



Effect of weather parameters on the foraging activity of *Apis cerana indica* in a coastal agroecosystem

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Abstract

Experiments were conducted under field conditions during summer and winter 2022 at Pandit Jawaharlal Nehru College of Agriculture and Research Institute (PAJANCOA and RI), Karaikal, Puducherry, to assess the influence of weather parameters on the foraging behaviour of *Apis cerana indica*. Correlation analysis revealed that foraging behaviour varied with season and time. In summer, morning foraging (06:00 h) showed negative association with temperature and positive correlation with relative humidity and rainfall, whereas evening activity (16:00 h) was positively correlated with all-weather parameters. In winter, foraging activity was positively associated with temperature and rainfall but negatively influenced by relative humidity. Foragers without pollen load showed positive correlation with temperature and humidity, while rainfall exerted a negative effect in summer. Foragers with pollen load exhibited positive association with temperature and negative correlation with relative humidity and rainfall. Overall, temperature emerged as a key driver of foraging activity, with humidity and rainfall showing season-dependent effects.

Keywords: *Apis cerana indica*, foraging behavior, weather parameters, correlation analysis, relative humidity, rainfall, temperature

Introduction

Honey bees are among the most important pollinators in both natural and agricultural ecosystems, contributing substantially to global food production and biodiversity conservation. It is estimated that a significant proportion of flowering plants and nearly one-third of global crop production depend on insect-mediated pollination, with honey bees playing a dominant role (Klein *et al.*, 2007) [13]. In India, the Indian honey bee, *Apis cerana indica* (Fabricius) is a widely distributed indigenous honey bee species, well adapted to diverse agroclimatic conditions, particularly in tropical and subtropical regions. Its ecological adaptability, disease resistance, and efficiency in pollination make it highly suitable for sustainable beekeeping practices in coastal agroecosystems (Abrol, 2011) [2].

Foraging behaviour in honey bees is a critical ecological process that determines colony survival, productivity, and pollination efficiency. It involves complex decision-making mechanisms influenced by both intrinsic factors (such as colony strength and nutritional status) and extrinsic environmental variables (Winston, 1987) [19]. Among the environmental factors, weather parameters including temperature, relative humidity, and rainfall—play a pivotal role in regulating the timing, frequency, and intensity of foraging activity (Corbet *et al.*, 1993) [5]. These abiotic factors directly affect flight activity, floral resource availability, and nectar secretion patterns.

Temperature is considered one of the most influential factors affecting bee activity, as it regulates metabolic processes and flight muscle function. Honey bees typically exhibit optimal foraging within a specific temperature range, beyond which activity declines (Heinrich, 1979) [10]. Relative humidity also influences foraging indirectly by affecting nectar concentration and pollen viability, thereby altering floral attractiveness to bees (Abrol, 2012) [3].

Rainfall, on the other hand, can limit flight activity, reduce foraging duration, and disrupt communication mechanisms such as waggle dances, ultimately affecting resource collection efficiency (Free, 1993) [8].

In coastal agroecosystems, weather conditions are often dynamic and characterized by high humidity, fluctuating temperatures, and intermittent rainfall. These conditions can significantly influence the behaviour and efficiency of pollinators, particularly *A. cerana indica*. The coastal region of Karaikal (Puducherry) experiences such climatic variability, which may alter the temporal patterns of foraging activity. Despite the ecological and economic importance of this species, region-specific studies focusing on the interaction between weather parameters and foraging behaviour under coastal conditions remain limited.

Previous studies have demonstrated that honey bee foraging activity varies with time of day and seasonal changes, often showing peak activity during favorable environmental conditions (Roubik, 1989; Abou-Shaara, 2014) [1, 18]. Additionally, the response of pollen and non-pollen foragers to environmental factors may differ, reflecting variations in resource requirements and colony demands (Dreller *et al.*, 1999) [7]. Understanding these patterns is essential for improving beekeeping management practices and enhancing pollination services in crop production systems.

Given the increasing concerns over climate variability and its impact on pollinator populations, it is important to investigate how weather parameters influence the foraging behaviour of key pollinator species. Such knowledge can aid in developing adaptive strategies for sustainable apiculture and crop pollination, particularly in vulnerable coastal agroecosystems. Therefore, the present study was undertaken to evaluate the effect of major weather parameters on the foraging activity of *Apis cerana indica* in a coastal agroecosystem.

Materials and Methods

1. Study Area

The field experiments were conducted at the Eastern Farm of Pandit Jawaharlal Nehru College of Agriculture and Research Institute (PAJANCOA and RI), Karaikal, Union Territory of Puducherry, India. The region represents a coastal agroecosystem characterized by tropical climatic conditions, including moderate to high temperatures, elevated relative humidity, and seasonal rainfall.

2. Experimental Period

The study was carried out during two seasons, summer (March–June 2022) and winter (October–January 2022–23), to capture seasonal variability in weather parameters and their influence on foraging activity.

3. Colony Maintenance

Healthy and uniform colonies of *Apis cerana indica* were maintained in standard wooden hives under natural field conditions. Colonies were standardized based on brood area,

adult bee population, and food reserves. Regular inspections were conducted, and standard apicultural practices were followed throughout the experimental period (Abrol, 2011) [2].

4. Recording of Foraging Activity

Foraging activity was assessed by counting the number of outgoing bees at the hive entrance. Observations were recorded at two fixed time intervals, 06:00 h and 16:00 h, representing peak and moderate foraging periods (Free, 1993) [8] (Plate 1).

Foragers were classified into:

1. Total outgoing foragers
2. Foragers without pollen load
3. Foragers with pollen load

Counts were taken for a fixed duration of 5 minutes per colony and replicated across selected colonies at regular intervals (Abou-Shaara, 2014) [1].



Plate 1: Foraging behaviour of the Indian bee, *A. cerana indica*

5. Weather Data Collection

Meteorological data corresponding to the observation periods were obtained from the meteorological observatory at PAJANCOA and RI, Karaikal. The parameters recorded included maximum and minimum temperature (°C), maximum and minimum relative humidity (%), total rainfall (mm), wind velocity (kmph) and sunshine hours as these are key environmental variables influencing honey bee activity (Corbet *et al.*, 1993) [5].

6. Correlation Analysis

The relationship between weather parameters and foraging activity was determined using Pearson’s correlation coefficient (r) following standard statistical procedures (Gomez and Gomez, 1984) [9]:

$$r = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2} \sqrt{\sum(y-\bar{y})^2}}$$

Where,
X = weather parameter,
Y = foraging activity,
 \bar{X} and \bar{Y} = respective means.

Correlation coefficients were computed separately for each season and observation time. The significance of correlation was tested at appropriate probability levels.

7. Regression Analysis

To assess the combined influence of weather parameters on foraging activity, multiple linear regression analysis was performed using the following model (Draper and Smith, 1998) [6]:

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + \epsilon$$

Where,
Y = foraging activity (dependent variable),
*X*₁ = maximum temperature,
*X*₂ = minimum temperature,
*X*₃ = maximum relative humidity,
*X*₄ = minimum relative humidity,
*X*₅ = total rainfall,
a = intercept,
*b*₁, *b*₂, *b*₃, *b*₄, *b*₅ = regression coefficients,
 ϵ = random error term.

The coefficient of determination (R^2) was used to evaluate the proportion of variation in foraging activity explained by the independent variables.

8. Statistical Tools

All statistical analyses were carried out following the procedures described by Gomez and Gomez (1984)^[9]. The results were interpreted to determine the individual and combined effects of weather parameters on the foraging behaviour of *Apis cerana indica*.

Results and Discussion

1. Influence of Weather Parameters on Foraging Activity of *Apis cerana indica*

The correlation analysis indicated that weather parameters exerted variable and largely non-significant effects on the foraging activity of *Apis cerana indica*, with clear differences observed between time of day, season, and type of foragers.

At 06:00 h during summer 2022, outgoing foragers showed non-significant negative correlations with maximum ($r = -0.41$) and minimum temperature ($r = -0.07$), and positive associations with relative humidity ($r = 0.00$ to 0.33) and rainfall ($r = 0.53$). In contrast, non-pollen foragers exhibited positive correlations with relative humidity and temperature but a negative association with rainfall, suggesting that early morning nectar foraging is less constrained by moderate humidity but sensitive to precipitation. Pollen foragers, however, showed weaker or negative relationships with relative humidity and rainfall, indicating that pollen collection is more sensitive to moisture conditions, possibly due to its effect on pollen availability and handling. During winter 2022, morning foragers showed positive associations with temperature ($r = 0.27$ – 0.45) and negative correlations with relative humidity ($r = -0.33$ to -0.50). A similar trend was observed for both pollen and non-pollen foragers, although pollen foragers were more negatively affected by higher humidity, reflecting constraints on pollen release and collection under moist conditions. These findings are consistent with Hemalatha *et al.* (2018)^[11], who reported seasonal variation in *A. cerana indica* foraging linked to environmental conditions.

At 16:00 h during summer 2022, outgoing foragers exhibited positive correlations with temperature ($r = 0.01$ – 0.30), relative humidity ($r = 0.35$ – 0.44), and rainfall ($r = 0.15$). Non-pollen foragers responded positively to relative humidity, indicating favourable nectar foraging conditions in the evening. In contrast, pollen foragers showed positive association with temperature but negative correlation with rainfall, suggesting that pollen collection declines under wet conditions even when temperature remains favourable. During winter 2022 evenings, outgoing foragers showed positive correlations with temperature ($r = 0.24$ – 0.43) and rainfall ($r = 0.22$), while relative humidity had a negative influence ($r = -0.30$ to -0.51). This pattern was more pronounced in pollen foragers, which exhibited stronger negative responses to humidity compared to non-pollen foragers. The differential response indicates that nectar foragers are relatively more tolerant to environmental variability, whereas pollen foragers are more sensitive to humidity and rainfall, likely due to the dependence of pollen availability on dry conditions.

Overall, the study demonstrates that temperature is a key positive regulator of foraging activity, while relative humidity and rainfall exert differential effects on pollen and non-pollen foragers. The diurnal variation suggests that evening foraging is more responsive to environmental conditions than morning activity. These findings are in agreement with Nunez (2015)^[16], who reported that honey bee foraging intensity varies with temperature thresholds and seasonal resource availability, and with Dreller *et al.* (1999)^[7], who highlighted the differential regulation of pollen and nectar foraging in honey bee colonies (Table 1 & 2) (Fig. 1 & 2).

2. Influence of weather parameters on *Apis cerana indica* with nectar load at 6:00 h and 16:00 h

The correlation analysis indicated that, during summer 2022 at 6:00 AM, nectar foragers exhibited non-significant relationships with all weather parameters, showing weak positive correlation with maximum temperature (0.02) and relative humidity (0.53), and negative association with minimum temperature (-0.28) and rainfall (-0.37). In winter 2022, a similar non-significant trend was observed, with positive correlations for temperature (maximum: 0.49; minimum: 0.31) and rainfall (0.16), while relative humidity showed negative associations (maximum: -0.53 ; minimum: -0.36).

At 16:00 h, nectar foragers during summer 2022 showed non-significant positive correlation with relative humidity (maximum: 0.45; minimum: 0.56) and maximum temperature (0.09), whereas minimum temperature (-0.28) and rainfall (-0.36) were negatively associated. During winter 2022, temperature again showed positive relationships (maximum: 0.44; minimum: 0.32), while relative humidity remained negatively correlated and rainfall weakly positive (0.15).

Although most relationships were non-significant, meteorological parameters, particularly temperature and relative humidity, influenced nectar foraging trends. These findings are consistent with Reddy *et al.* (2015)^[17], who reported a strong negative effect of higher temperature (>30 °C) on bee activity, and Mohanty *et al.* (2023)^[14], who highlighted rainfall as a key determinant affecting up to 97.5 per cent variation in nectar foraging (Table 1 & 2) (Fig. 1 & 2).

3. Influence of weather parameters on *Apis cerana indica* with pollen load at 6:00 h and 16:00 h

For pollen foragers at 6:00 AM during summer 2022, non-significant correlations were observed, with slight positive association with relative humidity (maximum: 0.38; minimum: 0.43) and negative association with minimum temperature (-0.31) and rainfall (-0.46). In winter 2022, temperature showed positive correlations (maximum: 0.41; minimum: 0.33), while relative humidity exhibited a significant negative relationship (maximum: -0.64), indicating its stronger influence during this season.

At 16:00 h, summer 2022 showed non-significant positive associations with relative humidity (maximum: 0.45; minimum: 0.50) and weak negative relationships with rainfall (-0.38) and minimum temperature (-0.27). In winter 2022, temperature maintained positive correlations (maximum: 0.46; minimum: 0.47), whereas relative

humidity again showed a significant negative association (maximum: -0.64).

These findings align with earlier reports by Hosamani *et al.* (2019) [12], and Bharath *et al.* (2020) [4], who emphasized the critical role of temperature and relative humidity in regulating foraging activity, with rainfall generally exerting an inhibitory effect.

The present findings are in close agreement with those of Nishanthini and Kanagarajan (2024) [15], who reported that maximum temperature (>30 °C) exerted a strong negative

influence on bee activity, with correlation coefficients of -0.83 , -0.34 , and -0.33 for outgoing foragers, nectar collectors, and pollen gatherers, respectively. In contrast, relative humidity showed a positive association with foraging activity, particularly in terms of outgoing worker bees ($r = 0.79$), nectar foragers ($r = 0.27$), and pollen foragers ($r = 0.29$). Furthermore, rainfall adversely affected foraging activity, whereas solar radiation had no significant impact on bee activity, corroborating the trends observed in the present investigation (Table 1 & 2) (Fig. 1 & 2).

Table 1: Influence of weather parameters on the foraging activities of the Indian honey bee *A. cerana indica* during summer 2022 (Experiment I)

Weather parameters		Mean of foraging bees					
		Outgoing foragers		With nectar load		With pollen load	
		6.00 AM	4.00 PM	6.00 AM	4.00 PM	6.00 AM	4.00 PM
Temperature °C	Max	-0.41	0.30	0.02	0.09	0.01	0.04
	Min	-0.07	0.01	-0.28	-0.28	-0.31	-0.27
Relative Humidity %	Max	0.00	0.44	0.53	0.45	0.38	0.45
	Min	0.33	0.35	0.52	0.56	0.43	0.50
Total rainfall (mm)		0.53	0.15	-0.37	-0.36	-0.46	-0.38
Sunshine hour		-0.25	0.49	0.24	0.32	0.38	0.26
Wind velocity (Kmph)		-0.46	0.40	-0.28	-0.27	-0.16	-0.24

* - significant at 0.05 % °C- The degree Celsius %- Percentage

Table 2: Influence of weather parameters on the foraging activities of the Indian honey bee *A. cerana indica* during winter 2022 (Experiment II)

Weather parameters		Mean of foraging bees					
		Outgoing foragers		With nectar load		With pollen load	
		6.00 AM	4.00 PM	6.00 AM	4.00 PM	6.00 AM	4.00 PM
Temperature °C	Max	0.45	0.43	0.49	0.44	0.41	0.46
	Min	0.27	0.24	0.31	0.32	0.33	0.47
Relative Humidity %	Max	-0.50	-0.51	-0.53	-0.52	-0.64*	-0.64*
	Min	-0.33	-0.30	-0.36	-0.35	-0.42	-0.41
Total rainfall (mm)		0.05	0.22	0.16	0.15	-0.02	-0.05
Sunshine hour		-0.22	-0.32	-0.26	-0.22	-0.48	-0.23
Wind velocity (Kmph)		0.68	0.78	0.79	0.79	0.77	0.78

* - significant at 0.05 % °C- The degree Celsius %- Percentage

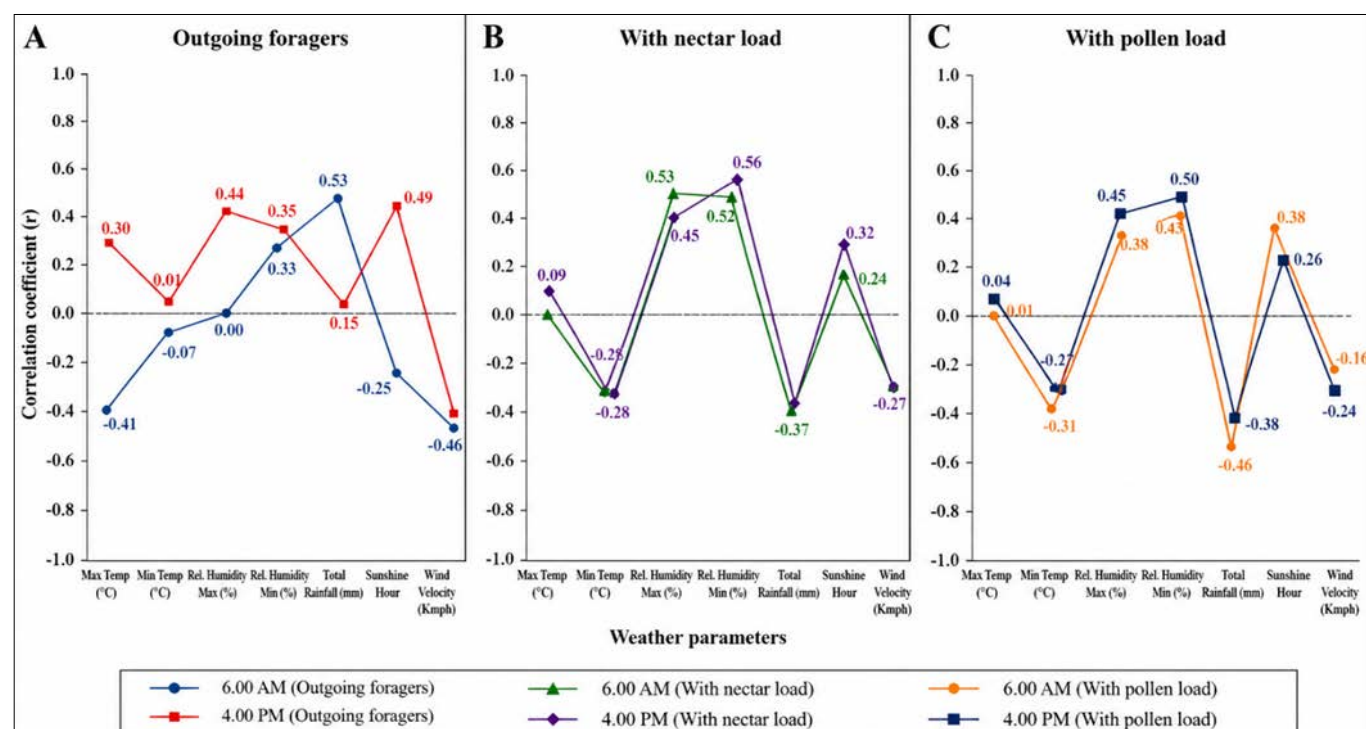


Fig 1: Influence of weather parameters on the foraging activities of the Indian honey bee *A. cerana indica* during summer 2022 (Experiment I)

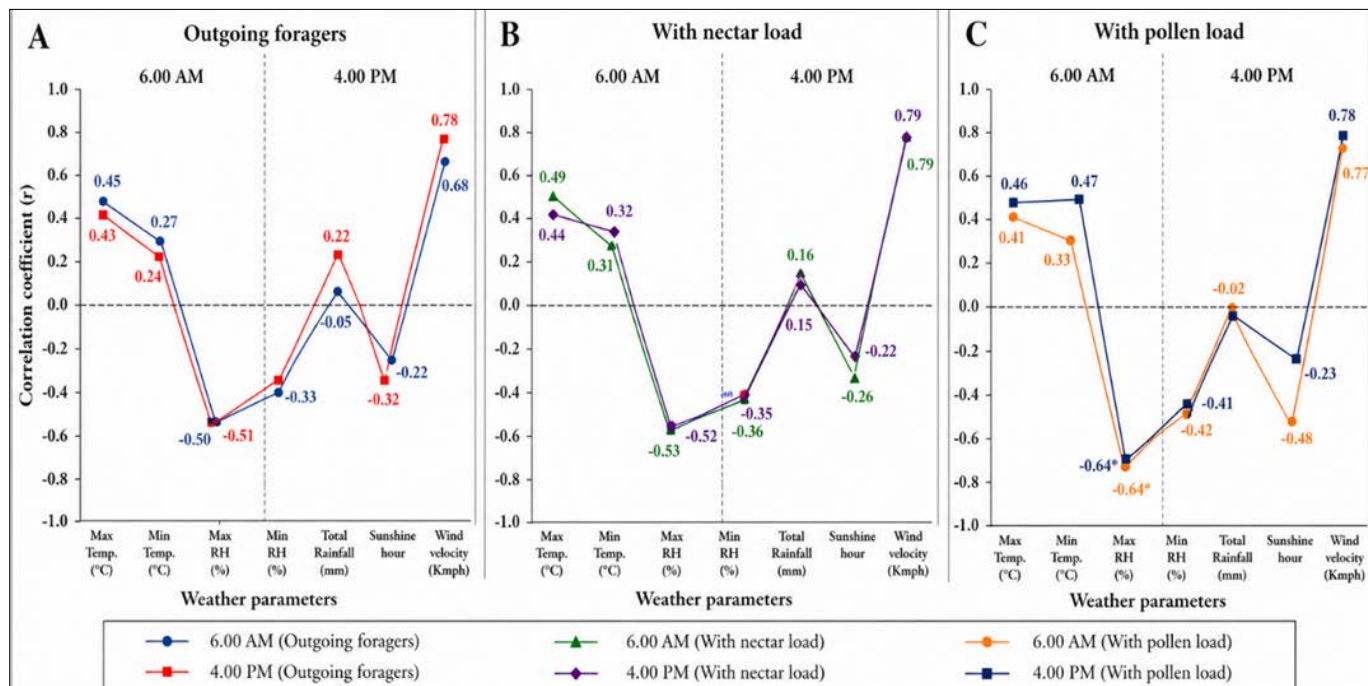


Fig 2: Influence of weather parameters on the foraging activities of the Indian honey bee *A. cerana indica* during winter 2022 (Experiment II)

Conclusion

The foraging activity of *A. cerana indica* is primarily influenced by temperature, which showed a consistent positive effect across seasons. Relative humidity and rainfall exerted variable, season-dependent impacts, particularly constraining pollen foraging. Evening activity was more responsive to weather variations than morning foraging. Overall, the study highlights the significant role of climatic factors in regulating bee foraging behaviour and their implications for pollination management.

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