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Foraging activity of stingless bee, *Tetragonula iridipennis* smith (Hymenoptera: Apidae) during summer season in Madurai district of Tamil Nadu, India

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Abstract
The climate variables have influence on the foraging performance of stingless bees. Studies were conducted at Insectary of Department of Agricultural Entomology, Agricultural College and Research Institute, Madurai, Tamil Nadu, India from March to May of 2018, to study the impact of abiotic factors *viz.*, maximum temperature, minimum temperature, relative humidity, rainfall and wind speed on the seasonal and diurnal variations in foraging activity of stingless bee during summer. The activity of worker bees was recorded maximum (57.3 numbers of incoming bees/5 min) during the morning hours between 8.00 am to 9.00 pm. Overall foraging activity was gradually decreased in the evening hours with minimum of 14.74 bees per five minutes. In summer from 9th to 14th standard week the foraging activity of stingless bee showed higher total activity (115.04 to 130.5 bees/5 min) with the pollen gatherers peak activity of 13.33 bees per five minutes during 9th standard week. The mean climatic factors, minimum temperature of 23.27 °C, maximum temperature of 36.01 °C, relative humidity of 61.83%, rainfall of 12.36 mm and wind velocity of 1.15 kmph. Minimum temperature had negatively affected foraging bee activity with correlation coefficient of r = -0.82, r = -0.69 and r = -0.50 for outgoing bees, incoming bees and pollen collectors respectively. Contrary to this, the relative humidity showed positive impact on the frequency of worker bees going out of hive (r = 0.14) and those incoming bees (r = 0.03) but negatively affected the pollen collectors (r = - 0.06).

Keywords: stingless bee, foraging activity, summer, pollen, weather parameters, diurnal variations, seasonal variations

Introduction
Stingless bees are the smallest of the honey producing bees, belong to the family Apidae and sub-family Meliponinae. Stingless bee colonies are perennial and usually comprise of hundreds or thousands of workers (Wille, 1983) [19]. As in honeybees, their principal resources are pollen and nectar, but they also collect materials such as resin, water, sap, wax, honeydew, extrafloral nectar, mud, salts, animal protein, and fungal spores for nutrition or nest-building materials (Roubik, 1980) [15]. Large proportion of tropical plant species, summing up to one fifth of the local angiosperm flora requires the service of stingless bee pollination (Wilms *et al.*, 1996; Corlett, 2004) [20, 3]. There are more than 500 species of stingless bees described all over the world (Michener, 2013). The most common stingless bee species of South India is *Tetragonula iridipennis* Smith (Michner, 1974) [11]. They are highly social insects like honey bees, living in permanent colonies, nesting in old walls, void logs, cavities in tree trunks, crevices and such other concealed places. Foraging activity of the worker bee population in the colony decides the bee's efficiency for survival and hence, the number of bees going out for foraging per unit time is an indicator of colony strength (Mattu and Verma, 1985; Reddy *et al.*, 2015) [10, 13].

Devanesan *et al*. (2002) [5] observed foraging activity of *T. iridipennis* at Kerala, and reported the peak foraging activity at the month of July and least foraging activity during December and January. Danareddi (2007) [4] reported foraging behaviour of *T. iridipennis* at different seasons and also the high activity of outgoing bees in October and November and pollen foraging in the month of February. Foraging activity will depend on in-colony factors and out-colony factors (Abou-shaara, 2014) [1]. Stingless bees may have one or two peak foraging hours, depending on species. For example, *Trigona iridipennis* has two peak hours of foraging activity, which are in the morning and in the afternoon (Layek and Karmakar, 2018) [9]

Temperature and rainfall have a significant effect on foraging behaviour of honey bees. Considering the prior investigations on the impact of critical seasonal factors on the foraging activity of bees the present study was planned to find the impact of abiotic parameters such as temperature, rainfall, relative humidity, wind speed on foraging performance of Stingless bee, *Tetragonula iridipennis* during summer.

Materials and Methods

The present work was conducted at the Insectary of Department of Agricultural Entomology, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai, India. The study area was surrounded by several agricultural, horticultural crops and natural vegetation, encompasses a geographical area of approximately about 154 hectares alongside the foot hills of Yanaimalai rock hillock (Latitude 9°55'25.79" N; Longitude 78°05'27.00" E) and a variety of floral resources for the bees throughout the season. Stingless bee colonies maintained at the Insectary were selected for the study. For observing the effect of ambient weather factors on bees, three colonies having uniform strength were selected. Each colony was considered as a replication.

The meteorological data were recorded from the Automatic Weather Station located in the Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai, India, which is located within 700 m radius from the experimental location. The meteorological parameters *viz*., maximum and minimum temperature (°C), relative humidity (%), rainfall (mm) and wind speed (kmph) recorded were used for estimating the systemic and functional relationship of bee foraging *viz*., pollen, nectar and resin gathering activities.

Foraging bees was resolved in terms of the number of worker bees going out and coming in with and without pollen loads per five minutes with stop watch and hand tally counter by following the methodology of Reddy, *et al*. (2015) [13] and Hemalatha, *et al*. (2018) [7]. Bees returning to hive without pollen load are recorded as nectar and resin collectors.

The seasonal variations were studied from 9th to 22nd standard meteorological weeks of 2018, observations were recorded at three times a day *viz*., 8.00 a.m., 12.00 noon and 4.00 p.m. for 5 min. The mean value of three intervals was taken as the foraging activity of that particular day. Weekly observations were recorded at hourly interval starting from morning 6.00 a.m. to evening 6.00 p.m. for five minutes for diurnal patterns study. The foraging data of stingless bee with the mean number of worker bees going out and coming in (pollen and nectar collectors) were correlated with the weather data of the corresponding days. Analysis of variance (ANOVA) at 5% significance was used to test the significance of mean differences of seasonal and diurnal observations.

Results and Discussion

Seasonal foraging activity was studied in terms of the number of bees going out and bees coming in with and without pollen, per five minutes. Observations were recorded at hourly intervals from 6.00 a.m to 7.00 p.m. The peak activity of incoming bees was recorded from morning 8.00 to 9.00 am (58.83 bees/5 min) and the bee activity was significantly high from 11.00 to 12.00 pm 56.78 bees/5 min and then there was a drastic decline in bee activity (36.12 bees/5 min) followed by increse in bee activity by 16.00 pm (43.83 bees/5 min).

Pollen gatherers activity was high from 7.00 to 8.00 am (8.44 bees/5 min) and reached peak by 10.00 to 11.00 am (8.83 bees/5 min) followed by 8.00 to 9.00 am (8.72 bees/5 min), thenceforth the pollen collection activity was decreased by recording 2.21 bees/5 min from 17.00 to 18.00 pm, followed by 1.71 bees/5 min from 18.00 to 19.00 pm in the evening hours (Fig. 1). The average foraging activity was maximum in the morning between 8 to 9.00 am (57.30 bees/5 min), the bee activity was found to be decreased after 12.00 pm and registering minimum in the evening 18.00 to 19.00 pm (14.74 bees/5 min)

The incoming bees were more in the first part of the day 6.00 am to 12.00 noon, less toward the afternoon hours and again marginally brought up in the evening hours (16.00 to 17.00 hr) were observed in diurnal pattern of Stingless bee. Outgoing foragers activity was recorded peak from 6.00 to 7.00 am (59.45 bees/5 min), subsequently stingless bee activities was critically high from 9.00 am to 10.00 am (54.41 bees/5 min). In the afternoon it again reached the pinnacle of 56.67 and 48.39 bees/5 min at 12.00 to 13.00 pm and 13.00 to 14.00 pm respectively. Toward the evening it again reached the zenith of 41.06 /5 min at 16.00 to 17.00 pm and afterward the bee activity become less in the evening 18.00 to 19.00 pm (10.41 bees/5 min) (Fig. 1).

Comparable perceptions have been described by numerous specialists in different ecosystems (Ghazi *et al.,* 2014; Vijayan *et al.,* 2018; Hemalatha *et al.,* 2018) [17, 7]. Vijayan *et al*. (2018) [17] also reported that the foraging behaviour of stingless bee was maximum between 7.00 to 13.00 hr and afterward a relentless decline and suddenly diminished between 17.00 to 19.00 hr. Hemalatha *et al*. (2018) [7] found the most elevated numbers of Indian honeybees activity in the first part of the day, while the minimum numbers were recorded at evening hours. Ghazi *et al.* (2014) [6] revealed that the highest outgoing of foragers was observed in the morning hours. The least number of active foragers was seen in the late evening and there was no huge contrast of the complete number of outgoing foragers from the hives.

The seasonal variation of stingless bee foraging activity divulged that the total foraging activity was observed peak during 10th and 9th standard weeks by registering 130.5 bees/5 min and 123.18 bees/5 min, respectively. The least total foraging activity was found in the 20th and 19th standard week showed 89.61 and 88.83 bees/5 min, respectively (Fig. 2). The pollen collecting bees was found active from 9th standard week with maximum activity of 13.33 bees/ 5 min and witnessed minimum in 18th (7.21 bees/ 5 min) and 17th standard week (7.13 bees/ 5 min). The incoming foragers activity was raised high during 10th standard week (64.34 bees/ 5 min), 12th standard week (60.78 bees/ 5 min) and recorded low in 20th standard week (42.33 bees/ 5 min). The outgoing foragers activity noted during this work was dynamic from 9th standard week (63.33 bees/ 5 min), reached pinnacle of 66.16 bees/5 min at 10th standard meteorological week and marked least in 21st standard week (42. 33 bees/ 5 min) (Fig. 3).

The surrounding climate conditions delineated fluctuating association with stingless honey bee foragers. Average weather parameters persisted during the study period was minimum temperature of 23.27 °C, maximum temperature of 36.01 °C, relative humidity of 61.83%, rainfall of 12.36 mm and wind velocity of 1.15 kmph during this season. Temperature tend to decrease in the evening hours and slight increase in relative humidity were positive for the bees other than pollen foragers. Henceforth, the nectar and resin gathering activity was higher and pollen collectors were minimum. These contentions are concurrent with the discoveries of Sommeijer *et al.* (1983) [16] and Reddy *et al.*

(2015) [13] found that with increase in temperature nectar got solidified, requiring more time and energy to collect, inciting bees to make maximum use in the morning hours itself. The preferential foraging in the morning session might be an evolutionary adaptation to amplify their resource collection proficiency (Wang *et al.*, 2009; Reddy *et al.*, 2012) [18, 14].

The maximum temperature had positive correlations with pollen collectors (r = 0.01), negative correlation with total incoming bees (r = -0.24) and outgoing bees (r = -0.24) while minimum temperature depicted negative correlation of r = -0.50, r = -0.69 and r = -0.82 respectively of pollen collectors, incoming bees and outgoing bees. However relative humidity showed positive correlation with outgoing bees (r = 0.14), incoming bees (r = 0.03) and negative correlation with pollen collectors (r = -0.35). Rainfall had negative correlation with outgoing bees, incoming bees and incoming bees with pollen (r = -0.47, r = -0.40, r = -0.06 respectively), similarly wind speed also showed negative correlation to outgoing bees (r = -0.06), incoming bees (r = -0.07) and positive correlation (r = 0.15) to pollen collecting bees (Table 1).

Hemalatha *et al.* (2018) [7] recorded that Indian bee had a negative correlation with maximum temperature (r = -0.062, r = -0.309) and minimum temperature (r = -0.107, r = -0.407) for both incoming and outgoing bees, respectively and positive relationship with relative humidity to incoming bees (r = 0.06) and outgoing bees (r = 0.008). Similar observations were also in accordance with relative humidity and rainfall, which are comparable in our investigations.

The study revealed that strong winds diminish the speed of bees and it resulted in lower number of flights per day. Reddy *et al.* (2015) [13] reported that wind speed stronger than 12 kmph tend to affect honey bee foraging as they could not carry load upwind at a speed > 15 kmph. The wind speed was ideal (1.15 kmph) during our investigation and this range did not influence the foraging activity of stingless bee. Kumar *et al.* (2015) [8] studied that foraging movement of stingless bee was halted with high wind speed and rainfall which tend to reduce the ground speed of bees which resulted in decrease in the number of flights per day. Likewise a strong negative correlation was showed by bees during rainfall, as the bees had not come for foraging.

Multiple regression analysis depicted the contribution of each climate parameters on the bee foraging activity. Maximum temperature drew positive regression coefficient to the pollen collectors (a = +0.92), incoming bees (a = +0.44) and outgoing bees (a = +2.42) and minimum temperature showed negative regression coefficient to pollen collectors (b = -0.85), incoming bees (b = -3.46) and outgoing bees (b = -4.99). Relative humidity had negative regression coefficient with pollen collectors (c = -0.14), positive regression coefficient with incoming bees (c = +0.44) and outgoing bees (c = +1.16) during this season (Table 2).

Maximum temperature prevailed during the study period was 34.4 ºC to 37.3 ºC, during this condition pollen collectors activity was decreased with increase in temperature and increased with minimum temperature (20 ºC to 25 ºC). Higher temperature and low humidity were reported to adversely affect the flight activity of honey bees. At higher temperatures, the number of pollen collectors decreases as compared with nectar and water collectors. Al Qarni (2006) [2] stated that pollen foragers carry relatively little fluid during hotter periods, and pollen foraging decreases at high ambient temperatures, which was reported to reflect in higher thoracic temperatures of pollen collectors and that of water and nectar gatherers. Reddy *et al.* (2015) [13] reported that the maximum temperature had negatively affected (r =-0.72) the number of bees moving out to forage. There was a decreasing trend in the number of bees going out with increase in temperature which became more pronounced (< 20/5 min) at temperature.

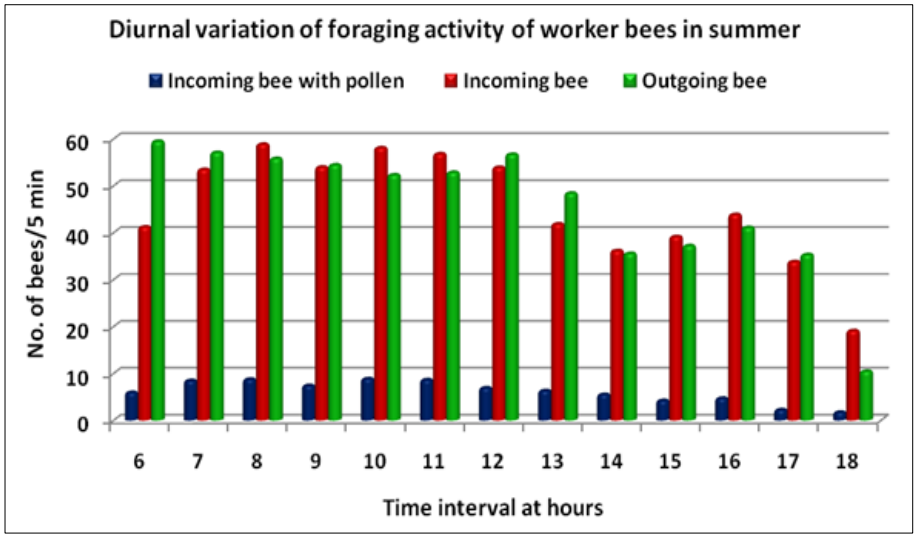

Fig 1: Diurnal variation of foraging activity of worker bees in summer – 2018

Table 1: Correlation of foraging activity with climatic variables during summer, 2018

Weather parameters	Correlation coefficient (r)		
	No. Bees going out/5 min	No. Bees coming in /5 min	No. Bees coming with pollen/5 min
Maximum temperature (°C)	-0.24*	-0.24*	0.01
Minimum temperature (°C)	-0.82*	-0.69*	-0.50*
Average RH (%)	0.14*	0.03	-0.35*
Rainfall (mm)	-0.47*	-0.40*	-0.06*
Wind speed (kmph)	-0.06*	-0.07*	0.15*

*Significance at 0.05%

Table 2: Multiple Regression equations for the foraging activity with climatic variables during summer, 2018

Division of worker bees	Multiple regression equation	R^2 values
Incoming bees with pollen	$y = 0.23 + 0.92\ x_1 - 0.85x_2 - 0.14x_3 + 0.003x_4 + 3.73\ x_5$	0.42
Incoming bees	$y = 92.10 + 0.44x_1 - 3.46x_2 + 0.44x_3 - 0.07x_4 - 1.06x_5$	0.53
Outgoing bees	$y = -4.56 + 2.42\ x_1 - 4.99x_2 + 1.16\ x_3 - 0.09\ x_4 + 5.21\ x_5$	0.83

Where,
x_1 – Maximum temperature; x_2 - Minimum temperature;
x_3 - Relative humidity; x_4 - Rainfall; x_5 - Wind speed

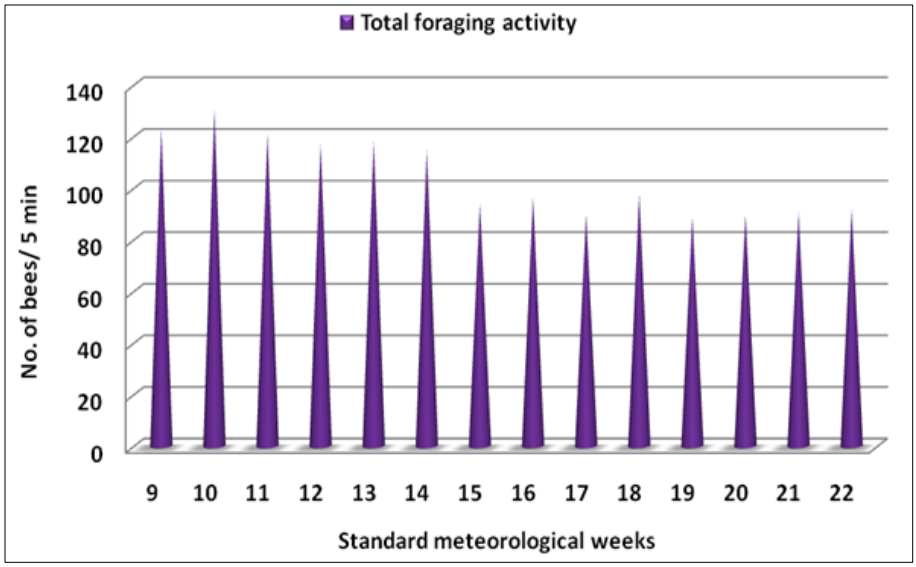

Fig 2: Total foraging activity of bees during summer -2018

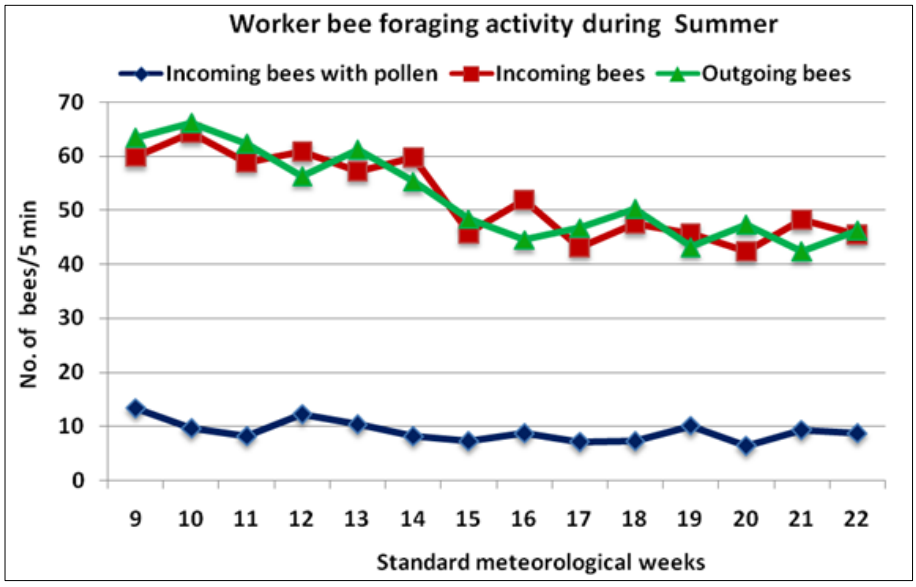

Fig 3: Summer Seasonal variation of Stingless bee foraging activity

Conclusion

The present study indicated that foraging activity of bees was maximum from 9th to 14th standard week. Pollen foraging was recorded peak from 10.00 to 11.00 am (8.83 bees/5 min), foraging behaviour of stingless bee was active during morning hours due to availability of pollen and nectar or both in ample quantities and become decreased in evening hours. Among all climatic factors, rainfall had hampered the foraging activity while wind speed was found to have no remarkable effect. The environmental factors should be optimum for the efficient performance of bees, both inside the colony and outside the colony. Understanding about the foraging behaviour between different seasons will be helpful for better maintenance of colonies and improving meliponiculture by seasonal management.

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