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Foraging behaviour of stingless bees on cucurbitaceous crops: Diurnal patterns, visitation rates and floral handling time

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Abstract
The present study was conducted to evaluate the foraging behaviour of stingless bees on five cucurbitaceous crops sponge gourd (*Luffa aegyptiaca*), bitter gourd (*Momordica charantia*), spine gourd (*Momordica dioica*), ridge gourd (*Luffa acutangula*) and cucumber (*Cucumis sativus*) under field conditions during the Kharif season of 2024-2025 at the Instructional Farm of the Vegetable Improvement Scheme (VIS), CES Wakawali, Dapoli. The objective was to assess crop-wise and time-wise variations in three key parameters of bee foraging behaviour: diurnal activity, foraging rate and floral handling time. Diurnal foraging activity was quantified as the number of stingless bees visiting 20 flowers per 5 minutes across five time intervals. Results revealed peak activity at 10:00 h with an average of 8.58 bees, while the lowest visitation was recorded at 16:00 h (3.36 bees). Bitter gourd showed the highest crop-wise visitation rate (6.69 bees), whereas spine gourd had the lowest (4.63 bees). Foraging rate, measured as the number of flowers visited per minute, was highest at 10:00 h (2.29 flowers/min) and lowest at 14:00 h (1.87 flowers/min). Cucumber recorded the highest average foraging rate (2.40 flowers/min) and bitter gourd the lowest (1.62 flowers/min). Handling time per flower peaked at 12:00 h (35.62 seconds) and was lowest at 16:00 h (29.20 seconds), with bitter gourd showing the longest average handling time (43.14 seconds) and cucumber the shortest (25.82 seconds). These findings demonstrate that both crop species and time of day significantly influence the foraging dynamics of stingless bees, which has implications for pollination management in cucurbitaceous crops.

Keywords: Stingless bees, foraging behaviour, diurnal activity, foraging rate, handling time

Introduction
Pollination is a key ecological process essential for the reproductive success of many flowering plants particularly in entomophilous agricultural crops. Among them cucurbitaceous vegetables such as sponge gourd (*Luffa aegyptiaca*), bitter gourd (*Momordica charantia*), spine gourd (*Momordica dioica*), ridge gourd (*Luffa acutangula*) and cucumber (*Cucumis sativus*) rely heavily on insect-mediated pollination due to their unisexual flowers and low self-pollination capacity (Klein *et al*. 2007) [12]. In recent years stingless bees (Meliponini) have garnered increasing attention as effective pollinators in tropical and subtropical agroecosystems. Their traits such as small body size, high floral constancy, ability to forage under low light, high humidity and moderate temperatures make them particularly suited for pollination in crops cultivated under open field or semi-protected conditions (Heard 1999; Nogueira-Neto 1997) [7, 17]. While *Apis* species have traditionally dominated pollination studies the ecological efficiency and crop compatibility of stingless bees have been well demonstrated in crops like chilli, tomatoes, guava and cucurbits (Slaa *et al*. 2006; Abrol 2012) [21, 1].
Time-wise or diurnal foraging activity is a critical component of pollinator ecology as it directly reflects the synchronization between pollinator behaviour and floral resource availability. For most bee species foraging activity follows a diurnal rhythm influenced by ambient temperature, light intensity, floral scent emission and nectar secretion dynamics (Stone *et al*. 1999; Willmer 2011) [22, 23]. Previous studies have shown that stingless bees exhibit peak foraging activity during mid-morning hours typically between 09:00 to 11:00 h when floral rewards are most abundant and weather conditions are favourable (Kumar

et al. 2012; Jha and Jha 2014) [14, 9]. Such time-specific foraging patterns are crop-dependent and can vary based on the floral architecture, nectar availability and competition with other pollinators. Quantifying this diurnal behaviour along with associated foraging rate and handling time provides valuable insights into the efficiency and potential of stingless bees as pollinators. The present study was therefore undertaken to evaluate the foraging behaviour of stingless bees on five cucurbitaceous crops with specific emphasis on diurnal activity patterns in order to inform pollinator management strategies and optimize crop yield through enhanced natural pollination services.

Material and Methods

The present study on the foraging behaviour of stingless bees on cucurbitaceous crops was conducted during the Kharif season of 2024-2025 at the Instructional Farm of the Vegetable Improvement Scheme (VIS), CES Wakawali, Dapoli, Dist. Ratnagiri. Five cucurbitaceous crops sponge gourd (*Luffa aegyptiaca*), bitter gourd (*Momordica charantia*), spine gourd (*Momordica dioica*), ridge gourd (*Luffa acutangula*) and cucumber (*Cucumis sativus*) were selected to evaluate bee activity and pollination efficiency. Standard pollination ecology methodologies adapted from Free (1993) [6] and Kearns and Inouye (1993) [11] were employed to assess three key behavioural parameters: diurnal foraging activity, foraging rate and handling time. Diurnal activity was measured by counting the number of stingless bees visiting 20 flowers per 5 minutes at five time intervals (08:00, 10:00, 12:00, 14:00 and 16:00 hours) across three observation spots per crop plot with data collected weekly over seven Standard Meteorological Weeks (SMWs). Foraging rate defined as the number of flowers visited by a bee per minute was recorded by following individual bees for one minute during the same time intervals and locations. Handling time representing the duration a bee spent per flower was timed using a stopwatch for individual bees following protocols by Heinrich (1979) [8] and Willmer (2011) [23]. All observations were conducted under favourable weather to minimize environmental bias. Data were aggregated and analyzed both time-wise and crop-wise to determine diurnal patterns and crop-specific preferences of stingless bees. This multi-dimensional approach enabled a robust comparative assessment of the pollination dynamics of stingless bees across different cucurbitaceous species.

Experimental Result

The comparative analysis of stingless bee foraging behaviour on five cucurbitaceous crops revealed distinct patterns in diurnal activity, foraging rate and floral handling time. Diurnal activity observations (Table 1 and Fig. 1) indicated that bee visitation peaked at 10:00 h with an average of 8.58 bees per 20 flowers per 5 minutes across all crops, and bitter gourd exhibited the highest visitation at this time (10.66 bees). The lowest overall activity occurred at 16:00 h (3.36 bees), with cucumber recording the minimum individual visitation rate (1.81 bees). On a crop-wise basis, bitter gourd recorded the highest average visitation (6.69 bees), while spine gourd had the lowest (4.63 bees). In terms of foraging rate (Table 2 and Fig. 2), the highest average was also observed at 10:00 h (2.29 flowers/min), with cucumber showing the peak rate of 3.05 flowers/min. The lowest foraging rate occurred at 14:00 h (1.87 flowers/min), where spine gourd recorded the minimum rate (1.62 flowers/min). Overall, cucumber exhibited the highest average foraging rate (2.40 flowers/min), whereas bitter gourd recorded the lowest (1.62 flowers/min). Analysis of floral handling time (Table 3 and Fig. 3) showed that stingless bees spent the most time per flower at 12:00 h (35.62 seconds) and the least at 16:00 h (29.20 seconds). Among the crops, bitter gourd had the highest average handling time (43.14 seconds), while cucumber recorded the lowest (25.82 seconds). These findings suggest that both crop type and time of day significantly influence the foraging dynamics of stingless bees on cucurbitaceous flowers.

Discussion

More or less similar results were obtained by Appanch *et al.* (1986) [2] who observed the foraging behaviour of *T. erythrogastra* in Malaysia for a period from August to November and March to May. Pollen supply was continuously available throughout the observation period from 0700 hr to 1800 hr when foraging activity approximately ceased. Kleinert-Giovannini and Imperatriz-Fonseca (1986) [13] studied the foraging activity of *Melipona marginata* Lepeletier took place throughout the day was most active between 1100 and 1300 h. Panda *et al.* (1993) [18] recorded maximum bee visitation in sunflower from 1100 h to 1200 h.

Devanesan *et al.* (2002) [5] found that the foraging activity of *T. iridipennis* in Vellayani (Kerala) started at 07.00 hr with a gradual rise in activity reaching its first peak at 12.00 hr. A decline in activity was observed at 13.00 hr then increased until it reached its second peak at 15.00 hr. There was almost no activity at 18.00 hr. The maximum number of pollen foragers was observed in the morning and the nectar foragers at mid-day. The average number of incoming foragers with pollen load was 17.9 compared with nectar collectors (11.5) during the first peak at 12.00 hr. The average number of pollen and nectar foragers was 13.9 and 10.8 respectively, during the second peak at 15.00 hr. Roopa (2002) [19] from Bangalore observed that the foragers of *T. iridipennis* were active in all the seasons and the foraging activity was found throughout the day during all the months. Major and minor peaks were observed between 12.00-13.00 hr and 16.00-17.00 hr. Nicodemo *et al.* (2013) [16] recorded the visit of *Nannotrigona testaceicornis*(Lepeletier) bees to parthenocarpic cucumber flowers, which was from 0700 to 1600 h and the visit become more frequent between 1000 and 1200 h. Sen *et al.* (2023) [20] studied that in protected cucumber (*Cucumis sativus*) cultivation, *T. iridipennis* consistently visited flowers most between 08:00-09:00 h, resulting in yields five times greater than treatments excluding pollinators. Bisui *et al.* (2020) [4] found that managed stingless bee colonies enhanced both fruit set and quality in bitter gourd (*Momordica charantia*), compensating for natural pollination deficits. Another field Kamatchi Murali *et al. (*2020) [10] reported foraging peaks on bitter gourd at 08:00-10:00 h with 3.30 bees/5 min.

Balaji *et al.* (2023) [3] observed floral visitor diversity and stingless bee foraging across a full flowering season on bitter gourd (*Momordica charantia*) and he found that the stingless bee activity was highest in mid-morning (10:00-12:00 h), followed by a tapering off by late afternoon. Lintu (2020) [15] observed foraging behavior of *T. iridipennis* on cucumber (*Cucumis sativus*) flowers, including diurnal and per-flower activity and hive entrance counts. Foraging on

male flowers peaked at 6.8 visits per 5 min during 08:00-09:00 h, with maximum intensity during 10:00-11:00 h. Hive traffic was highest at 13:00-14:00 h. He found that incoming/outgoing forager counts peaked mid-season (similar to week 35) and were lowest at early and late season periods (week 31 equivalent)

Tables

Table 1: Diurnal activity of stingless bees on different cucurbitaceous crops

Crops	Average number of bees/ 20 flowers/ 5min					Mean
	8:00h	10:00h	12:00h	14:00h	16:00h	
Sponge gourd	5.95	8.33	8.19	4.95	3.33	6.15
Bitter gourd	7.95	10.66	6.29	4.43	4.09	6.69
Spine gourd	4.38	6.43	6.14	3.81	2.38	4.63
Ridge gourd	5.24	7.76	6.10	3.43	5.19	5.54
Cucumber	6.81	9.71	5.29	2.48	1.81	5.22
Mean	6.07	8.58	6.40	3.82	3.36	

Table 2: Foraging rate of stingless bees on different cucurbitaceous crops

Crops	Average number of flowers visited by a bee / min					Mean
	8:00h	10:00h	12:00h	14:00h	16:00h	
Sponge gourd	2.29	2.81	2.19	2.00	1.71	2.20
Bitter gourd	1.43	1.67	1.48	1.86	1.67	1.62
Spine gourd	1.71	1.90	1.86	1.62	1.62	1.74
Ridge gourd	1.43	2.00	1.76	1.90	2.33	1.89
Cucumber	2.76	3.05	2.19	1.95	2.05	2.40
Mean	1.92	2.29	1.90	1.87	1.88	

Table 3: Floral handling time of stingless bees on different cucurbitaceous crops

Crops	Average time spent by a bee/ flower (sec.)					Mean
	8:00h	10:00h	12:00h	14:00h	16:00h	
Sponge gourd	30.33	31.33	30.38	32.15	32.12	31.26
Bitter gourd	58.53	48.62	51.49	28.94	28.12	43.14
Spine gourd	37.40	40.08	30.35	26.12	26.70	32.13
Ridge gourd	26.29	32.11	39.72	34.99	24.65	31.55
Cucumber	19.95	21.90	26.17	26.67	34.40	25.82
Mean	34.50	34.81	35.62	29.77	29.20	

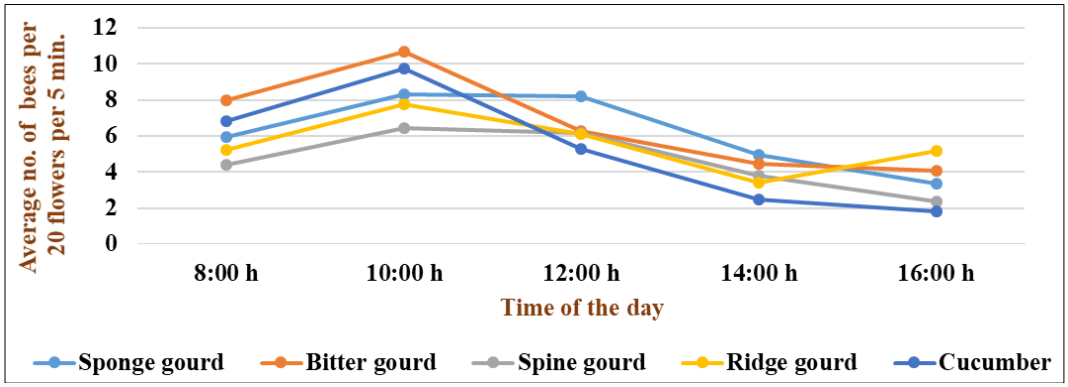

Fig 1: Diurnal activity of stingless bees on different cucurbitaceous crops

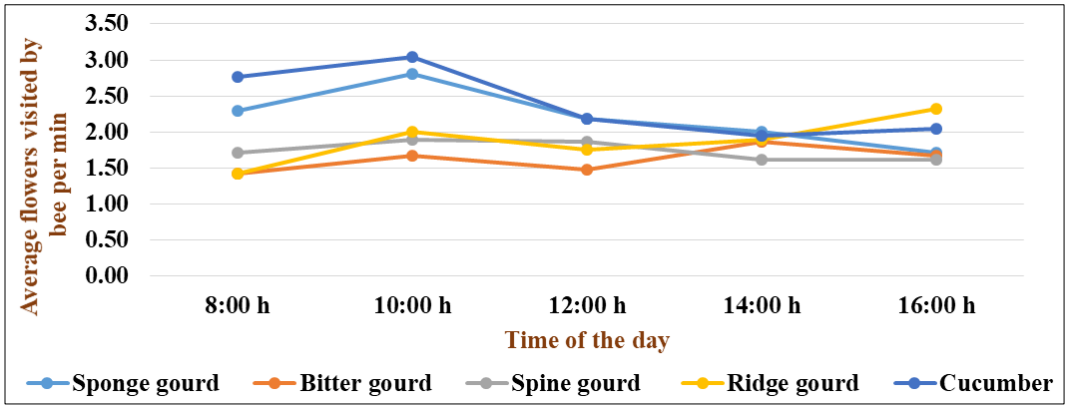

Fig 2: Foraging rate of stingless bees on different cucurbitaceous crops.

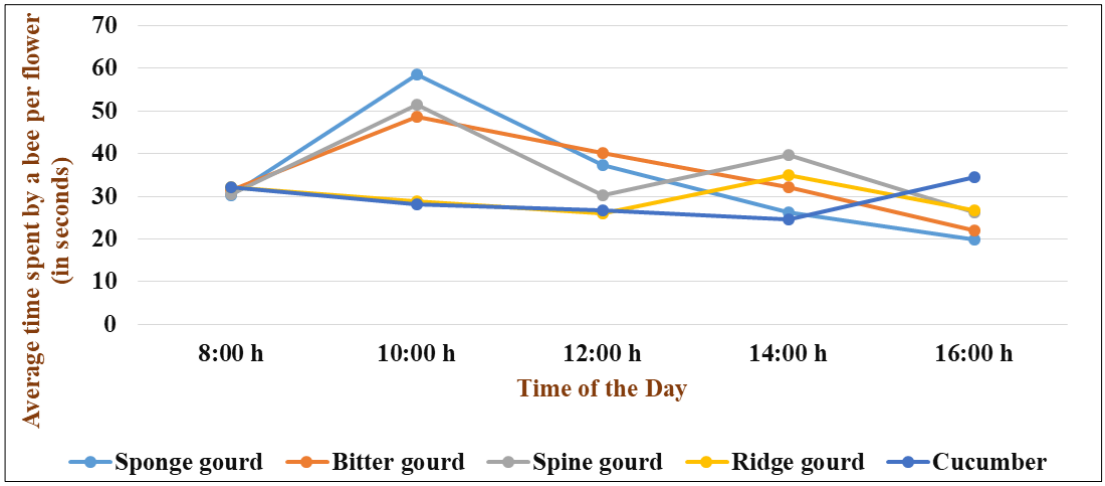

Fig 3: Floral handling time of stingless bees on different cucurbitaceous crops

Conclusion

The present study elucidated the temporal and crop-specific variations in the foraging behaviour of stingless bees on five cucurbitaceous species under field conditions during the Kharif season of 2024-2025. The findings revealed significant diurnal fluctuations in bee activity with peak foraging observed at 10:00 hours across all crops indicating a strong influence of time of day on pollinator activity. Among the cucurbitaceous crops evaluated *Momordica charantia* (bitter gourd) consistently recorded the highest bee visitation frequency and floral handling time suggesting a greater floral attractiveness and resource availability compared to other species. In contrast *Cucumis sativus* (cucumber) exhibited the highest foraging rate and the shortest handling time indicating more rapid exploitation of floral resources by stingless bees. These behavioural metrics visitation frequency foraging rate and handling time collectively reflect the pollination potential and preference of stingless bees across different host crops. The observed patterns underscore the ecological significance of stingless bees as efficient pollinators in cucurbitaceous cropping systems. Furthermore the results emphasize the importance of synchronizing crop phenology and pollinator activity periods to optimize pollination services. This study contributes to the understanding of stingless bee foraging ecology and supports their strategic integration into pollination management practices aimed at improving cucurbit crop productivity and sustainability.

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