



RESEARCH ARTICLE - BEES

Temporal and Spatial Foraging Activity of Indian Honey Bee (*Apis cerana indica* F.) at Different Migratory Sites

NISHANTHINI KAMARAJ, KANAGARAJAN RASAPPAN

Apiculture Laboratory, Department of Entomology, Faculty of Agriculture, Annamalai University, Chidambaram, Tamil Nadu, India

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Corresponding author

Nishanthini Kamaraj
 Department of Entomology, Faculty of Agriculture, Annamalai University, Chidambaram, Tamil Nadu, India.
 E-Mail: nishanthee97@gmail.com

Abstract

Migratory beekeeping increases honey production and reduces the feeding costs of stationary beekeeping during longer dearth periods. This study discerns the influence of environmental conditions on the foraging behavior of the Indian honey bee, *Apis cerana indica* F., at different migratory sites in Southern India. The total number of foraging bees, pollen foraging efficiency, and nectar foraging efficiency were estimated. Furthermore, the influence of environmental factors, including temperature, relative humidity, rainfall, and solar radiation, was recorded to identify its impact on the foraging behavior of honey bees. Among the climatic factors, maximum temperature (>30 °C) was the most crucial, negatively affecting bee activity with correlation coefficients of -0.83, -0.34, and -0.33 for outgoing bees, nectar, and pollen collectors, respectively. The relative humidity showed a positive impact on the frequency of worker bees moving out of the hive ($r = 0.79$), those coming in with nectar ($r = 0.27$), and pollen ($r = 0.29$). Rainfall hampered foraging activity, while solar radiation was found to have no significant effect on bee activity. Diurnal variations showed peak activity of bee foragers between 6.00 and 10.00 am. The visits by honey bees were significantly higher at low temperatures, solar radiation, precipitation, and high relative humidity. They made about 90% of their flower visits in the early morning, although plenty of bee flora was available throughout the day. Also, the environmental conditions at different sites strongly influenced the foraging behavior. However, the honey bees still focused their activities on favorable conditions depending on their biology and fixed their daily foraging patterns, improving beekeeping and honey production throughout the year.

Introduction

Indian honey bee, *Apis cerana indica* F., also known as the Asian honey bee or Indian honey bee, is native to the subcontinent and occurs both in wild and domesticated forms. Beekeeping with *A. cerana* is common across Asia, though it has declined significantly in the northern states of India following the introduction of the European bee, *A. mellifera* (Oldroyd & Nanork, 2009). However, in southern states, where *A. mellifera* is not as popular as in the northern parts of the country, *A. cerana* still holds the primary position in

commercial beekeeping. The species is valued not only for honey production but also as an effective pollinator of a wide range of wild flora and crops, including fruits, vegetables, oil seeds, etc. (Partap, 2011). *A. cerana* is preferred over *A. mellifera* from a pollination point of view since it is an indigenous species coevolved with native flora.

Several vegetation regions of the country show short or long interruptions in flowering. Therefore, there are one or more floral dearth periods of short or long duration. Migratory beekeeping is practiced to overcome these deficiencies in bee flora availability and find places where bees can avail flows



at different year periods. Such migratory management helps prevent colony losses and increase colony numbers and honey production (Martinez-Lopez et al., 2022). A migratory beekeeping system is more economical than a stationary beekeeping system, with 4-5 harvests per year, boosting the beekeeper's income (Sharma et al., 2013). Pollination activity is even more important in migratory beekeeping since crops and wild plants from different regions and flowering seasons benefit from honey bee foraging behavior (Lautenbach et al., 2012).

The successful survival of a honey bee colony depends on the foraging efficiency of worker bees, and hence, the number of bees going out for foraging per unit of time is an indicator of colony activity. Besides, the availability of sufficient flora in different migratory locations and the prevailing environmental factors could affect foraging activity through the energy needs of bees for flight activity (Abrol, 2005). Variability in the foraging activity of honey bees during different seasons, locations, and weather conditions was reported by several workers, with particular reference to *A. mellifera* (Al-Ghamdi, 2002; Corbet et al., 1993). Apart from this, the division of labor is an essential feature in social insects and is thought to be responsible for their ecological success (Page et al., 2006) as it enables different activities carried out simultaneously by different groups of specialized individuals (Jeanne, 1986). In honeybees, colony survival depends on efficiently collecting food sources, mainly protein and carbohydrates, through the division of labor between pollen and nectar foragers (Page et al., 2006).

Climatic conditions strongly influence the foraging and production activities of honeybees, the type of flowering plants (the bees' forage material), and the quantity of secreted nectar (Alqarni, 2020; Abou-Shaara et al., 2017). Nectar secretion is directly related to visiting pollinators and weather conditions (Boisvert et al., 2007). Honeybees show seasonal activity patterns depending on the prevailing weather conditions (Schneider & McNally, 1992).

The main objectives of this study were to investigate the foraging activities (outgoing, nectar, and pollen foragers activities) of honeybees at different migratory sites during

the abundant presence of flora and to compare the activity patterns of the honey bee concerning the weather conditions. The results of this study enhance our understanding of the flowering dynamics concerning foraging activity in different migratory ecosystems and provide data for further studies aiming to improve beekeeping and honey production throughout the year.

Materials and Methods

Experimental Area

Five colonies were subjected to migratory beekeeping for one year (mid-august 2021 to mid-august 2022) at three different migratory sites, Karaikal (KKL), Puducherry (PY) and lastly, Chidambaram (CDM) (Fig 1) (Table 1). North-East monsoons occur during October – December, with an average rainfall of 998 mm, with dominant northeast monsoon winds from the western disturbances emerging over the Bay of Bengal. The summer runs throughout March, April, May, and Mid-June and is characterized by intense heat with an average temperature of 32 °C in Tamil Nadu and Puducherry.

Foraging activity

The total numbers of foraging (outgoing bees), pollen foraging efficiency (number of worker bees returning with pollen loads), and nectar foraging (number of worker bees returning) to the hive were recorded for 5 minutes per hour, at the hive entrance from 6.00 hour to 18.00 hour per day. These observations were made at fortnightly intervals from August 2021 to July 2022 (Leena, 2014).

Collection of Meteorological Data

Temperature (°C), relative humidity (%), rainfall (mm), and solar radiation (W/m²) data were hypothesized to affect the foraging activities of the honeybees. These meteorological factor data were monitored in parallel to collecting outgoing, nectar, and pollen forager data. The meteorological data of the study were obtained from the Regional Meteorological Centre, Chennai, and hourly means were calculated for different migratory sites, Karaikal, Puducherry, and Chidambaram.

Table 1. Study area.

S. No.	Location	Latitude	Longitude	Vegetation	Duration
1.	KKL	10.921° N	79.755°E	Teak	Mid-August to mid-September (40 days)
		10.976°N	79.824°E	Eucalyptus	Mid-September to October (46 days)
		10.921° N	79.755°E	Coconut	November to December (62 days)
2.	PY	11.944° N	79.756°E	Common floral vegetation	January to mid-February (45 days)
		11.945° N	79.756°E	Cashew	Mid-February to March (44 days)
3.	CDM	11.350° N	79.729°E	Sesame	April to mid-May (50 days)
		11.359° N	79.726°E	Moringa	Mid-May to mid-August (70 days)

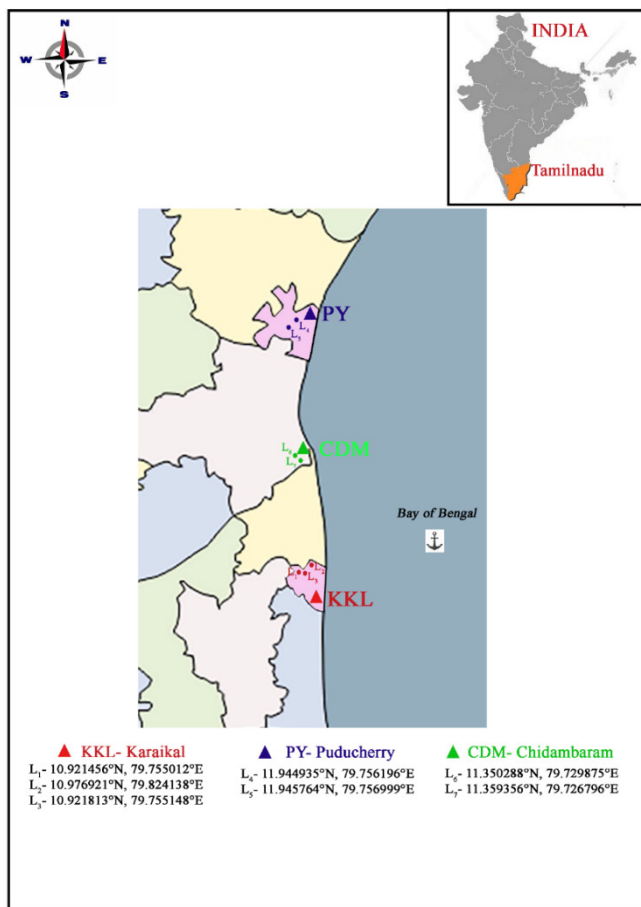


Fig 1. A map illustrating the installation locations of the colonies.

Statistical Analysis

Descriptive statistics were calculated and presented as means, followed by standard errors in the data analysis. The data were processed for normality and homogeneity using the Kolmogorov-Smirnov and Levene tests. The Kruskal-Wallis test was applied to compare bee foraging activity at different locations. The foraging activity was correlated with the weather data of the corresponding days, and the contribution of independent climatic factors to variability was determined through the coefficient of determination (R^2) through regression analysis using R statistical software. Statistical significance was indicated at $p < 0.05$, $p < 0.01$, and $p < 0.001$.

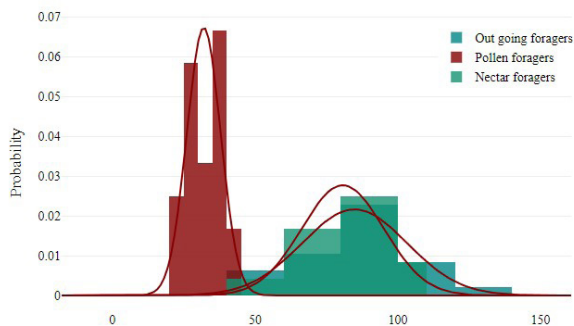


Fig 2. Histogram showing normal distribution of foragers showing the bell-shaped curve.

Results

Foraging Activities

The mean number of outgoing foragers, incoming nectar, and pollen foragers of the *A. cerana indica* workers were determined at different migratory beekeeping, KKL, PY, and CDM sites from mid-august 2021 to mid-august 2022.

A Kolmogorov-Smirnov test was used to determine normality in the forager population at different migratory sites. The percentage of x for the outgoing forager, nectar, and pollen foragers group, $D(24) = 0.93, 0.52, 0.75, p > 0.05$, indicating that the data were from a normally distributed population at different migratory sites (Fig 2). Similarly, Levene’s test assessed variances’ homogeneity on the forager populations at different migratory sites. The result shows equality of variances $p > 0.05$.

Outgoing Foragers

The foraging activity of *A. cerana indica* workers is predominantly diurnal, with two peak activities, one longer between 6:00 am and 10:00 am and the other shorter between 3:00 and 5:00 pm. The peak activity was 233.23 ± 5.45 mean number of bees leaving the colony during the 5 minutes of observation at 6 o’clock (Fig 3) (under a mean temperature of 26.81°C ; humidity of 86.03% ; rainfall of 0.16 mm ; solar radiation of 50.95 W/m^2).

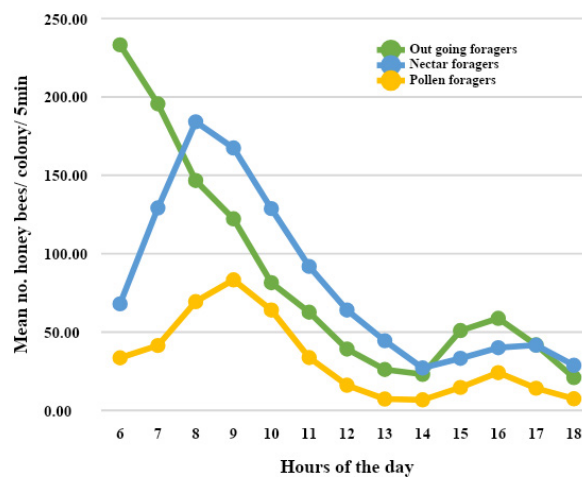


Fig 3. Diurnal variations in the foraging activity of *A. cerana indica*.

The mean of 5 colony foraging activity gradually began in August II (93.17 ± 5.23 workers/colony/day) and declined steadily in October I and II until reaching a minimum level in November II (56.28 ± 6.87 workers/colony/day), and foraging activity gradually increased in January I, II, February I, II. It peaked during March (120 ± 3.54 workers/colony/day) (Fig 4). The cumulative mean numbers of outgoing foraging workers (15 days interval) foraging activity of *A. cerana indica* have a significant difference between the three independent migratory beekeeping sites KKL, PY, and CDM location concerning the dependent variable outgoing forager (Fig 5; $p < 0.001$).

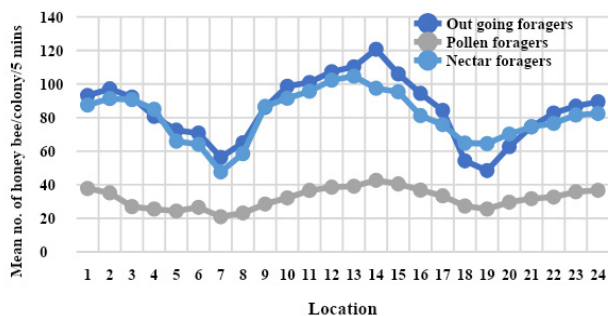


Fig 4. Foraging activity of *A. cerana indica* during different months at different migratory sites.

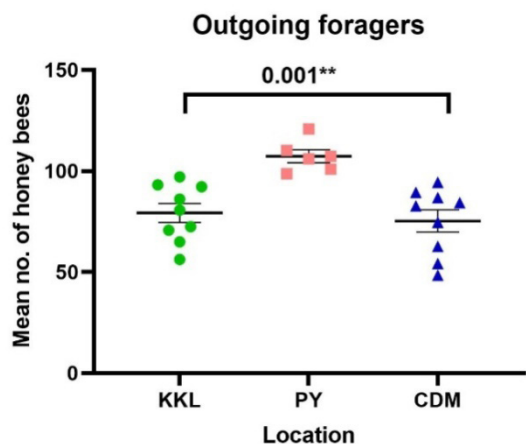


Fig 5. Monthly values (mean) of the outgoing forager's activities of *A. cerana indica* at different migratory sites. The asterisks indicate significant differences between the migratory sites (** $p < 0.01$).

Pollen foragers

Regarding the pollen foraging activity of *A. cerana indica* workers, we observed two peak activities, one longer between 7:00 am and 9:00 am and the other shorter at 4:00 pm. The peak activity was observed with an average of 83.31 ± 5.87 bees leaving the colony during the 5 minutes of observation at 9 o'clock (Fig 3) (under a mean temperature of 28.87°C ; humidity of 74.11%; rainfall of 0.17 mm; solar radiation of 340.70 W/m^2).

The monthly outgoing foraging activity gradually began in August II (37.79 ± 6.47 workers/colony/day). It declined steadily in October I and II until reaching a minimum level in November II (20.94 ± 9.34 workers/colony/day). Foraging activity gradually increased in January I, II, February I, II and peaked in March (42.68 ± 4.89 workers/colony/day) (Fig 4). The cumulative mean numbers of pollen foraging workers 15 days interval foraging activity of *A. cerana indica* have a significant difference between the three independent migratory beekeeping sites KKL, PY, and CDM location for the dependent variable pollen forager (Fig 6; $p < 0.01$).

Nectar foragers

The nectar foragers activity of *A. cerana indica* workers showed two peak activities, one longer between 7:00 am and 10:00 am and the other shorter between 3:00 and 5:00 pm. The peak activity was 184.16 ± 8.56 mean number of bees leaving the colony during the 5 minutes of observation at 8 o'clock (Fig 3) (under a mean temperature of 28.18°C ; humidity of 78.12%; rainfall of 0.18 mm; solar radiation of 256.42 W/m^2).

The monthly mean nectar foraging activity gradually began in August II (87.47 ± 8.64 workers/colony/day) and declined steadily in October I and II until reaching a minimum level in November II (47.64 ± 3.35 workers/colony/day), and foraging activity gradually increased in January I, II, February I, II. It peaked during March (42.68 ± 6.90 workers/colony/day) (Fig 4). The cumulative mean numbers of nectar foraging workers (15 days interval) foraging activity of *A. cerana indica*

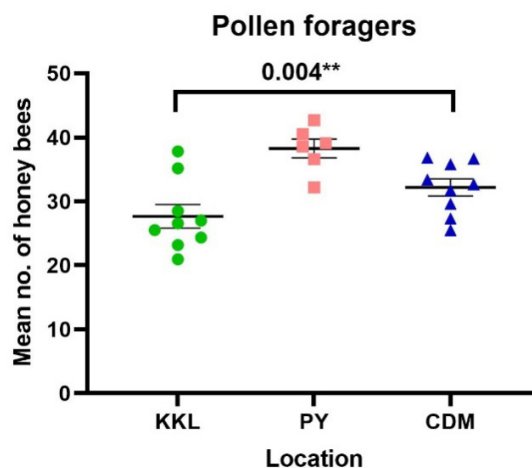


Fig 6. Monthly values (mean) of the pollen foragers' activities of *A. cerana indica* at different migratory sites. The asterisks indicate significant differences between the migratory sites (** $p < 0.01$).

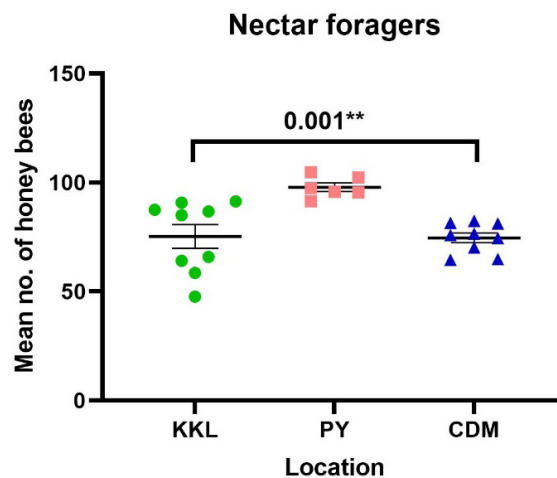


Fig 7. Monthly values (mean) of the nectar foragers' activities of *A. cerana indica* at different migratory sites. The asterisks indicate significant differences between the migratory sites (** $p < 0.01$).

have a significant difference between the three independent migratory beekeeping sites KKL, PY, and CDM location for the dependent variable nectar forager (Fig 7; $p < 0.01$).

Correlation and regression analysis

According to Figure 8, solar radiation does not impact honeybees, as all the values are non-significant. Rainfall had a significant negative impact, while RH had a significant positive impact on outgoing foragers alone and had a non-significant correlation with nectar and pollen foragers. Temperature also had a significant impact on outgoing foragers, while its effect was negligible over nectar and pollen foragers. The intercorrelations revealed that the nectar and pollen foragers were undeterred by temperature, RH, and solar radiation, while rainfall alone impacted all three. Figure 9 shows that all the points should be close to a regressed diagonal line. So, the actual foraging activity should be reasonably close to the predicted foraging activity and have a higher goodness of fit.

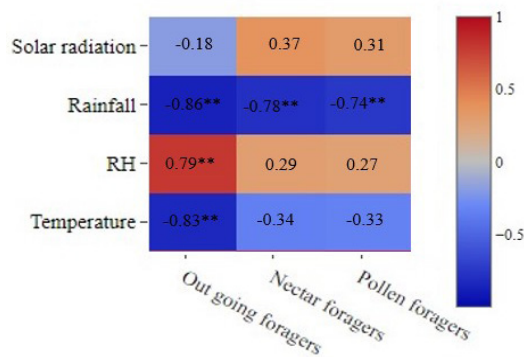


Fig 8. The heatmap shows the Pearson correlation coefficients among weather factors (temperature, relative humidity, rainfall, and solar radiation) and foraging activities (outgoing, pollen, and nectar forager). The asterisks indicate significant correlations ($* p < 0.05$).

Discussion

The pattern of bee activity varied, not only over seasons but also at different hours of the day, with a maximum during early hours between 6.00 and 11.00 am. Nectar foragers were observed to outnumber pollen foragers throughout the day. Foraging decreased significantly after 12.00 pm, and the lean period continued into the evening, apart from a small peak in the number of nectar foragers at 4.00 pm. The decreased activity during late afternoon hours, coinciding with higher day temperatures even though plenty of flora is available at different migratory sites, could be attributed to two factors. The first is the requirement for a greater number of bees to maintain the colony temperature. Thus, the number available for foraging is less. Secondly, the anthesis of many flowers takes place in the early morning; therefore, pollen availability was plentiful compared to hot hours. In addition, nectar solidified with increased temperature, requiring more time and energy to harvest, prompting bees to make maximum use

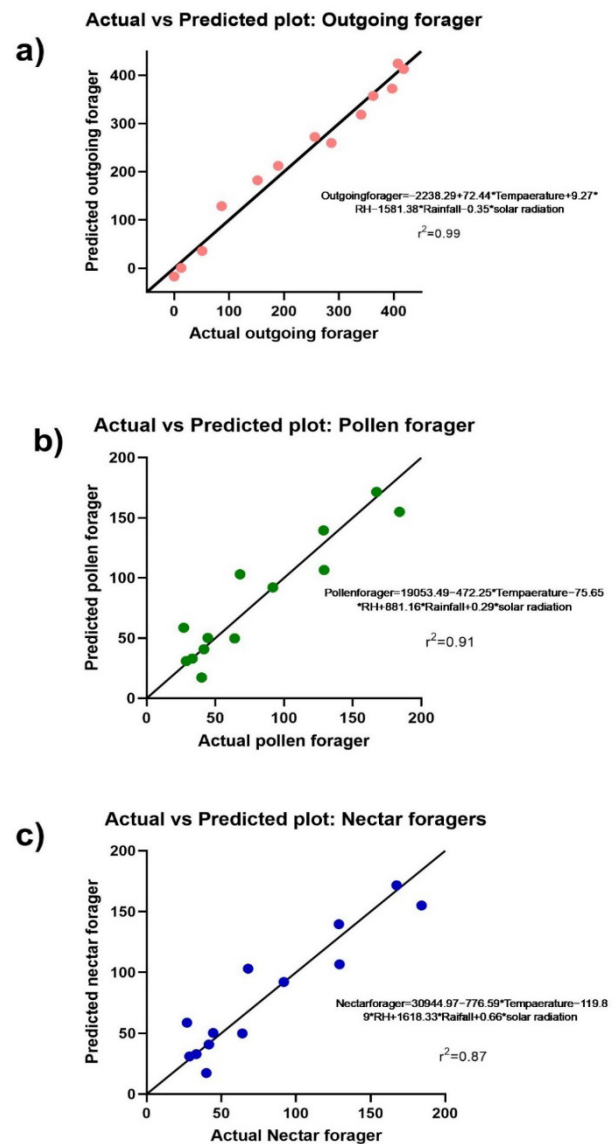


Fig 9. Regression model plot comparing the predicted and actual number of foragers activity; r^2 showing the goodness of fit.

in the morning hours. The preferential foraging in the morning hours may be an evolutionary adaptation to maximize their resource collection efficiency. From an applied angle, the relatively lesser activity in the late hours of the day could also be used by farmers to spray pesticides (if unavoidable during the blossom period) during the lean period to reduce the harmful effect on bees.

Climate influences flower development, nectar, and pollen production at different migratory sites, directly linked with colonies foraging activity and development (Winston, 1987). Effective crop pollination and foraging activity heavily depended on the biological timing of the crop and its honeybee pollinator. Crops such as teak, eucalyptus, cashew, moringa, sesame, etc., have periods of mass blooming over relatively short periods, requiring a tremendous peak in pollinators. Climate change may have profound impacts on the timing of these events. Honeybees are already under stress from climate

change and may be severely impacted by the extreme weather events that will accompany global warming. Different responses of plants and insects to temperature changes result in temporal (phenological) and spatial (distributional) mismatches that have negative demographic effects on the honey bee. When there are mismatches, plants may suffer from fewer honeybee visits and pollen deposition, and honeybees may have less access to food. Memmot et al. (2007) simulated the effect of increasing temperatures on a highly resolved plant-pollinator network. They found that shifts in phenology reduced the floral resources available for 17 to 50 percent of the pollinator species. A temporal mismatch can be detrimental to (*i.e.*, honey bees). For example, increased spring (February and March) temperatures may postpone plant flowering time while pollinators might be unaffected. Even if plants and pollinators respond to the same temperature cues, the strength of the response might differ (Hegland et al., 2009). Williams et al. (2007) found a relationship between climatic niches and bumblebee declines.

Among several abiotic factors, temperature is the most important factor affecting honey bee activity (Corbet et al., 1993). Honey bee larvae and pupae are extremely stenothermic, *i.e.*, they strongly depend on accurate regulation of brood nest temperature for proper development (Stabentheiner et al., 2010). Under extreme conditions, they must put extra effort into regulating body and colony temperature, impacting their foraging efficiency. Several workers reported significant effects of temperature on the flight activity of the honey bee *A. mellifera* (Puskadija et al., 2007), and a similar effect was also observed in our study. Though bees are known to withstand temperatures as high as 45 °C – 50 °C, their foraging activity was found to go down drastically at temperatures beyond 35 °C even though plenty of flora is available at different migratory sites (Cooper et al., 1985). The ability of some bees to forage above the 30 °C range of air temperature was attributed to their behavioral and physiological mechanisms of regulating the temperature of their flight muscles, which differ with foraging rewards and the age of worker bees (Heinrich, 1996).

Additionally, at higher temperatures, the number of pollen collectors decreases compared to nectar and water collectors. Pollen foragers carry relatively little fluid during hotter periods, and pollen foraging decreases at high ambient temperatures, reportedly reflected in higher thoracic temperatures of pollen collectors and water and nectar gatherers (Al Qarni, 2006). Moreover, increased global temperatures mean a reduced number of bees venturing out to collect pollen and nectar, which will affect pollination efficiency. Variations may also disrupt the synchrony between flowers and their pollinators (Reddy et al., 2012).

Relative humidity is vital in brood development and egg hatching (Human et al., 2006). Joshi and Joshi (2010) reported that relative humidity showed less effect on the flight activities of *Apis* species. Environmental factors in bee

foraging behavior, including humidity, positively impact our study. The number of bees that collected pollen, nectar, and outgoing bees positively correlated with relative humidity. This might be why the honeybees' activity was high at increased humidity from 7:00 to 11:00 am. After that, activity decreased when humidity decreased, and a high temperature was recorded. Higher humidity can trigger nectar secretion in flowers, increasing foraging to access this reward despite a less-than-optimal environment (Willmer, 1983). Many studies contradict our findings on the relationship between relative humidity and bee foraging activity (Corbet, 1990; Sung et al., 2011; Alves et al., 2015) and pointing direct and indirect effects on the bees (Corbet, 1990). Directly, the flight can be difficult for bees under humid conditions, and pollen collection can also be problematic, as pollen grains can fail to adhere to a humid body because of an electrostatic charge, which makes it difficult for the corbiculated bees to pack moist loads of pollen (Corbet, 1990). Indirectly, humidity can strongly affect flowers since humidity can change the color and structure of flowers and change nectar secretion or sugar concentration of nectar, making flowers less attractive to bees (Corbet, 1990).

A significant negative correlation was established between the foraging activity of *A. cerana indica* and rainfall. The reduction in the number of bees coming could be attributed to the lower number of bees moved out and the death of foragers caught in heavy rain. Abou-Shaara et al. (2017) also noted that flight activity decreased drastically during rain, and both *A. cerana* and *A. mellifera* were reported to prefer to be in their hives during rain. Though there was a significant reduction in bee movement during the rainy period, considerable activity was observed during light drizzling. The breakeven point of rain intensity, where exactly bee activity comes to a complete standstill, needs to be estimated. Another implication of heavy rainfall is the washout of pollen and nectar, which adversely affects bees' foraging and pollination efficiency.

Solar radiation and air temperature are positively related, with the former driving the latter (Peixoto & Oort, 1992), and we observed honeybee decreased their activity with rising solar radiation. A solar radiation measure of 1000 W/m², or the maximum normal surface irradiance, is typical for a clear day at solar noon or when the sun is at its zenith, and reductions in honeybee activity have been observed at this time (Burrill & Dietz, 1981). This could be related to the honeybee's zeitgedachtnis or 'time sense' in which the bee will adhere to a diurnal pattern of activity driven by factors such as memory or the timing of reward availability (Bennett & Renner, 1963; Moore & Rankin, 1983; Lehmann et al., 2011). Besides acting as a heat source, the light from the sun is necessary for bee navigation (Reber et al., 2015). Eye size allometry is established in honeybees (Streinzer et al., 2013; Taylor et al., 2019): the larger eye of bumblebees allows them to see in lower light conditions, which could explain the larger effect of solar radiation on honeybee activity and the lack of an effect on bumblebees. Reduced honeybee activity

observed at lower solar radiation could be due to low sunlight in the morning or reduced visibility in cloudy conditions. Furthermore, a decline in activity as solar radiation levels increased toward solar noon could explain the modal pattern of honeybee activity observed, and the negative effect of sunlight was detected.

Conclusion

Establishing the colonies at new migratory sites could increase their exposure to different climatic conditions. Despite the above considerations, environmental factors do not act separately in nature. Together, they could create conditions that can result favorably (or not) for bees, depending on their characteristics (biology, body size, color, pubescence, etc.) which can affect their daily foraging patterns. We can conclude that environmental conditions strongly affect the foraging behavior of bees at different migratory sites due to the impact of local climatic conditions on individuals. Bees concentrate their activities in particular environmental conditions according to their biology, avoiding times that can hinder their foraging or even be dangerous. Meanwhile, honeybees focus their activity early in the morning, helping to avoid high temperatures, solar radiation, low humidity, and possibly competition with other bees. These outcomes will help researchers understand the relationships among bee foraging, weather conditions, and the abundance of nectar-rich flora at migratory sites.

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Disclosure statement

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Authors' Contributions

KN: methodology, investigation, writing-original draft, writing-review & editing, visualization.

RK: conceptualization, resources, methodology, writing-review & editing, project administration, funding acquisition.

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