth period. Foragers carry pollen using specialized structures called corbiculae, located on their hind legs. The collected pollen is moistened with saliva and nectar, then packed into compact pollen loads. Pollen traps of various designs are used to dislodge these corbicular pollen loads from foragers' legs as they enter the hive. As honeybees pass through holes specifically designed to narrow the passage for the worker's body, the pollen pellets are scraped off their legs and fall into a collection tray (2, 15).

Pollen abundance during flowering seasons provides an opportunity to trap and store pollen for use during dearth periods. However, previous research has shown that excessive pollen trapping can severely affect colony growth (16). To address the above concern, various pollen sources that honeybees forage were also observed from the available floral diversity during Indian mustard crop. Impact of various pollen trapping frequencies on colony growth of *A. mellifera* colonies have been examined during the flowering of *B. juncea* (Indian mustard) to optimize honeybee colony health and productivity.

Materials and Methods

Site description

This study was carried out at the Research Area of Oilseed Section and Dryland Farm, Department of Genetics and Plant Breeding, CCS (Chaudhary Charan Singh) Haryana Agricultural University, Hisar, Haryana, India. During 2022-23, twenty bee hives were placed around fields of *B. juncea* (Indian mustard) which were maintained at 45 cm row to row and 15 cm plant to plant spacing. The experimental trial was carried out in a randomized block design, comprising five treatments, each replicated four times during the flowering season.

Experimental setup

Twenty new honeybee colonies of equal strength with 10 bee frames, brood stores and same aged queen were placed near fields of *B. juncea*, fitted with pollen traps following the standard protocol (17). These traps possess removable grids with round holes, allowing bees to pass through while dislodging pollen loads from the legs of returning foragers into a collecting tray. The colonies were divided into five treatment groups, each having four honeybee colonies. Each colony within a group acted as a replication. The first group represented pollen collected daily during the mustard flowering season. In the second group, pollen was collected on alternative days. The third and fourth groups involved pollen collected once in three days and once a week, respectively. The fifth one referred as control and colonies in this treatment were not installed with traps at any time.

Identification of pollen sources visited by *A. mellifera* during the flowering period of *B. juncea*

To identify the pollen collected by honeybees, pollen loads were collected from each hive using pollen traps at weekly interval. For pollen identification, microscopic slides were prepared using the acetolysis method (18). A small part of pollen load was placed on microscopic slide and few drops of 96 % ethyl alcohol were added. The fat substances that appeared on the slide after the addition of alcohol were gently removed using blotting paper. Subsequently, 1-2 drops of acetolysis mixture, freshly prepared by mixing 9 parts acetic anhydride with 1-part sulphuric acid were added to the slide. The slide was gently warmed over an alcoholic lamp to prevent excessive darkening. The contents were then washed with 70 % ethyl alcohol and fixed with dibutylphthalate polystyrene xylene (DPX) mountant, after which a cover slip placed over the preparation. Photomicrographs of the pollen grains were taken by camera attached to a trinocular microscope (Fig. 1).

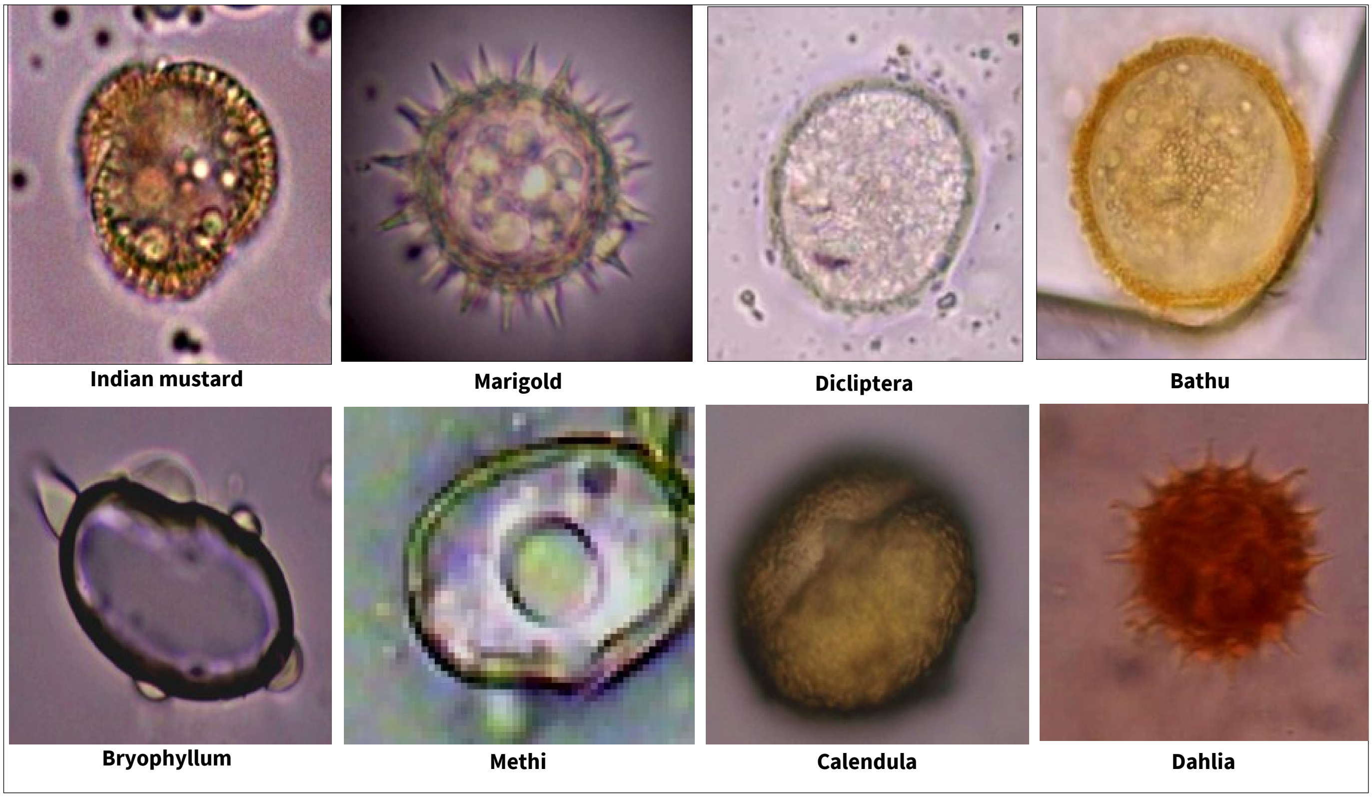

Fig. 1. Photomicrograph of collected pollen grains.

Collection of pollen loads by *A. mellifera* foragers

The pollen traps were removed from the experimental colonies according to the frequency pattern of each treatment (daily, alternate days, etc.) after sunset. The trapped pollen loads from the collection trays of each experimental colony were collected into paper bags and weighed using a digital weighing balance to determine the quantity of pollen collected (in grams).

Impact of different pollen collection frequency on colony growth parameters

Colony growth parameters such as honey stores, nectar stores, egg laying area, brood area and pollen area were recorded for evaluation of the effect of different pollen trapping frequency. The growth parameters of each experimental colony were assessed before observations began (18 December) and recorded at 15 day intervals during the flowering period of Indian mustard. For this purpose, a grid frame having squares of 6.45 cm^2 was used. The number of squares was counted and converted into cm^2 by multiplying the number of squares with a factor of 6.45. The bee strength of colonies was assessed by the number of frames covered by the bees.

Pollen collected at two hour interval during flowering season of the Indian mustard

Pollen collected from *A. mellifera* colony at two-hour interval (0800 hr, 1000 hr, 1200 hr, 1400 hr, 1600 hr and 1800 hr) and were collected separately into paper bags and weighed in grams using the digital balance.

Statistical analysis

A correlation matrix was constructed to examine the relationship between pollen collections and trapping frequency on colony traits across experimental periods. Data recorded for pollen collection and colony growth parameters were statistically analysed by using OPSTAT system software (19). The significance of differences in the effects of treatments was evaluated by the F test and critical difference (CD) was computed at 5 per cent level of significance.

Results and Discussion

Identification of pollen sources collected by *A. mellifera* during the flowering period of *B. juncea*

Laboratory studies identified the different pollen sources that honeybees (*A. mellifera*) collected during the flowering period of Indian mustard (*B. juncea*). It was found that *A. mellifera* foraged on 8 different plant species representing 6 plant families during the mustard flowering season (Table 1). Asteraceae family provided three plants species as pollen sources followed by Brassicaceae, Acanthaceae, Chenopodiaceae, Crassulaceae and Fabaceae which provided one plant species each. Table 1 provides details on the morphology of the pollen grains and the floral source of each species. Among all the observed plant species, the highest number of pollen grains was collected from *B. juncea*, a member of the Brassicaceae family. Flowering plants and other natural vegetation can serve as a secondary food source for *A. mellifera*. Forager bees gathered different floral resources based on seasonal availability of food resources and the nutritional requirements of the colony, indicated by the number of larval and adult bees present in the hive (20-22). Pollen identification enables beekeepers to authenticate the geographical and botanical origin of honey (23).

Collection of pollen loads by *A. mellifera* foragers

Pollen collected by *A. mellifera* during Indian mustard blooming season was extracted from traps after sunset and quantified. Pollen collection frequency was found to be significantly impacting both mean and total pollen collection during Indian mustard season. The mean pollen collection was highest (366.44 g/colony) in daily pollen trapped colonies followed by alternate trapping (167.31 g/colony), once in three days trapping (70.64 g/colony) and weekly trapping (26.80 g/colony).

The amount of pollen load collected appeared to have a positive correlation with the trapping frequencies (Table 2). The trend of increasing mean pollen load collection with increasing pollen trapping frequencies was witnessed by the experiment. The increased pollen trapping frequencies resulted in greater pollen collection in the pollen traps, limiting the supply of pollen to the honeybee colony to meet their pollen requirements. The colony responds to this scarcity by increasing the foraging efforts of individual workers (intensity and load size). As a result, the colony recruited a larger proportion of its total foraging force for pollen collection at the expense of other foraging duties.

The effect of four different pollen collection frequencies (continuous trapping, alternate day, 3 days and weekly) showed the maximum pollen load collection from the continuous trapping followed by alternate day, 3 days and weekly trappings (24). Other workers have also reported higher percentage of pollen foragers with the installation of pollen traps (16, 25). Similar phenomenon was also observed in the continuous or daily trapping of pollen loads that may not have allowed the enhancement of the pollen store area inside the hive therefore, it triggers the colony to recruit more foragers for pollen foraging to

Table 1. Various pollen sources visited by *Apis mellifera* during the *Brassica juncea* blooming period at the study site in 2022-23.

S. No.	Common name	Scientific name	Family	Pollen morphology	Habit and nature
1.	Indian mustard	*Brassica juncea*	Brassicaceae	Round, small, radial symmetry	Herb, oil seed crop
2.	Marigold	*Tagetes* spp.	Asteraceae	Round, small, spinolous, radial symmetry	Herb, ornamental plant
3.	Dicliptera	*Dicliptera bupleuroides*	Acanthaceae	Long, medium, bilateral symmetry	Herb, wild plant
4.	Bathu	*Chenopodium album*	Amaranthecaeae	Round, small, radial symmetry	Herb, weed
5.	Bryophyllum	*Kalanchoe pinnata*	Crassulaceae	Long, medium, bilateral symmetry	Ornamental plant
6.	Methi	*Trigonella foenum-graecum*	Fabaceae	Oval, small, bilateral symmetry	Seed spices crop
7.	Calendula	*Calendula officinalis*	Asteraceae	Round, small, bilateral symmetry	Herb, ornamental plant
8.	Dahlia	*Dahlia pinnata*	Asteraceae	Regular, small, spinolous radial Symmetry	Annual flowering plant

Table 2. Effect of corbicular pollen trapping frequency on pollen collection by *A. mellifera* colonies during flowering of Indian mustard.

Trapping frequency→ weeks↓		Pollen collection (g/colony/week)				
		Daily	Alternate day	3 days	Weekly	Mean
1st week	19-25 December 2022	235.70	95.58	32.35	9.81	**93.36**
2nd week	26 December, 2022-01 January 2023	343.59	128.65	71.56	20.12	**140.80**
3rd week	02-08, January 2023	255.83	111.47	50.67	23.96	**110.48**
4th week	09-15, January 2023	391.90	174.78	84.08	27.79	**169.64**
5th week	16-22, January 2023	524.46	236.12	118.23	36.77	**228.89**
6th week	23-29, January 2023	509.83	256.15	96.74	45.03	**226.94**
7th week	30 January- 05 February 2023	353.43	164.67	69.50	31.60	**154.80**
8th week	06-12 February 2023	316.80	171.05	42.01	19.33	**137.30**
Mean		**366.44**	**167.31**	**70.64**	**26.80**	**157.80**
Total pollen collection		**2931.54**	**1338.46**	**565.13**	**214.42**	
Factors		**CD (p = 0.05)**			**SE(m)**	
Week (A)		10.85			3.83	
Pollen collection frequency (B)		15.35			5.42	
Interaction (A X B)		30.70			10.83	

***wk- week**

meet the demand of pollen with the supply (26). The size of the pollen load, bees size and the diameter of the circular hole in the trap all have an impact on the efficiency of the trap. In addition, the variations in pollen load collection across and within places can be related to changing weather conditions as well as the availability of floral resources throughout the season (25).

Impact of different pollen collection frequency on colony growth parameters

Honey and nectar area

The honey and nectar area in the hive was negatively impacted by the continued trapping of pollen. This may be due to either the physical presence of the pollen traps slowing down foragers returning to the colony or the decline of pollen stores compensated for by additional pollen foraging at the expense of other tasks. The maximum expansion in honey area was recorded by control colonies (136.52 %) followed by weekly trapping (127.27 %), alternate day trapping (125.38 %), three days trapping (121.10 %) and daily trapped colonies (35.03 %). The daily trapped colonies had significantly less mean honey stores (1849.13 cm^2/colony) than alternate day trapped colonies (2260.56 cm^2/colony), three days trapped colonies (2332.87 cm^2/colony), weekly trapped colonies (2407.33 cm^2/colony) and control colonies (2235.24 cm^2/colony). However, there were no significant differences found in the mean amount of honey area between alternate day trapped colonies, three days trapped colonies, weekly trapped and control colonies. As with nectar area, the daily trapped colonies have significantly less than alternate trapping, once in three days trapping, weekly trapping and control colonies.

The highest mean nectar area was recorded in control colonies (1404.54 cm^2/colony) which was found statistically at par with pollen trapping at alternate days (1344.38 cm^2/colony), three days interval (1320.76 cm^2/colony) and at weekly interval (1368.09 cm^2/colony) (Table 3). The decrease in the production of honey or nectar could be due to either the fact that traps imposed a physical restriction on the foragers or may be due to that more foragers were recruited for the purpose of collecting pollen (27). Honey production was reduced by regular pollen trapping throughout the season compared to periodic trapping of pollen (28). On the contrary, there is no effect of different pollen trapping frequencies on overall honey production (24). Insignificant difference was found when compared honey stores between high and low pollen storage colonies (26). These findings suggest that honeybee colonies possess a remarkable ability to regulate their foraging activity in response to pollen availability. When faced with depleted pollen stores, colonies get triggered and try to attain the pre-existing pollen store level through recruiting more pollen foragers, increasing more pollen foraging trips, carrying bigger pollen loads etc to colony strength.

Brood and egg laying area

The brood area of *A. mellifera* colonies did not gain significant brood area when pollen trapping was performed daily, brood area only expanded by 19.01 % while under lower trapping or control the expansion was massive. The maximum expansion in brood area was reported in weekly trapping (68.56 %) while similar to three days of pollen trapping (60.76 %) and control (62.00 %). The highest mean brood area was recorded in control colonies (3120.54 cm^2/colony) which were found statistically at par with pollen trapping at alternate days (2998.70 cm^2/colony), three days intervals (3060.33 cm^2/colony) and at a weekly interval (3019.24 cm^2/colony). As for the egg-laying area, a similar trend of increasing area with decreasing pollen trapping frequency during the Indian mustard bloom was also observed (Table 4). Therefore, alternate day, three days and weekly can be considered as a viable option among all the trapping frequencies.

Availability of the pollen is the trigger for the honeybee colony to rear eggs as in its absence egg production is suspended. The brood development largely depends up on the optimum supply of high proteinaceous pollen loads (29-31). Thus, adult bees without access to adequate protein may also have decreased longevity and decreased development of ovaries and hypopharyngeal glands, thus impacting their ability to rear brood (31-33). Pollen trapping in general and its intensity has been reported to restrict the brood development due to reduced

Table 3. Effect of corbicular pollen trapping frequency on honey and nectar area of *A. mellifera* colonies during flowering of Indian mustard at fortnight intervals.

Trapping frequency→ Date of observation ↓	Honey area (cm²/colony)						Nectar area (cm²/colony)					
	Daily	Alternate day	Three days	Weekly	Control	Mean	Daily	Alternate day	Three days	Weekly	Control	Mean
18 December 2022 (PT)*	1477.93 (0.00)**	1461.52 (0.00)	1513.51 (0.00)	1529.71 (0.00)	1433.01 (0.00)	**1483.14 (0.00)**	678.65 (0.00)**	762.41 (0.00)	665.58 (0.00)	701.28 (0.00)	733.76 (0.00)	**708.34** (0.00)
03 January 2023	1682.76 (13.86)	1754.68 (20.06)	1855.93 (22.62)	1910.34 (24.88)	1824.21 (27.30)	**1805.58 (21.74)**	871.68 (28.44)	1040.68 (36.50)	992.33 (49.09)	1119.95 (59.70)	1148.33 (56.50)	**1034.59 (46.06)**
17 January 2023	2240.21 (51.58)	2532.16 (73.26)	2615.67 (72.82)	2712.75 (77.34)	2694.33 (88.02)	**2559.02 (72.54)**	1243.88 (83.29)	1672.20 (119.33)	1694.40 (154.58)	1620.75 (131.11)	1690.29 (130.36)	**1584.30 (123.67)**
03 February 2023	1995.63 (35.03)	3293.90 (125.38)	3346.39 (121.10)	3476.52 (127.27)	3389.41 (136.52)	**3100.37 (109.04)**	1315.03 (93.77)	1902.23 (149.50)	1930.73 (190.08)	2030.38 (189.53)	2045.80 (178.81)	**1844.83 (160.45)**
Mean	**1849.13**	**2260.56**	**2332.87**	**2407.33**	**2335.24**	**2237.03**	**1027.31**	**1344.38**	**1320.76**	**1368.09**	**1404.54**	**1293.01**
Factors		**C.D. (p = 0.05)**			**SE(m)**			**C.D. (p = 0.05)**			**SE(m)**	
Date of observation (A)		135.12			47.71			81.07			28.63	
Pollen trapping frequency (B)		151.07			53.34			90.64			32.01	
Interaction (A × B)		302.13			106.69			181.28			64.01	

PT** -pre-treated or initial values. *** Figures in parentheses shows the percent change in the area over pre-treated values.

pollen intake or the intake of pollen of lower protein content (16, 34). The colonies with higher trapping frequencies (daily and alternate days) probably have restricted pollen intake in the hives as the pollen loads were trapped by mounting pollen traps of 50 % efficiency (Table 4).

Similar results were observed, where decrease in brood area by 39.5 % when pollen traps were fitted during active pollen availability (35). Brood rearing and colony development may be adversely affected by trapping pollen from colonies (36). The reduction in brood rearing and bee population when colonies were regularly pollen trapped for two months but feeding pollen patties to these colonies during the trapping period increased brood rearing and thus compensated for the negative effect of the trap (37). The increase in capped brood area in continuously trapped colonies initially but in the final interval of almond flowering season capped brood area reduced drastically (16). On the contrary, no significant impact of different trapping frequencies on brood development (24, 25). Honeybee colonies can efficiently compensate for pollen loss through adjusting their foraging behaviour, such as increasing the number of pollen foragers, extending the foraging time or collecting greater pollen loads. These adaptive behaviours help to maintain adequate pollen store for consistent brood rearing during short pollen trapping period.

Pollen store area

In all different pollen trapping frequencies, the pollen store area expanded with the progression of the Indian mustard season but with variable rates (Table 5). The pollen store area grew by 132.25 % in un-trapped (control) colonies compared to their pre-treated values while 24.69 % growth of pollen store area was registered in daily pollen trapping colonies. Whereas when pollen trapped alternatively, at three days and weekly the pollen store area increased progressively compared to daily trapping. However, there were no significant differences found in the mean amount of pollen store area between three days trapping colonies (731.07 cm²/colony), weekly trapping (745.56 cm²/colony) and control colonies (766.34 cm²/colony).

The daily installation of pollen traps significantly reduced the amount of pollen supply to colony and ultimately the storage inside the colony (Table 5). The lower pollen consumption due to pollen trapping was not sufficient to make up the growing demand of the brood and this scarcity may have led to a decrease in the colony pollen store area (38). Similar results were obtained where the colonies that were mounted with pollen traps had significantly lower pollen store area than the colonies without trap with a corresponding increase in proportion of pollen foragers in colonies with traps on (25).

Bee strength

The strength of bees ultimately depends upon the amount of brood reared and food stores available in the colonies. As the present studies indicated that continuous trapping resulted in reduction of brood and food stores, this effect has also been reflected in the strength of bees. Colonies subjected to daily pollen trapping had significantly less mean bee strength (10.84 bee frames/colony) than control (12.92 bee frames/colony), weekly pollen trapped (12.72 bee frames/colony), at three days interval (12.50 bee frames/colony) as well as alternate days trapped (11.61 bee frames/colony) colonies (Table 5).

Table 4. Effect of corbicular pollen trapping frequency on brood and egg laying area of *A. mellifera* colonies.

Trapping frequency→ Date of observation ↓	Brood area (cm²/colony)						Egg laying area (cm²/colony)					
	Daily	Alternate day	Three days	Weekly	Control	Mean	Daily	Alternate day	Three days	Weekly	Control	Mean
18 December 2022 (PT)*	2361.60 (0.00)**	2442.58 (0.00)	2394.65 (0.00)	2286.93 (0.00)	2415.68 (0.00)	**2380.29** (0.00)	571.00 (0.00)**	635.59 (0.00)	577.15 (0.00)	528.76 (0.00)	586.35 (0.00)	**579.77 (0.00)**
03 January 2023	2540.13 (7.56)	2803.74 (14.76)	2756.58 (15.11)	2710.83 (18.54)	2827.10 (17.03)	**2727.67 (14.59)**	613.85 (7.50)	701.83 (10.42)	685.90 (18.84)	634.44 (19.99)	666.43 (13.66)	**660.49 (13.92)**
17 January 2023	2736.4 (15.87)	3179.45 (30.17)	3240.43 (35.32)	3224.48 (41.00)	3326.03 (37.69)	**3141.36 (31.97)**	716.76 (25.53)	832.46 (30.97)	875.96 (51.77)	935.81 (76.98)	948.29 (61.73)	**861.86 (48.65)**
03 February, 2023	2810.53 (19.01)	3569.03 (46.12)	3849.68 (60.76)	3854.75 (68.56)	3913.36 (62.00)	**3599.47 (51.22)**	651.56 (14.11)	898.19 (41.32)	940.43 (62.94)	994.24 (88.03)	1005.91 (71.55)	**898.07 (54.90)**
Mean	**2612.16**	**2998.70**	**3060.33**	**3019.24**	**3120.54**	**2962.20**	**638.29**	**767.02**	**769.86**	**773.31**	**801.74**	**750.04**
Factors		**C.D. ($p = 0.05$)**			**SE(m)**			**C.D. ($p = 0.05$)**			**SE(m)**	
Date of observation (A)		184.28			65.07			44.17			15.60	
Pollen trapping frequency (B)		206.03			72.75			49.38			17.44	
Interaction (A × B)		NS			145.51			98.76			34.87	

***PT** -pre-treated or initial values. ** Figures in parentheses shows the percent change in the area over pre-treated values.

Table 5. Effect of corbicular pollen trapping frequency on pollen store and bee strength of *A. mellifera* colonies.

Trapping frequency→ Date of observation ↓	Pollen store area (cm²/colony)						Bee strength (No. of bee frames/colony)					
	Daily	Alternate day	Three days	Weekly	Control	Mean	Daily	Alternate day	Three days	Weekly	Control	Mean
18 December 2022 (PT)*	524.67 (0.00)**	550.63 (0.00)	517.15 (0.00)	468.64 (0.00)	485.28 (0.00)	**509.27** (0.00)	10.00 (0.0)**	10.00 (0.0)	10.00 (0.0)	10.00 (0.0)	10.00 (0.0)	**10.00 (0.0)**
03 January 2023	563.02 (7.31)	634.11 (15.16)	616.30 (19.17)	591.12 (26.14)	610.11 (25.72)	**602.93 (18.39)**	10.70 (7.00)	11.38 (13.75)	11.63 (16.25)	11.79 (17.88)	12.20 (22.00)	**11.54 (15.38)**
17 January 2023	598.76 (14.12)	741.73 (34.71)	793.18 (53.37)	823.56 (75.73)	842.92 (73.70)	**760.03 (49.24)**	11.13 (11.25)	12.20 (22.00)	13.45 (34.50)	13.85 (38.50)	14.07 (40.70)	**12.94 (29.39)**
03 February 2023	654.21 (24.69)	858.75 (55.96)	997.67 (92.92)	1098.91 (134.9)	1127.06 (132.25)	**947.32 (86.01)**	11.55 (15.50)	12.88 (28.75)	14.92 (49.20)	15.25 (52.50)	15.42 (54.15)	**14.00 (40.02)**
Mean	**585.16**	**696.30**	**731.07**	**745.56**	**766.34**	**704.89**	**10.84**	**11.61**	**12.50**	**12.72**	**12.92**	**12.12**
Factors		**C.D. ($p = 0.05$)**			**SE(m)**			**C.D. ($p = 0.05$)**			**SE(m)**	
Date of oObservation (A)		43.56			15.38			0.22			0.08	
Pollen trapping frequency (B)		48.70			17.20			0.24			0.09	
Interaction (A × B)		97.39			34.39			0.48			0.17	

***PT** -pre-treated or initial values. ** Figures in parentheses shows the percent change in the area over pre-treated values.

The bee strength grew by 54.15 % in un-trapped (control) colonies compared to their pre-treated values while 15.50 % increase of bee strength was recorded in daily pollen trapping colonies. Even short-duration trapping, or the mere presence of a pollen trap, resulted in a significant drop in bee strength compared to control colonies (39). The average bee covered frame increase in daily trapped *A. mellifera* colonies was significantly lesser than the increase in colonies without being trapped during almond and prune flowering season (16). Prolonged pollen removal can lead to nutritional deficiencies, impacting the health and lifespan of adult bees.

Reduced availability of protein and essential nutrients can impair the development of young bees, potentially leading to smaller adult bees with shorter lifespans, or even reduced emergence rates. The present study showed that the full-time trapping had significantly fewer adult bees than the part time or control treatments (36). Part-time trapping or allowing periods of unrestricted pollen flow, seemingly provides a sufficient window for colonies to replenish their stores and support adult bee development, thereby mitigating the negative effects observed under continuous trapping.

Pollen trapping at two-hour interval during flowering season of the Indian mustard

During Indian mustard flowering, the pollen was trapped at two-hour interval such as 0800, 1000, 1200, 1400, 1600 and 1800 hr. The maximum pollen collection of 22.81 g/colony was recorded between 1200-1400-hr time intervals and found significantly higher than pollen collection between 1000-1200 hr (16.48 g/colony) and 1400-1600 hr (12.31 g/colony). Significant differences were noticed among different interval during the flowering season. However, no pollen collection was recorded before 0800 hr. The starting and ending time periods such as 0800-1000 and 1400-1600 hr showed lower mean values of 6.44 and 3.64 g/colony/day, respectively (Fig. 2). Similar results that least pollen collected during the timings 0800-1000 and 1400-1600 hr and concluded that pollen collection was found in correlation with the foraging ratio (15). The findings are also in accordance with maximum foraging rate during the afternoon period (36.02 foragers/min) than the morning period (17.66 foragers/ min) (32).

Similarly, maximum foraging activity of *A. mellifera* on *B. juncea* for 1300 hr (40). Foraging rate starts increasing early in the morning, reaches its peak at the midday and later on declines in the afternoon (41). The maximum percentage of nectar and pollen foraging at 1200-1400 hr (47.75 %) and 0800-1000 hr (44.86 %) respectively (11).

Conclusion

A. mellifera gathered pollen from 8 different plant species representing 6 plant families during the flowering season of *B. juncea*. Three pollen sources belong to Asteraceae family followed by Brassicaceae, Acanthaceae, Chenopodiaceae, Crassulaceae and Fabaceae, providing one plant species each. Among different trapping frequencies, alternate trapping frequency is a viable strategy for beekeepers to obtain optimum pollen yield without significantly compromising colony growth parameters. Beekeepers should adopt alternate-day pollen trapping instead of continuous daily trapping, to maintain colony health. Policymakers and extension agencies should promote pollen trapping as an additional source of income, especially during high pollen flow crops such as Indian mustard, complementing honey production and pollination services. It will eventually reduce dependence on fluctuating honey prices and improve the overall economic sustainability of their farm.

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Authors' contributions

PY conducted the experiment and drafted the manuscript. SY designed the study, edited the manuscript. MKJ assisted in the study and provided technical support. PY and VY contributed to data collection and data analysis. SY and MKJ contributed to the conceptualization and supervision of the research. VKM and KMK reviewed the final manuscript. All authors read and approved the final manuscript.

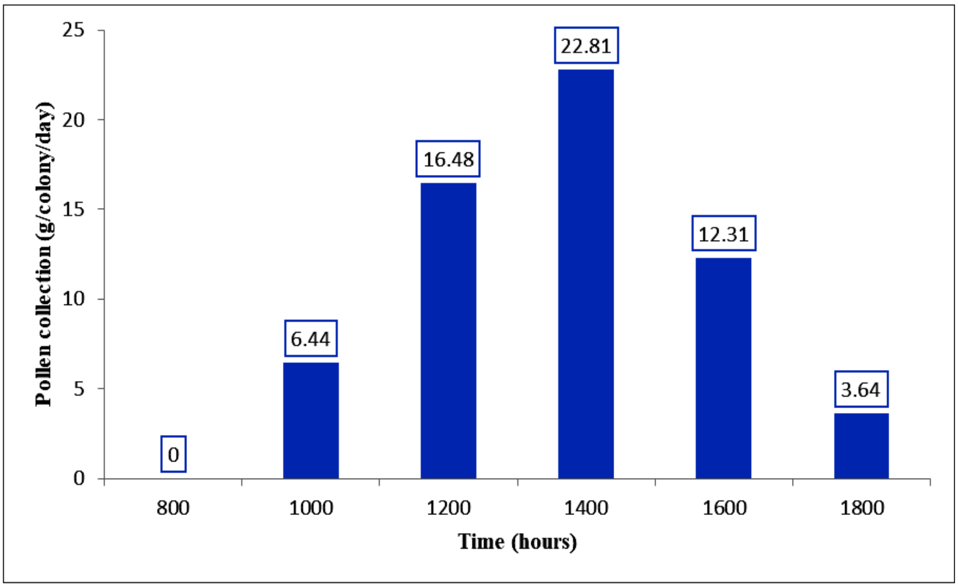

Fig. 2. Pollen trapped at two-hour interval during the flowering season of Indian mustard.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None.

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