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Synchrony of sunflower bloom and bee activity: A Diurnal study on *Apis cerana indica* foraging efficiency

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Abstract
The foraging dynamics of *Apis cerana indica* were evaluated on sunflower (*Helianthus annuus*) across 50% and 100% flowering stages to assess variations in trip frequency, duration, and pollen collection. Results revealed a significant increase in the number of foraging trips during full bloom, with peak activity recorded between 10:00-14:00 h, where trip frequency reached up to 1.66 trips per 10 minutes compared to 1.16 trips at 50% flowering. Enhanced floral abundance at 100% flowering also improved foraging efficiency, as evidenced by shorter trip durations (6.19-6.68 min) compared to the longer times recorded during 50% flowering (6.84-6.98 min). Even during early morning hours (06:00-08:00 h), bees foraged more rapidly at full bloom, completing trips in 7.00-7.34 min versus 7.40-7.85 min at 50% flowering. Colony-wise variations were minimal, indicating that external factors such as floral availability and time of day exerted stronger influence on foraging patterns than intra-colony conditions. In contrast, pollen load per forager showed no significant differences between flowering stages, remaining consistent at 10.06-13.14 mg ($p = 0.956$). All marked bees successfully returned to their hives, confirming strong homing ability. Overall, the findings highlight that honey bees dynamically adjust their foraging frequency and efficiency on sunflower in response to floral abundance and diurnal cues, while maintaining stable pollen collection.

Keywords: *Apis cerana indica*, foraging behavior, flowering stages, pollen, trips

Introduction

Pollinators are key components of crop ecosystems, playing an important role in seed production, fruit set, and quality improvement. Among them, honey bees are considered the most efficient pollinators because of their social behavior, large colony size, and regular foraging activity (Klein *et al*., 2007) [6]. In Asian countries, *Apis cerana indica* F., the Indian hive bee, is widely distributed and managed by farmers. This species is smaller than *Apis mellifera* but is well adapted to tropical and subtropical conditions, capable of effective foraging even in variable environments (Verma, 1990) [12].

Sunflower (*Helianthus annuus* L.) is one of the major oilseed crops cultivated in India and across the world. Its seeds are valued for high-quality edible oil and protein-rich meal used for animal feed. Although sunflower can self-pollinate, cross-pollination by insects significantly improves seed set, seed filling, and oil content (Free, 1993; Mishra & Kumar, 2018) [5, 9]. Honey bees are the most reliable and dominant pollinators of sunflower. They visit flowers in large numbers and transfer pollen effectively between florets, which results in improved seed formation and uniform head filling.

The flowering stage of sunflower influences bee visitation. At 50% flowering, fewer flowers are open and resources are partially available, whereas at 100% flowering, floral density, nectar, and pollen availability are at their peak, attracting more bees and increasing foraging activity (Singh *et al*., 2017) [11]. Time of day also affects bee activity. Honey bees are generally less active in early morning (06:00-08:00 h) and late afternoon (16:00-18:00 h), while peak activity occurs during mid-morning to early afternoon (10:00-14:00 h), coinciding with optimal temperature, light, and nectar availability. Longer foraging trips are usually observed during cooler hours, whereas shorter trips occur during peak periods (Corbet *et al*., 1993) [4]. Environmental conditions such as temperature, humidity, and floral resource availability are the main drivers of bee activity, while differences among colonies are generally minor.

Effective pollination by honey bees contributes to higher seed yield and quality in sunflower (Free, 1993; Mishra & Kumar, 2018) [5, 9].

Materials and Methods

Experimental field

This study was conducted by using PENNA 306 variety of sunflower under natural field conditions during *Kharif* 2024-25. The crop was raised by following all the standard agronomic practices as per the recommendation of package of practices of the University of Agricultural Sciences, Raichur. The experiment was conducted at Entomology experimental field, College of Agriculture, Gangavathi.

Marking of Honey bees

Seven young and active foraging bees carrying visible pollen loads were identified and collected from each of the three colonies. Collected bees were refrigerated for 2 minutes in 4℃ to make them immobile. Each bee was marked with one bright colour and totally seven colours were used *viz;* red, yellow, orange, green, blue, white and pink (Plate 1) to mark the chilled bees on their thorax and then they were released back to the hive (Scheiner *et al*., 2013) [10].

Observations

Observations on marked bees were made at 50 % and 100% flowering days for three consecutive days. Six Observations were made at every two-hour interval starting from 6:00 to 18:00 for a period of 10 minutes at each interval.

Time Taken Per Trip

The time taken by an individual marked bee to complete one foraging trip was recorded. It is the time taken by a bee from the take-off from the alighting board to come back on the alighting board after completing the foraging.

Number of Trips: The total number foraging trips done by each marked bee was counted.

Pollen Quantification

At the end of the experiment all the marked bee returning after foraging from three colonies were collected at pollen trap and the pollen loads on their body were collected using camel hair brush after immobilising bee and quantified.

All seven colour-marked bees from three colonies were continuously monitored throughout the study. No loss of marked bees was observed during three consecutive days of data collection, ensuring consistency in individual tracking and reliability of the recorded data.

Table 1: Foraging activity of colour marked bees at different times of day during different flowering stages of sunflower

		No of Trips/10min																	
		Time(h)																	
		06:00:00-8:00:00			8:00:00-10:00:00			10:00:00-12:00:00			12:00:00-14:00:00			14:00:00-16:00:00			16:00:00-18:00:00		
No of Colonies		R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3
Colours	Parameters	50% Flowering																	
RED	No of Trips	0.67	0.67	0.33	0.67	0.33	0.67	1.33	1.16	1.33	0.33	0.67	0.33	0.00	0.33	0.33	0.67	0.67	0.67
	Time taken	7.40	7.45	7.85	7.95	7.94	7.64	6.98	6.84	6.91	8.01	8.01	8.04	0.00	8.45	8.47	7.95	7.68	7.91
YELLOW	No of Trips	0.33	0.33	0.67	1.00	0.67	1.00	1.16	1.00	1.33	0.67	0.33	0.67	0.67	0.67	0.67	0.67	1.00	0.97
	Time taken	7.48	7.58	7.67	7.48	7.67	7.94	6.89	6.81	6.57	8.29	8.16	8.34	8.37	4.57	8.67	7.64	7.61	7.34
GREEN	No of Trips	0.67	0.33	0.67	0.33	0.67	0.33	1.33	1.33	1.00	0.33	0.67	0.33	0.67	0.67	0.33	1.00	0.67	0.67
	Time taken	7.38	7.67	8.04	7.28	7.91	7.68	6.92	6.94	6.84	8.38	8.34	8.16	8.37	8.33	8.54	7.18	7.08	7.94
BLUE	No of Trips	0.67	0.00	0.33	1.00	0.67	0.67	1.16	1.16	1.33	0.00	00	0.33	0.67	0.33	0.33	0.67	0.67	0.33
	Time taken	7.83	0.00	7.98	7.84	7.39	7.93	6.81	6.94	6.79	8.65	00	8.49	8.29	8.57	8.19	7.82	7.64	7.81
PINK	No of Trips	0.33	0.67	0.33	1.16	1.00	1.00	1.33	1.33	1.16	0.67	0.67	0.67	0.33	0.00	0.33	0.67	0.67	0.33
	Time taken	7.77	7.76	7.69	7.96	7.34	7.34	6.87	6.78	6.75	8.59	8.06	8.57	8.17	0.00	8.49	7.28	7.97	7.08
WHITE	No of Trips	0.67	0.67	0.33	0.67	1.00	0.67	1.33	1.00	1.33	1.00	0.33	0.67	0.33	0.33	0.33	0.67	0.33	0.67
	Time taken	7.43	7.58	7.91	7.84	7.94	7.87	6.79	6.91	6.90	8.74	8.14	8.49	8.19	8.49	8.30	7.38	7.65	7.90
ORANGE	No of Trips	0.00	0.33	0.67	0.67	1.00	0.67	1.33	1.16	1.00	0.67	0.33	0.33	0.00	0.67	0.33	0.67	1.00	0.67
	Time taken	0.00	7.54	7.61	7.69	7.73	7.71	6.93	6.59	6.83	8.69	8.17	8.67	0.00	8.88	8.17	7.28	7.91	7.80
		No of Trips/10min																	
		Time(h)																	
		06:00:00-8:00:00			8:00:00-10:00:00			10:00:00-12:00:00			12:00:00-14:00:00			14:00:00-16:00:00			16:00:00-18:00:00		
No of Colonies		R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3
Colours	Parameters	100% Flowering																	
RED	No of Trips	0.67	0.33	0.67	1.00	1.33	1.00	1.50	1.50	1.16	1.00	1.00	1.00	0.67	0.67	0.33	1.00	0.67	1.00
	Time taken	7.14	7.08	7.34	7.01	7.29	7.16	6.59	6.59	6.19	8.01	8.06	8.09	8.09	8.34	8.34	7.19	7.03	7.19
YELLOW	No of Trips	0.67	0.67	0.67	1.00	1.00	1.33	1.16	1.16	1.5	0.67	1.33	1.00	0.67	0.67	0.67	1.00	0.67	1.00
	Time taken	7.02	7.27	7.16	7.25	7.27	7.04	6.54	6.67	6.37	7.96	8.07	8.06	7.94	8.16	8.06	7.69	7.15	7.09
GREEN	No of Trips	0.67	0.67	0.67	1.00	1.00	1.33	1.16	1.66	1.5	0.67	0.67	1.00	0.67	0.67	0.67	1.00	1.00	0.67
	Time taken	7.19	7.09	7.19	6.99	7.39	709	6.57	6.57	6.19	7.92	8.06	8.16	8.39	8.06	8.15	7.09	7.16	7.25
BLUE	No of Trips	0.33	0.67	0.33	1.33	1.33	1.00	1.33	1.33	1.66	0.67	0.67	0.67	0.67	0.67	0.67	1.00	1.00	1.00
	Time taken	7.29	7.37	7.27	7.34	7.08	7.34	6.49	6.91	6.48	8.16	8.71	8.24	8.17	8.45	8.45	6.98	7.16	7.19
PINK	No of Trips	0.67	0.67	0.00	1.33	1.00	1.00	1.66	1.66	1.16	1.00	0.67	0.67	0.67	0.33	0.67	1.00	0.67	1.00
	Time taken	7.36	7.06	0.0	7.19	7.09	7.06	6.68	6.27	6.92	8.07	8.15	8.34	8.08	8.61	8.06	6.87	7.19	7.06
WHITE	No of Trips	0.67	0.67	0.33	1.16	1.00	1.00	1.5	1.50	1.55	1.00	1.00	0.67	0.67	0.67	0.67	0.67	1.00	0.67
	Time taken	7.01	7.04	7.18	7.36	7.45	7.08	6.97	6.19	6.64	8.06	8.09	8.09	7.83	8.24	8.27	7.23	7.06	7.20
ORANGE	No of Trips	0.67	0.33	0.67	1.00	1.00	1.00	1.33	1.16	1.16	1.33	0.67	1.00	0.67	0.67	0.67	0.67	0.67	1.00
	Time taken	7.37	7.15	7.37	7.09	7.19	7.17	6.68	6.974	6.78	7.94	8.31	8.31	7.84	8.05	8.02	7.49	7.09	7.10

Table 2: Pollen quantification of marked bees from different flowering stage of sunflower

	Pollen Weight (mg)					
	50% Flowering			100% Flowering		
Colours	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**
Red	11.21±0.09	10.96±0.23	11.36±0.13	12.36±0.01	10.06±0.03	11.98±0.11
Yellow	10.78±0.07	13.02±0.18	10.48±0.07	11.95±0.21	11.89±0.06	11.82±0.12
Green	11.54±0.08	12.94±0.02	12.45±0.05	12.09±0.28	11.34±0.17	10.67±0.26
Blue	12.84±0.24	11.57±0.20	11.16±0.24	11.28±0.11	11.34±0.17	12.57±0.11
Pink	11.56±0.23	10.36±0.06	13.11±0.13	10.62±0.02	12.49±0.33	11.09±0.18
White	10.98±0.11	11.01±0.17	11.52±0.18	13.14±0.15	10.93±0.09	10.99±0.17
Orange	12.84±0.24	12.07±0.29	10.88±0.21	11.08±0.06	12.34±0.07	12.26±0.08
t value	$t = 0.056$, $p = 0.956$ (NS)					

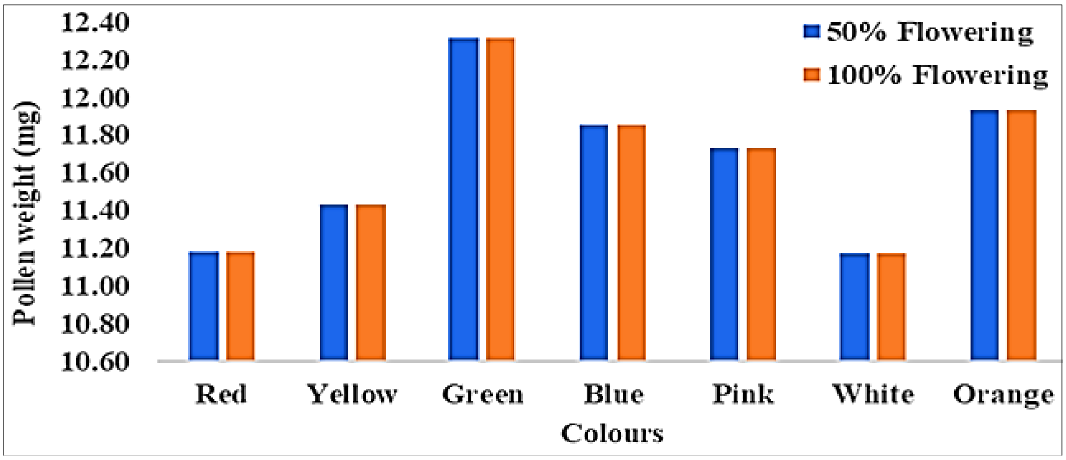

Fig 1: Pollen quantification of marked bees from different flowering stage of sunflower

Plate 1: Tagging of Bees

Results and Discussion

Influence of Flowering Stage on Foraging Activity

The foraging behavior of honey bees showed a significant difference between the 50% and 100% flowering stages. During the 100% flowering period, bees exhibited a higher number of foraging trips per 10 minutes across all colonies and times of the day. During 10:00-12:00 h interval, the average number of trips increased from 1.16 times at 50% flowering to approximately 1.5 trips at 100% flowering. Similarly, during the 08:00-10:00 h period, trip frequency improved from 0.67-1.00 trips at 50% flowering to 1.00-1.33 trips at full bloom. This clear enhancement in foraging frequency can be attributed to increased floral resource availability during the full bloom, which encourages more foragers to be active. In addition to the number of trips, the time taken per foraging trip also showed noticeable improvement. At 50% flowering, bees spent around 6.84-6.98 minutes per trip during the 10:00-12:00 h interval whereas, at 100% flowering, the time dropped to about 6.19-6.68 minutes, reflecting higher foraging efficiency. Even during early morning (06:00-08:00 h), where foraging is typically lower, bees at 100% flowering completed trips slightly faster (7.00-7.34 min) compared to 50% flowering (7.40-7.85 min). In general, bees were more efficient and frequent in their foraging efforts when flower density and nectar availability were optimal, emphasizing the strong impact of floral abundance on foraging performance. The results are inline with Bruninga-Socolar *et al*. (2016) [2] found that bees increased visitation rates in patches of higher floral abundance, and that floral density is a key driver of foraging intensity in field settings. Similarly, Klein *et al*. (2019) [8] demonstrated that honey bee foragers improve their performance and frequency of trips with experience; only a subset of bees performed the majority of trips, and trip efficiency improved over time. This resonates with our finding of more frequent and faster trips under optimal floral conditions.

Influence of Time of Day and Colony-wise Variations

Time of day had a clear and consistent impact on both the number of trips and time taken per trip. Across both flowering stages, peak foraging activity occurred between 10:00 and 14:00 h, during which the number of trips per 10 minutes was highest, reaching up to 1.66 trips at 100% flowering. In contrast, the early morning hours (06:00-08:00 h) and late afternoon (16:00-18:00 h) recorded fewer trips, often between 0.33 and 0.67 trips per 10 minutes at 50% flowering, and slightly better at 100% flowering. Additionally, foraging trips during early and late hours tend to be longer, with durations exceeding 7.5 minutes in some cases, likely due to cooler temperatures or reduced nectar secretion. In contrast, during peak hours, bees completed trips in 6.19 minutes. Colony-wise, the foraging patterns among the replications were similar across both flowering stages and time intervals. At 100% flowering during 10:00-12:00 h, all three colonies recorded more than 1.16 trips per 10 minutes with only minor differences in trip duration (Table 1). The results are on par with Beutler and Loman, (1951) who reported that the average time taken by honey bees to complete its foraging trip was 7-10 minutes. This consistency across colonies suggests that environmental cues, particularly flower availability and time of day, played more significant role in shaping foraging activity than internal colony conditions.

The results demonstrate that, honey bees dynamically adjusted their foraging behavior in response to external floral cues and diurnal changes, optimizing their efficiency when resources are most abundant and conditions are favorable. All seven marked bees (Red, Yellow, Green, Blue, Pink, White, and Orange) successfully returned to the hive after release with no loss, confirming their strong homing ability.

Pollen Quantification

The quantity of pollen collected by honey bee foragers remained consistent from the 50% flowering stage to the 100% flowering stage across all observed colonies and marked bees. At 50% flowering, average pollen loads ranged from 10.36 mg to 13.11 mg, while at 100% flowering, they ranged from 10.06 mg to 13.14 mg, indicating that pollen collection per forager was largely similar across both stages. Statistical analysis confirmed that there was no significant difference in pollen loads between the two flowering stages (paired t-test, p value 0.956), suggesting that honey bees maintained stable foraging efficiency regardless of flowering intensity (Table 2 and Fig.1). The results and in line with Chamer *et al*. (2015) [3] reported that on average honey bees collect 10-14mg of pollen.

Summary and Conclusion

Honey bees exhibited clear differences in foraging behavior between 50% and 100% flowering stages of sunflower. During full bloom, the number of foraging trips increased across all colonies and time periods, while trip durations decreased, reflecting higher foraging efficiency when floral resources were abundant. Peak activity occurred between 10:00 and 14:00 h, whereas early morning and late afternoon showed reduced trips and longer durations. Colony-wise patterns were consistent, indicating that external factors such as flower availability and time of day had a stronger influence on foraging behavior than internal colony conditions.

Despite variations in foraging frequency and duration, pollen loads per forager remained stable across both flowering stages, ranging from approximately 10-13 mg. This suggests that honey bees maintained consistent pollen collection regardless of flower density. The successful return of all marked bees further confirmed their strong homing ability. Overall, honey bee foraging activity is strongly influenced by floral abundance and diurnal changes, while pollen acquisition per bee remains largely unaffected by flowering intensity.

Future studies could explore the influence of environmental stressors, such as temperature extremes or pesticide exposure, on foraging efficiency and pollen collection. In addition, assessing the role of different floral species in shaping foraging patterns could help optimize pollination strategies for crop improvement.

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