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Seasonal foraging activity of stingless bee *Tetragonula travancorica* Shanas and Faseeh (Hymenoptera: Apidae: Meliponini)

Lincy Abraham[1] and S. Shanas[*2]

[1]Department of Agricultural Entomology, College of Agriculture, Kerala Agricultural University, Vellayani, Thiruvananthapuram 695522, Kerala, India; [2]Integrated Farming System Research Station, Kerala Agricultural University, Karamana, Thiruvananthapuram 695002 , Kerala, India. Email: abrahamlincy7@gmail.com; shanassudheer@gmail.com

ABSTRACT: The foraging hive activity of stingless bee *Tetragonula travancorica* Shanas and Faseeh was studied from November 2018 to August 2019. The activity varied between the seasons, weather conditions and time hours of study. The outgoing and incoming pollen foragers exhibited two peaks in activity, from 0800-1200 h (first) and during 1500-1600 h (second).The activity of incoming non-pollen foragers displayed only one distinct peak between 1000-1200 h except during the south-west monsoon period. The greatest activity was recorded during the dry season (January-May), followed by the south-west monsoon (June-August) and north-east monsoon (November- December) seasons. Maximum overall activity was recorded during hotter months February, March and April while the lowest was observed in January and December. At any season or time, the number of incoming foragers without pollen was greater than pollen foragers.

KEYWORDS: *Tetragonula travancorica*, outgoing, incoming, foragers, pollen

INTRODUCTION

Stingless bees are eusocial insects that are considered to be the smallest honey-producing bees found in tropical and subtropical regions around the world. The social stingless bees (Meliponini) are globally more diverse than Apis, with approximately 500 species (Engel *et al*., 2018) among which, the genus *Tetragonula* Moure, 1961 is the most speciose with 31 valid species (Rasmussen *et al*., 2017; Engel *et al*., 2018). The genus *Tetragonula* is the most abundant in the Indo- Malayan region (Moure, 1961; Velthuis, 1997). Shanas and Faseeh (2019) provided keys to the species of *Tetragonula* of the Indian subcontinent and described three new species of stingless bees viz., *T. travancorica*, *T. calophyllae* and *T. perlucipinnae* from south India. Stingless bees are also called dammer bees since they collect dammer from dipterocarp trees and mix with the wax they produce to build their nests (Rasmussen, 2013). The term stingless bees denote the presence of a vestigial sting that cannot inflict pain in humans. The defence mechanism is marked by the biting with modified powerful mandibles or production of a caustic agent in some species irritating the enemy (Makkar *et al*., 2018).

* Author for correspondence

Stingless bees serve as pollinators for a large portion of tropical plant species which constitutes one-fifth of local angiosperms (Wilms *et al*., 1996) as well as economically important crops (Heard, 1999). Foraging activity of the worker bee population is very crucial to the perpetuation of the colony in a healthy state and the number of outgoing bees per unit time indicates the strength of the colony (Mattu and Verma, 1985). Considering the facts, proper knowledge about the foraging activity of the colony is essential to maintain the efficiency of controlled pollination using stingless bees and also honey production. Hence foraging studies on *T. travancorica* Shanas and Faseeh were conducted and results are presented in this paper.

MATERIALS AND METHODS

Study site: The present study was conducted on the campus of College of Agriculture, Vellayani, in district Thiruvananthapuram, Kerala which is located at 8° 25' 47" north latitude and 76° 59' 7" east longitude and an altitude of 29 m above mean sea level. The location of the study is in a suburban region covering an area of 2.52 square km and has various agricultural, horticultural and natural ecosystems with diverse floral resources. The campus is bordered by Vellayani Lake on three sides, the only rainfed freshwater lake in the district. The study area comes under the tropical monsoon region experiencing the main part of its annual rainfall under the influence of south-west monsoon winds (800 to 1200 mm average rainfall) and lesser part during the north-east monsoon (450 to 500 mm average rainfall) period. The area also exhibits dry periods of winter and summer witnessing a very less amount of average rainfall ranging from 20 to 195 mm with an average daytime temperature varying between 22 to 25°C and 32 to 35°C respectively.

Bee colonies: Two stingless bee colonies of *T. travancorica* with uniform strength approx. 1500 worker bees maintained in wooden hives located 80 m apart were selected for observation. The stingless bee was identified based on the key provided in Shanas and Faseeh (2019). The measurements were taken under a stereoscopic microscope with the help of ocular micrometre.

Collection of data on foraging activity: The observations on foraging frequencies of worker bees were made from November 2018 to August 2019 at an interval of 14 days. The study period was divided into three seasons namely, North-east monsoon (November to December), Dry season (January to May) and South-west monsoon (June to August). The hive entrance was observed for 5 minutes at an hourly interval from morning 0600 to evening 1800 h with the help of a stopwatch (Bharath *et al.*, 2020; Jaapar *et al.*, 2018) and the mean value of recorded data for the twelve intervals was considered as foraging activity of the day.

Statistical analysis: The data were quantified in terms of the number of foragers leaving the hive eliminating the foragers with garbage load as 'outgoing foragers', the number of bees returning with pollen load as 'incoming pollen foragers' and without pollen load excluding the resin and mud foragers as 'incoming foragers without pollen'. The number of bees returning without pollen load was calculated by subtracting the number of bees carrying garbage from the total number of incoming foragers without pollen load. The term incoming without pollen loads indicates the bees carrying in nectar as well as water occasionally. Monthly and hourly mean of the data obtained was square-root transformed and classified accordingly into three seasons after which two factorial analysis was used to analyse the data.

RESULTS

Diurnal variation in foraging activity: The foraging activity observed as per the number of outgoing foragers and incoming foragers were between 0630 and 1800 h during north-east monsoon season, 0600 and 1840 h during the dry season and 0610 and 1820 h during south-west monsoon season. The numbers of foragers active at different hours of the day and seasons differed statistically. The least number of outgoing foragers was seen during the early morning from 0600-0700 h. The activity gradually increased and reached a peak at 0900-1000 h thereafter declining slowly up to 1800 h (Table 1). Similar to outgoing foragers, the number of incoming foragers with pollen loads was

Table 1.Outgoing foragers irrespective of season

Months↓	Mean number of bees/5 minutes/colony - Hours →												Mean
	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	
November	3.27 (1.94)	8.42 (2.99)	33.16 (5.80)	29.68 (5.49)	14.96 (3.93)	20.23 (4.55)	16.68 (4.15)	11.72 (3.49)	11.87 (3.51)	14.56 (3.88)	8.23 (2.95)	4.72 (2.28)	14.79 (3.75^{de})
December	1.00 (1.23)	3.20 (1.92)	28.13 (5.35)	23.15 (4.86)	13.96 (3.8)	22.39 (4.78)	12.95 (3.67)	9.23 (3.12)	11.20 (3.42)	12.40 (3.59)	5.98 (2.55)	2.73 (1.79)	12.19 (3.34^{e})
January	1.00 (1.23)	1.42 (1.39)	11.79 (3.51)	27.38 (5.28)	24.16 (4.97)	11.30 (3.44)	19.42 (4.46)	15.90 (4.05)	8.06 (2.93)	7.87 (2.89)	7.83 (2.87)	5.77 (2.50)	11.82 (3.29^{e})
February	1.60 (1.45)	18.41 (4.35)	56.84 (7.57)	48.51 (7.00)	31.21 (5.63)	30.64 (5.58)	27.48 (5.29)	16.52 (4.13)	17.71 (4.27)	13.83 (3.79)	18.01 (4.30)	7.48 (2.83)	24.02 (4.68^{c})
March	1.00 (1.23)	30.45 (5.56)	34.97 (5.96)	48.93 (7.03)	56.08 (7.52)	41.56 (6.49)	31.96 (5.69)	22.09 (4.75)	27.06 (5.25)	24.27 (4.98)	15.65 (4.02)	11.66 (3.49)	28.81 (5.16^{b})
April	10.73 (3.35)	32.89 (5.78)	49.84 (7.09)	55.03 (7.45)	45.77 (6.80)	38.40 (6.24)	34.61 (5.93)	33.61 (5.84)	32.93 (5.78)	26.86 (5.23)	27.71 (5.31)	18.90 (4.41)	33.94 (5.77^{a})
May	9.75 (3.20)	25.32 (5.08)	29.12 (5.44)	39.99 (6.36)	29.08 (5.44)	30.24 (5.54)	24.30 (4.98)	14.48 (3.87)	25.10 (5.06)	19.53 (4.48)	14.77 (3.91)	13.32 (3.72)	22.92 (4.76^{bc})
June	7.15 (2.77)	10.92 (3.38)	21.71 (4.71)	24.47 (4.99)	20.63 (4.59)	19.19 (4.44)	15.01 (3.94)	15.82 (4.04)	12.57 (3.62)	18.15 (4.32)	16.15 (4.1)	4.56 (2.25)	15.53 (3.93^{d})
July	4.52 (2.24)	4.60 (2.26)	13.92 (3.79)	20.69 (4.60)	23.86 (4.94)	28.38 (5.37)	21.34 (4.67)	14.86 (3.92)	12.35 (3.59)	15.04 (3.94)	9.03 (3.1)	5.83 (2.51)	14.53 (3.74^{de})
August	1.00 (1.23)	3.42 (1.98)	11.83 (3.51)	17.47 (4.24)	27.94 (5.33)	23.65 (4.91)	30.57 (5.57)	21.07 (4.64)	11.46 (3.46)	16.54 (4.13)	9.31 (3.13)	6.53 (2.65)	15.07 (3.73^{de})
Mean	4.10 (1.98^{g})	13.90 (3.47^{e})	29.13 (5.27^{ab})	33.53 (5.73^{a})	28.77 (5.29^{ab})	26.60 (5.13^{b})	23.43 (4.83^{b})	17.53 (4.18^{c})	17.03 (4.09^{cd})	16.90 (4.12^{cd})	13.27 (3.62^{de})	8.15 (2.84^{f})	

Factors	SEm±	CD at 5%
Months (M)	0.168	0.469
Time (T)	0.185	0.514
M x T	0.584	

Means in the columns/ rows with same alphabet do not differ significantly by DMRT at 5%

Figures in the parenthesis are $\sqrt{(x+0.5)}$ transformed values

Table 2. Incoming foragers with pollen irrespective of season

Months	Mean number of bees/5 minutes/colony - Hours →												Mean
	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	
November	1.00 (1.23)	2.39 (1.7)	15.72 (4.03)	18.74 (4.39)	13.56 (3.75)	7.15 (2.77)	2.90 (1.85)	2.70 (1.79)	1.47 (1.40)	2.18 (1.64)	1.00 (1.23)	1.00 (1.23)	5.82 (2.25^{d})
December	1.00 (1.23)	1.47 (1.31)	13.73 (3.77)	13.33 (3.72)	9.42 (3.15)	5.98 (2.55)	3.97 (2.12)	3.92 (2.10)	2.24 (1.65)	2.09 (1.61)	1.47 (1.40)	1.23 (1.31)	4.99 (2.16^{d})
January	1.00 (1.23)	1.00 (1.23)	4.42 (2.22)	14.84 (3.92)	10.82 (3.37)	4.55 (2.25)	3.39 (1.97)	3.08 (1.89)	2.39 (1.7)	3.10 (1.9)	2.83 (1.83)	2.35 (1.68)	4.48 (2.09^{de})
February	1.00 (1.23)	3.42 (1.98)	19.30 (4.45)	23.76 (4.93)	11.90 (3.52)	13.07 (3.68)	4.89 (2.32)	6.22 (2.59)	4.66 (2.27)	3.57 (2.02)	1.87 (1.54)	1.42 (1.39)	7.92 (2.66^{ab})
March	1.00 (1.23)	3.46 (1.99)	9.48 (3.16)	17.70 (4.27)	23.94 (4.94)	12.68 (3.63)	8.47 (2.99)	4.85 (2.31)	2.77 (1.81)	2.69 (1.79)	2.39 (1.7)	2.09 (1.61)	7.63 (2.62^{bc})
April	1.47 (1.4)	3.62 (2.03)	18.10 (4.31)	25.26 (5.08)	21.43 (4.68)	10.87 (3.37)	6.10 (2.57)	6.22 (2.59)	4.47 (2.23)	3.21 (1.93)	2.51 (1.73)	1.60 (1.45)	8.74 (2.78^{a})
May	1.00 (1.23)	4.81 (2.3)	7.54 (2.84)	5.15 (2.38)	4.49 (2.23)	4.08 (2.14)	2.90 (1.85)	3.08 (1.89)	2.39 (1.7)	1.68 (1.48)	1.95 (1.57)	1.00 (1.23)	3.34 (1.90^{ef})
June	1.47 (1.4)	3.00 (1.87)	4.85 (2.31)	3.55 (2.01)	3.49 (1.99)	2.99 (1.87)	1.47 (1.4)	2.09 (1.61)	1.68 (1.48)	2.49 (1.73)	2.15 (1.63)	1.00 (1.23)	2.52 (1.71^{f})
July	1.00 (1.23)	1.68 (1.48)	2.84 (1.83)	6.19 (2.59)	7.62 (2.85)	8.87 (3.06)	7.78 (2.88)	3.98 (2.12)	2.77 (1.81)	2.49 (1.73)	1.77 (1.51)	1.47 (1.4)	4.04 (2.04^{def})
August	1.00 (1.23)	1.42 (1.39)	7.50 (2.83)	8.04 (2.92)	9.04 (3.09)	12.71 (3.63)	9.59 (3.18)	8.66 (3.03)	2.21 (1.65)	3.90 (2.1)	2.15 (1.63)	1.23 (1.31)	5.62 (2.33^{bcd})
Mean	1.09 (1.26^{f})	2.63 (1.73^{ef})	10.35 (3.17^{bc})	13.65 (3.62^{a})	11.57 (3.36^{ab})	8.30 (2.89^{c})	5.15 (2.31^{d})	4.48 (2.19^{d})	2.70 (1.77^{e})	2.74 (1.79^{e})	2.01 (1.57^{ef})	1.44 (1.38^{ef})	

Factors	SEm±	CD at 5%
Months (M)	0.121	0.336
Time (T)	0.132	0.368
M x T	0.418	1.162

Means in the columns/ rows with same alphabet do not differ significantly by DMRT at 5%

Figures in the parenthesis are $\sqrt{(x+0.5)}$ transformed values

Table 3. Incoming foragers without pollen irrespective of season

Months	Mean number of bees/5 minutes/colony - Hours →												Mean
	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	
November	1.68 (1.48)	6.75 (2.69)	5.67 (2.48)	8.66 (3.03)	11.67 (3.49)	15.43 (3.99)	16.96 (4.18)	13.67 (3.76)	15.68 (4.02)	12.19 (3.56)	9.47 (3.16)	6.99 (2.74)	10.40 (3.21^{de})
December	1.00 (1.23)	2.48 (1.73)	5.56 (2.46)	8.23 (2.96)	9.39 (3.15)	17.22 (4.21)	17.73 (4.27)	11.71 (3.49)	10.97 (3.39)	10.17 (3.27)	12.21 (3.57)	5.98 (2.55)	9.39 (3.02^{e})
January	1.00 (1.23)	1.00 (1.23)	5.41 (2.43)	15.42 (3.99)	13.47 (3.74)	11.51 (3.47)	18.44 (4.35)	10.90 (3.38)	9.04 (3.09)	9.75 (3.2)	7.36 (2.8)	5.28 (2.40)	9.05 (2.94^{e})
February	1.42 (1.39)	14.36 (3.86)	31.83 (5.69)	28.35 (5.37)	22.86 (4.83)	27.91 (5.33)	21.36 (4.68)	19.73 (4.49)	17.03 (4.19)	18.28 (4.33)	19.28 (4.45)	9.35 (3.14)	19.31 (4.31^{b})
March	1.00 (1.23)	25.28 (5.08)	23.06 (4.85)	25.83 (5.13)	38.56 (6.25)	30.07 (5.53)	23.69 (4.92)	21.93 (4.74)	24.55 (5.01)	22.63 (4.81)	17.55 (4.25)	17.36 (4.23)	22.62 (4.67^{b})
April	7.11 (2.76)	20.98 (4.64)	27.06 (5.25)	32.64 (5.76)	41.28 (6.46)	35.52 (6.00)	30.55 (5.57)	30.40 (5.56)	24.90 (5.04)	26.22 (5.17)	22.78 (4.83)	23.83 (4.93)	26.94 (5.16^{a})
May	4.45 (2.23)	17.20 (4.21)	22.33 (4.78)	30.83 (5.59)	26.34 (5.18)	31.94 (5.69)	29.06 (5.44)	25.56 (5.11)	23.03 (4.85)	18.93 (4.41)	15.52 (4.00)	9.54 (3.17)	21.23 (4.55^{b})
June	4.49 (2.23)	9.89 (3.22)	14.90 (3.92)	21.19 (4.66)	19.13 (4.43)	14.08 (3.82)	11.89 (3.52)	17.58 (4.25)	15.76 (4.03)	17.28 (4.22)	15.27 (3.97)	6.30 (2.61)	13.98 (3.74^{c})
July	1.68 (1.48)	5.01 (2.35)	7.33 (2.79)	13.27 (3.71)	20.55 (4.59)	21.25 (4.66)	19.89 (4.52)	19.69 (4.49)	16.58 (4.13)	11.31 (3.44)	9.12 (3.1)	6.38 (2.62)	12.67 (3.49^{cd})
August	1.00 (1.23)	2.69 (1.79)	9.51 (3.16)	11.15 (3.41)	14.85 (3.92)	18.90 (4.41)	22.86 (4.83)	19.08 (4.43)	12.59 (3.62)	16.80 (4.16)	12.15 (3.56)	10.63 (3.34)	12.68 (3.49^{cd})
Mean	2.48 (1.64^{f})	10.56 (3.08^{e})	15.27 (3.78^{d})	19.56 (4.36^{abc})	21.81 (4.60^{ab})	22.38 (4.71^{a})	21.24 (4.63^{a})	19.02 (4.37^{abc})	17.01 (4.13^{bcd})	16.36 (4.05^{cd})	14.07 (3.77^{d})	10.16 (3.17^{e})	

Factors	SEm±	CD at 5%
Months (M)	0.163	0.453
Time (T)	0.178	0.496
M x T	0.564	

Means in the columns/ rows with same alphabet do not differ significantly by DMRT at 5%

Figures in the parenthesis are $\sqrt{(x+0.5)}$ transformed values

Table 4.Outgoing foragers during north-east monsoon season

Months	Mean number of bees/5 minutes/colony - Hours →												Mean
	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	
November	3.27 (1.94)	8.42 (2.99)	33.16 (5.80)	29.68 (5.49)	14.96 (3.93)	20.23 (4.55)	16.68 (4.15)	11.72 (3.49)	11.87 (3.51)	14.56 (3.88)	8.23 (2.95)	4.72 (2.28)	14.79 (3.75^{a})
December	1.00 (1.23)	3.20 (1.92)	28.13 (5.35)	23.15 (4.86)	13.96 (3.8)	22.39 (4.78)	12.95 (3.67)	9.23 (3.12)	11.20 (3.42)	12.40 (3.59)	5.98 (2.55)	2.73 (1.79)	12.19 (3.34^{a})
Mean	2.14 (1.58^{d})	5.81 (2.45^{d})	30.65 (5.58^{b})	26.42 (5.18^{a})	14.46 (3.87^{c})	21.31 (4.67^{d})	14.82 (3.91^{d})	10.48 (3.31^{d})	11.53 (3.47^{c})	13.48 (3.74^{d})	7.11 (2.75^{d})	3.72 (2.04^{d})	

Factors	SEm±	CD at 5%
Months (M)	0.044	0.118
Time (T)	0.109	0.289
M x T	0.154	0.435

Means in the columns/ rows with same alphabet do not differ significantly by DMRT at 5%

Figures in the parenthesis are $\sqrt{(x+0.5)}$ transformed values

Table 5.Outgoing foragers during dry season

Months	Mean number of bees/5 minutes/colony - Hours →												Mean
	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	
January	1.00 (1.23)	1.42 (1.39)	11.79 (3.51)	27.38 (5.28)	24.16 (4.97)	11.30 (3.44)	19.42 (4.46)	15.90 (4.05)	8.06 (2.93)	7.87 (2.89)	7.83 (2.87)	5.77 (2.50)	11.82 (3.29^{c})
February	1.60 (1.45)	18.41 (4.35)	56.84 (7.57)	48.51 (7.00)	31.21 (5.63)	30.64 (5.58)	27.48 (5.29)	16.52 (4.13)	17.71 (4.27)	13.83 (3.79)	18.01 (4.30)	7.48 (2.83)	24.02 (4.68^{b})
March	1.00 (1.23)	30.45 (5.56)	34.97 (5.96)	48.93 (7.03)	56.08 (7.52)	41.56 (6.49)	31.96 (5.69)	22.09 (4.75)	27.06 (5.25)	24.27 (4.98)	15.65 (4.02)	11.66 (3.49)	28.81 (5.16^{b})
April	10.73 (3.35)	32.89 (5.78)	49.84 (7.09)	55.03 (7.45)	45.77 (6.80)	38.40 (6.24)	34.61 (5.93)	33.61 (5.84)	32.93 (5.78)	26.86 (5.23)	27.71 (5.31)	18.90 (4.41)	33.94 (5.76^{a})
May	9.75 (3.20)	25.32 (5.08)	29.12 (5.44)	39.99 (6.36)	29.08 (5.44)	30.24 (5.54)	24.30 (4.98)	14.48 (3.87)	25.10 (5.06)	19.53 (4.48)	14.77 (3.91)	13.3 2(3.72)	22.92 (4.76^{b})
Mean	4.82 (2.09^{g})	21.69 (4.43^{e})	36.51 (5.91^{abc})	43.97 (6.62^{a})	37.26 (6.07^{ab})	30.43 (5.45^{bc})	27.55 (5.27^{cd})	20.52 (4.52^{de})	22.17 (4.65^{de})	18.47 (4.27^{e})	16.79 (4.08^{ef})	11.42 (3.38^{f})	

Factors	SEm±	CD at 5%
Months (M)	0.177	0.508
Time (T)	0.275	0.788
M x T		0.615

Means in the columns/ rows with same alphabet do not differ significantly by DMRT at 5%

Figures in the parenthesis are $\sqrt{(x+0.5)}$ transformed values

Table 6. Outgoing foragers during south-west monsoon season

Months	Mean number of bees/5 minutes/colony - Hours →												Mean
	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	
June	7.15 (2.77)	10.92 (3.38)	21.71 (4.71)	24.47 (4.99)	20.63 (4.59)	19.19 (4.44)	15.01 (3.94)	15.82 (4.04)	12.57 (3.62)	18.15 (4.32)	16.15 (4.1)	4.56 (2.25)	15.53 (3.92^{a})
July	4.52 (2.24)	4.60 (2.26)	13.92 (3.79)	20.69 (4.60)	23.86 (4.94)	28.38 (5.37)	21.34 (4.67)	14.86 (3.92)	12.35 (3.59)	15.04 (3.94)	9.03 (3.1)	5.83 (2.51)	14.53 (3.74^{a})
August	1.00 (1.23)	3.42 (1.98)	11.83 (3.51)	17.47 (4.24)	27.94 (5.33)	23.65 (4.91)	30.57 (5.57)	21.07 (4.64)	11.46 (3.46)	16.54 (4.13)	9.31 (3.13)	6.53 (2.65)	15.07 (3.73^{a})
Mean	4.22 (2.08^{d})	6.31 (2.54^{bcd})	15.82 (4.00^{ab})	20.88 (4.61^{a})	24.15 (4.95^{abc})	23.74 (4.91^{bcd})	22.30 (4.73^{abc})	17.25 (4.20^{bc})	12.13 (3.55^{cd})	16.57 (4.13^{abc})	11.50 (3.43^{abc})	5.64 (2.47^{cd})	

Factors	SEm±	CD at 5%
Months (M)	0.174	0.209
Time (T)	0.347	0.419
M x T	0.602	

Means in the columns/ rows with same alphabet do not differ significantly by DMRT at 5%

Figures in the parenthesis are $\sqrt{(x+0.5)}$ transformed values

Table 7. Incoming foragers with pollen during north-east monsoon season

Months	Mean number of bees/5 minutes/colony - Hours →												Mean
	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	
November	1.00 (1.23)	2.39 (1.7)	15.72 (4.03)	18.74 (4.39)	13.56 (3.75)	7.15 (2.77)	2.90 (1.85)	2.70 (1.79)	1.47 (1.40)	2.18 (1.64)	1.00 (1.23)	1.00 (1.23)	5.82 (2.24^{a})
December	1.00 (1.23)	1.47 (1.31)	13.73 (3.77)	13.33 (3.72)	9.42 (3.15)	5.98 (2.55)	3.97 (2.12)	3.92 (2.10)	2.24 (1.65)	2.09 (1.61)	1.47 (1.40)	1.23 (1.31)	4.99 (2.1^{a})
Mean	1.00 (1.22^{g})	1.93 (1.50^{ef})	14.72 (3.9^{a})	16.03 (4.05^{a})	11.49 (3.45^{b})	6.56 (2.65^{c})	3.44 (1.98^{d})	3.31 (1.94^{d})	1.85 (1.52^{ef})	2.14 (1.62^{e})	1.23 (1.31^{fg})	1.11 (1.26^{g})	

Factors	SEm±	CD at 5%
Months (M)	0.039	0.133
Time (T)	0.096	0.325
M x T	0.136	0.385

Means in the columns/ rows with same alphabet do not differ significantly by DMRT at 5%

Figures in the parenthesis are $\sqrt{(x+0.5)}$ transformed values

Table 8.Incoming foragers with pollen during dry season

Months	Mean number of bees/5 minutes/colony - Hours →												Mean
	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	
January	1.00 (1.23)	1.00 (1.23)	4.42 (2.22)	14.84 (3.92)	10.82 (3.37)	4.55 (2.25)	3.39 (1.97)	`3.08 (1.89)	2.39 (1.7)	3.10 (1.9)	2.83 (1.83)	2.35 (1.68)	4.48 (2.09^{b})
February	1.00 (1.23)	3.42 (1.98)	19.30 (4.45)	23.76 (4.93)	11.90 (3.52)	13.07 (3.68)	4.89 (2.32)	6.22 (2.59)	4.66 (2.27)	3.57 (2.02)	1.87 (1.54)	1.42 (1.39)	7.92 (2.65^{a})
March	1.00 (1.23)	3.46 (1.99)	9.48 (3.16)	17.70 (4.27)	23.94 (4.94)	12.68 (3.63)	8.47 (2.99)	4.85 (2.31)	2.77 (1.81)	2.69 (1.79)	2.39 (1.7)	2.09 (1.61)	2.09 2.61^{a})
April	1.47 (1.4)	3.62 (2.03)	18.10 (4.31)	25.26 (5.08)	21.43 (4.68)	10.87 (3.37)	6.10 (2.57)	6.22 (2.59)	4.47 (2.23)	3.21 (1.93)	2.51 (1.73)	1.60 (1.45)	8.74 (2.78^{a})
May	1.00 (1.23)	4.81 (2.3)	7.54 (2.84)	5.15 (2.38)	4.49 (2.23)	4.08 (2.14)	2.90 (1.85)	3.08 (1.89)	2.39 (1.7)	1.68 (1.48)	1.95 (1.57)	1.00 (1.23)	3.34 (1.90^{b})
Mean	1.09 (1.26^{f})	3.26 (1.90^{de})	11.77 (3.39^{bc})	17.34 (4.11^{a})	14.52 (3.75^{ab})	9.05 (3.01^{c})	5.15 (2.34^{d})	4.69 (2.25^{d})	3.34 (1.94^{de})	2.85 (1.82^{de})	2.31 (1.67^{ef})	1.69 (1.47^{ef})	

Factors	SEm±	CD at 5%
Months (M)	0.143	0.430
Time (T)	0.221	0.667
M x T		0.495

Means in the columns/ rows with same alphabet do not differ significantly by DMRT at 5%

Figures in the parenthesis are $\sqrt{(x+0.5)}$ transformed values

Table 9. Incoming foragers with pollen during south-west monsoon season

Months	Mean number of bees/5 minutes/colony - Hours →												Mean
	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	
June	1.47 (1.4)	3.00 (1.87)	4.85 (2.31)	3.55 (2.01)	3.49 (1.99)	2.99 (1.87)	1.47 (1.4)	2.09 (1.61)	1.68 (1.48)	2.49 (1.73)	2.15 (1.63)	1.00 (1.23)	2.52(1.71^{b})
July	1.00 (1.23)	1.68 (1.48)	2.84 (1.83)	6.19 (2.59)	7.62 (2.85)	8.87 (3.06)	7.78 (2.88)	3.98 (2.12)	2.77 (1.81)	2.49 (1.73)	1.77 (1.51)	1.47 (1.4)	4.04 (2.04^{a})
August	1.00 (1.23)	1.42 (1.39)	7.50 (2.83)	8.04 (2.92)	9.04 (3.09)	12.71 (3.63)	9.59 (3.18)	8.66 (3.03)	2.21 (1.65)	3.90 (2.1)	2.15 (1.63)	1.23 (1.31)	5.62 (2.33^{a})
Mean	1.16 (1.28^{e})	2.03 (1.58^{de})	5.06 (2.32^{abc})	5.93 (2.50^{ab})	6.71 (2.64^{ab})	8.19 (2.85^{a})	6.28 (2.48^{ab})	4.91 (2.25^{bc})	2.22 (1.64^{de})	2.96 (1.85^{cd})	2.02 (1.59^{de})	1.23 (1.31^{de})	

Factors	SEm±	CD at 5%
Months (M)	0.107	0.333
Time (T)	0.214	0.667
M x T	0.37	

Means in the columns/ rows with same alphabet do not differ significantly by DMRT at 5%

Figures in the parenthesis are $\sqrt{(x+0.5)}$ transformed values

Table 10. Incoming foragers without pollen during north-east monsoon season

Months	Mean number of bees/5 minutes/colony - Hours →												Mean
	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	
November	1.68 (1.48)	6.75 (2.69)	5.67 (2.48)	8.66 (3.03)	11.67 (3.49)	15.43 (3.99)	16.96 (4.18)	13.67 (3.76)	15.68 (4.02)	12.19 (3.56)	9.47 (3.16)	6.99 (2.74)	10.40 (3.21^{a})
December	1.00 (1.23)	2.48 (1.73)	5.56 (2.46)	8.23 (2.96)	9.39 (3.15)	17.22 (4.21)	17.73 (4.27)	11.71 (3.49)	10.97 (3.39)	10.17 (3.27)	12.21 (3.57)	5.98 (2.55)	9.39 (3.02^{b})
Mean	1.34 (1.35^{g})	4.61 (2.21^{f})	5.61 (2.47^{ef})	8.44 (2.99^{d})	10.53 (3.31^{c})	16.32 (4.1^{a})	17.34 (4.22^{a})	12.69 (3.63^{bc})	13.33 (3.70^{b})	11.18 (3.41^{bc})	10.84 (3.36^{c})	6.48 (2.64^{e})	

Factors	SEm±	CD at 5%
Months (M)	0.046	0.138
Time (T)	0.112	0.34
M x T	0.158	0.446

Means in the columns/ rows with same alphabet do not differ significantly by DMRT at 5%

Figures in the parenthesis are $\sqrt{(x+0.5)}$ transformed values

Table 11. Incoming foragers without pollen during dry season

Months	Mean number of bees/5 minutes/colony - Hours →												Mean
	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	
January	1.00 (1.23)	1.00 (1.23)	5.41 (2.43)	15.42 (3.99)	13.47 (3.74)	11.51 (3.47)	18.44 (4.35)	10.90 (3.38)	9.04 (3.09)	9.75 (3.2)	7.36 (2.8)	5.28 (2.40)	9.05 (2.94^{c})
February	1.42 (1.39)	14.36 (3.86)	31.83 (5.69)	28.35 (5.37)	22.86 (4.83)	27.91 (5.33)	21.36 (4.68)	19.73 (4.49)	17.03 (4.19)	18.28 (4.33)	19.28 (4.45)	9.35 (3.14)	19.31 (4.31^{b})
March	1.00 (1.23)	25.28 (5.08)	23.06 (4.85)	25.83 (5.13)	38.56 (6.25)	30.07 (5.53)	23.69 (4.92)	21.93 (4.74)	24.55 (5.01)	22.63 (4.81)	17.55 (4.25)	17.36 (4.23)	22.62 (4.66^{b})
April	7.11 (2.76)	20.98 (4.64)	27.06 (5.25)	32.64 (5.76)	41.28 (6.46)	35.52 (6.00)	30.55 (5.57)	30.40 (5.56)	24.90 (5.04)	26.22 (5.17)	22.78 (4.83)	23.83 (4.93)	26.94 (5.16^{a})
May	4.45 (2.23)	17.20 (4.21)	22.33 (4.78)	30.83 (5.59)	26.34 (5.18)	31.94 (5.69)	29.06 (5.44)	25.56 (5.11)	23.03 (4.85)	18.93 (4.41)	15.52 (4.00)	9.54 (3.17)	21.23 (4.55^{b})
Mean	3.00 (1.76^{f})	15.76 (3.8^{de})	21.94 (4.6^{abc})	26.61 (5.16^{a})	28.50 (5.29^{a})	27.39 (5.20^{a})	24.62 (4.99^{ab})	21.70 (4.65^{abc})	19.71 (4.43^{bcd})	19.16 (4.38^{bcd})	16.50 (4.06^{cde})	13.07 (3.57^{e})	

Factors	SEm±	CD at 5%
Months (M)	0.165	0.478
Time (T)	0256	0.741
M x T	0.572	

Means in the columns/ rows with same alphabet do not differ significantly by DMRT at 5%

Figures in the parenthesis are $\sqrt{(x+0.5)}$ transformed values

Table 12. Incoming foragers without pollen during south-west monsoon season

Months	Mean number of bees/5 minutes/colony - Hours →												Mean
	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	
June	4.49 (2.23)	9.89 (3.22)	14.90 (3.92)	21.19 (4.66)	19.13 (4.43)	14.08 (3.82)	11.89 (3.52)	17.58 (4.25)	15.76 (4.03)	17.28 (4.22)	15.27 (3.97)	6.30 (2.61)	13.98 (3.74^{a})
July	1.68 (1.48)	5.01 (2.35)	7.33 (2.79)	13.27 (3.71)	20.55 (4.59)	21.25 (4.66)	19.89 (4.52)	19.69 (4.49)	16.58 (4.13)	11.31 (3.44)	9.12 (3.1)	6.38 (2.62)	12.67 (3.49^{a})
August	1.00 (1.23)	2.69 (1.79)	9.51 (3.16)	11.15 (3.41)	14.85 (3.92)	18.90 (4.41)	18.90 (4.83)	19.08 (4.43)	12.59 (3.62)	16.80 (4.16)	12.15 (3.56)	10.63 (3.34)	12.68 (3.49^{a})
Mean	2.39 (1.65^{e})	5.86 (2.45^{de})	10.58 (3.30^{bcd})	15.20 (3.93^{ab})	18.18 (4.31^{a})	18.08 (4.29^{a})	18.21 (4.29^{a})	18.78 (4.39^{a})	14.98 (3.93^{ab})	15.13 (3.94^{ab})	12.18 (3.54^{abc})	7.77 (2.85^{cd})	

Factors	SEm±	CD at 5%
Months (M)	0.172	0.514
Time (T)	0.345	1.028
M x T	0.597	

Means in the columns/ rows with same alphabet do not differ significantly by DMRT at 5%

Figures in the parenthesis are $\sqrt{(x+0.5)}$ transformed values

least during early morning hours and gradually increased to attain the first peak during 0900-1000 h and a slight second peak at 1500 h (Table 2). After the second peak, the activity reduced until 1800 h. The number of incoming bees without pollen loads was recorded to be least during early morning hours 0600-0700 h where after it gradually increased to reach a peak during 1100-1200 h (Table 3). The activity gradually decreased for the rest of the day.

Monthly variation in foraging pattern: The maximum activity of outgoing foragers around the year was observed during April (33.94 bees/5 min) followed by March (28.81 bees/5 min) and the least activity was during January (11.82 bees/5 min). The highest activity was during hotter months and the lowest activity during the winter months. The month of April exhibited the highest activity of incoming foragers with pollen (8.74 bees/5 min) followed by February (7.92 bees/5 min). The month of June (2.52 bees/5 min) and May (3.34 bees/5 min) observed the least activity. The activity was highest in the dry season while lowest in the south-west monsoon season. The greatest activity in the incoming of non-pollen foragers was in the month of April (26.94 bees/5 min) followed by March (22.62bees/5 min) while the least was during January (9.05 bees/5 min). The maximum activity was during hotter months of the dry season and the least during the winter period.

Foraging activity of outgoing foragers: The outgoing foragers were active throughout the months in the north-east monsoon season (Table 4). The activity was on par for both the months in the season. Peak activity in the season occurred during the initial part of late morning hours from 0800-0900 h (30.65 bees/ 5 min) which then declined gradually to reach a second peak at 1100-1200 h (21.31 bees/ 5 min) which again decreased to reach the third peak at 1500 hrs (13.48 bees/ 5 min). The least activity was observed during 0600-0700 h (2.14 bees/ 5 min) and 1700-1800 h (3.72 bees/ 5 min). The outgoing foragers were most active in the dry season and differed between months of the season as well as hours of the day (Table 5). The month of April significantly differed from every other month (33.94 bees/ 5 min) which marked the highest activity of the season. The months of February (24.02 bees/ 5 min), March (28.81 bees/ 5 min) and May (22.92 bees/ 5 min) were on par whereas the lowest was observed during the cold month of January (11.82 bees/ 5 min). The first peak of the day was observed during 0900-1000 hrs (43.97 bees/ 5 min) after which it declined and reached a second peak at 1400 hrs (22.17 bees/ 5 min). The lowest activity of the day was recorded in the early morning 0600-0700 h. The outgoing foragers during the south-west monsoon season were moderately active and statistically on par in all three months with a slighter higher number of foragers during June month (15.92 bees/ 5 min). The hour with the least activity was from 0600-0700 (4.22 bees/ 5 min) which gradually increased to the first peak of activity at 1000 h (24.15bees/ 5 min). The activity declined afterwards to certain hours after which it attained a second peak at 1500 h (16.57 bees/ 5 min) which again declined until evening (Table 6).

Foraging activity of incoming foragers with pollen: The incoming foragers with pollen loads were also on par for both the months with a slightly higher value during November (5.82 bees/ 5 min). The least activity was during early morning hours from 0600-0700 h, and then increased to reach the first peak of activity 0900-1000 h (16.03 bees/ 5 min). After the first peak, the activity declined for a few hours and again attained a second peak at 1500 hrs (2.14 bees/ 5 min) after which it decreased until 1800 h (Table 7).

The incoming foragers with pollen during the dry season (Table 8) was recorded the highest in April (8.74 bees/ 5 min) which was on par with the months February (7.92 bees/ 5 min) and March (7.63 bees/ 5 min). The month of May had the least activity (3.34 bees/ 5 min) which was on par with January (4.48 bees/ 5 min). The activity was least during morning 0600-0700 h which then increased to a peak at 0900 hrs (17.34 bees/ 5 min). After the peak, the activity decreased gradually to a lower value until 1800 h. The incoming foragers with pollen loads were lowest in the month of June (2.52 bees/ 5 min). The month of August (5.62 bees/ 5 min) and July (4.04 bees/ 5 min) was on par (Table 9). The maximum activity of incoming pollen foragers

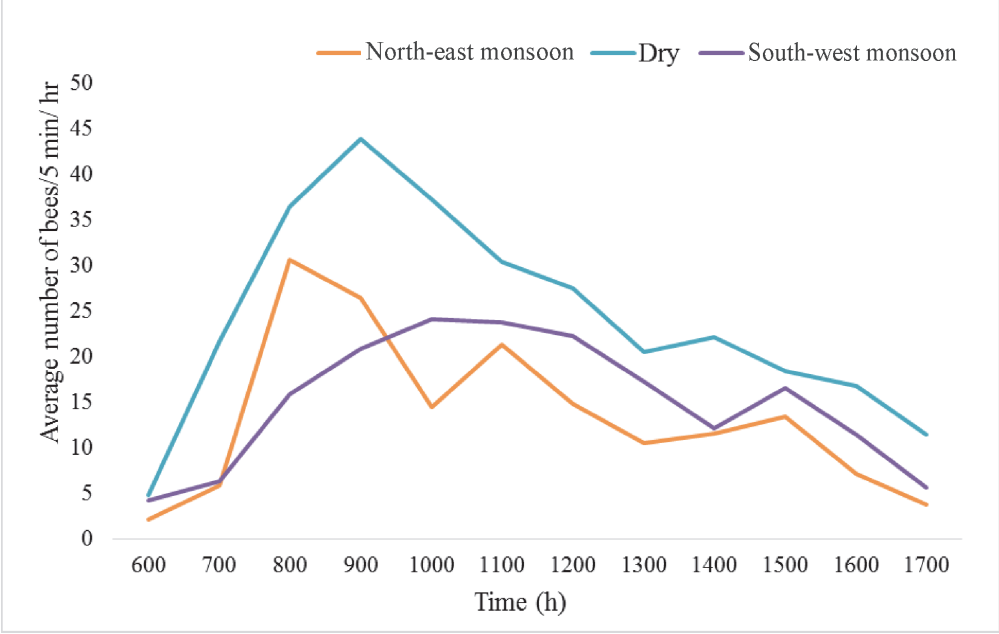

Fig 1. The foraging activity of outgoing foragers during north-east monsoon (November- December), dry (January- May) and south-west monsoon (June- August) season

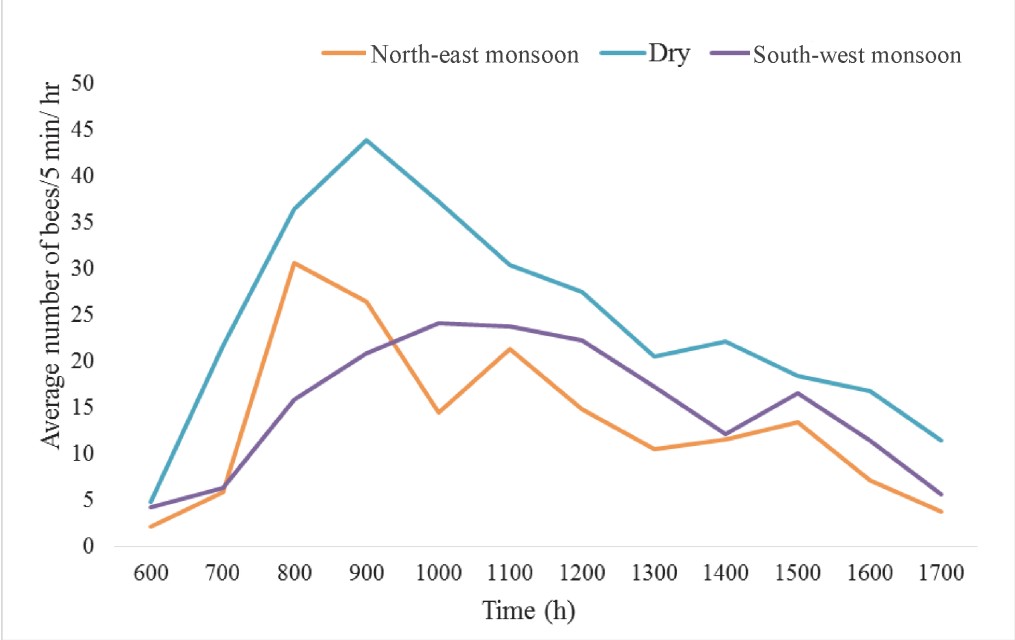

Fig 2.The foraging activity of incoming foragers with pollen during north-east monsoon (November- December), dry (January- May) and south-west monsoon (June- August) season

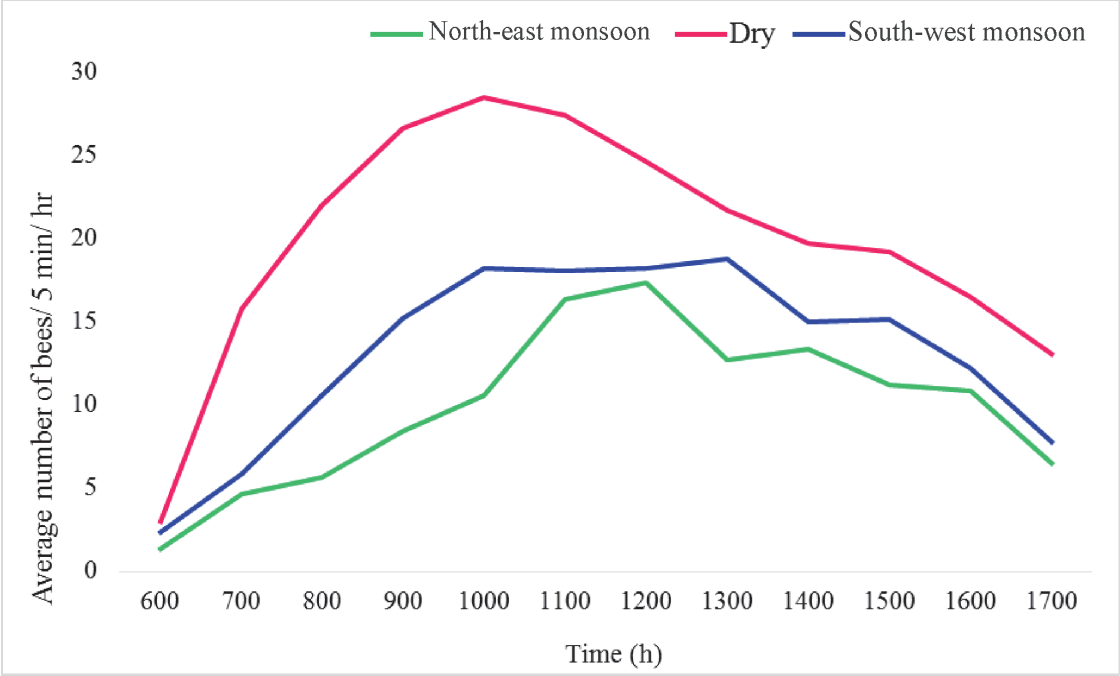

Fig 3.The foraging activity of incoming foragers without pollen during north-east monsoon (November- December), dry (January- May) and south-west monsoon (June- August) season

was from 1100-1200 h (8.19 bees/ 5 min), then it decreased for few hours and again increased into a slight peak during 1500-1600 hrs (2.96 bees/ 5 min). The activity was lowest during 0600-0700 h and 1700-1800 h (1.16 bees/ 5 min).

Foraging activity of incoming foragers without pollen: The incoming foragers without pollen loads were significantly different between months with a higher number in November (10.40 bees/ 5 min). The lowest number of bees was observed from 0600-0700 h (1.34 bees/ 5 min) in the early morning (Table 10), then increased gradually to a peak at 1200 h (17.34 bees/ 5 min), again to fall gradually until evening hour 1800. The incoming foragers without pollen loads were the highest during April (26.94 bees/ 5 min) which significantly differed from every other month (Table 11). The months of February (19.31 bees/ 5 min), March (22.62 bees/ 5 min) and May (21.23 bees/ 5 min) were on par while January with the lowest value (9.05 bees/ 5 min) differed significantly. The peak activity of the day was during 1000-1100 h (28.50 bees/ 5 min) and the lowest value of the day (3 bees/ 5 min) during 0600-0700 h. After the peak, the activity gradually decreased for the rest of the day until 1800 h. The incoming foragers without pollen loads did not differ significantly between the months which had their highest number of bees during June (13.98 bees/ 5 min). The activity of incoming non-pollen foragers was lowest during early morning 0600-0700 h (2.39 bees/ 5 min) which increased gradually to reach the first peak at 1000 hrs (18.18 bees/ 5 min) and a second peak during 1300-1400 h (18.78 bees/ 5 min) which again reached a third slight peak at 1500 h (15.13 bees/ 5 min). The activity then decreased gradually until 1800 h (Table 12).

DISCUSSION

The foraging activity of stingless bees differed between the three seasons due to the fluctuations in weather conditions and time-based disparity in resource availability.

Diurnal variation in foraging activity: The foraging activity started as early as 0600 hrs during April and May which are the months of the dry season with high average temperature. This is rather early to the formerly reported starting time by Devanesan *et al*. (2002) which was 0700 h in Kerala. Meanwhile, foraging started later between 0645 and 0700 h during December and January with cool, chilly or foggy mornings. Similar slight late initiation of activity during colder months December and January was reported by Roopa (2002). During the rainy months of June, July and August too, the activity started late around 0610 h. The foraging activity continued up to 1840 h during the dry hot season, though in other seasons, the activity ended in advance.

The highest foraging activity of outgoing and incoming pollen foragers was between 0800-1100 h in the late morning period whereas incoming foragers without pollen were most active during 1000-1300 h. The study on foraging behaviour conducted by Biesmeijer *et al.* (1992) showed that 75 per cent of pollen collection took place from 0800-1000 h which substantiate the present findings. The higher foraging activity, especially pollen gathering in the late morning hours (0900-1100 h), might be due to the need to fulfil their energy prerequisite, ideal accessibility of floral resources and favourable climatic conditions. This has also been documented by Azmi *et al*. (2015) for *Lepidotrigona terminata*. The foraging for nectar which was the function of non-pollen foragers seemed to increase during noon hours (1200-1300 h) due to the more sugar concentration in nectar. This is in line with the findings of Kajobe (2007) indicating that the sugar concentration of bee collected nectar increased from morning hours till 1300-1400 h, which might be due to the higher solar radiation causing evaporation and resulting in more concentrated nectar in flowers (Roubik and Buchmann, 1984; Roubik, 1989). In the afternoon hours (1300-1500) less activity has been observed in the hives, probably to conserve energy. The lowest activity observed during early morning hour (0600-0700) and late evening hour (1700-1800) might be attributed to non-favourable temperature, diminished sunlight intensity and also less availability of pollen and nectar.

Monthly variation in foraging activity: The greatest average activity evident during the dry season which included the hotter months of the year, March, April and May could be possibly due to the favourable weather conditions such as optimum temperature and low relative humidity. This was confirmed by the findings of Nunes-Silva *et al*. (2010) who stated that pollen and nectar foragers are positively correlated to temperature and negatively to humidity. Similar findings were also reported by Bharath *et al.* (2020) who stated that the highest activity was during March and reduced to the end of May. The higher activity in the month of July and August during the south-west monsoon could be attributed to the influence of rainfall on the blooming pattern which was also observed by Devanesan *et al*. (2009) and Aleixo *et al*. (2017). The overall activity was seen lowest during two months viz., January and December which were the coldest months, for which the low temperature can be held accountable. Pedro and Camargo (1991) and Managanvi *et al*. (2012) reported similar to findings.

Foraging activity of outgoing foragers: The activity of outgoing foragers in the north-east monsoon season attained three distinct peaks from 0800-0900, 1100-1200 and 1500-1600 h whereas south-west monsoon and dry seasons were observed to have two peaks (Fig. 1), one in the morning between 0900-1100 h and another one in the afternoon during 1500-1600 h. The studies by Roopa (2002) showed that during monsoon season, two distinct peaks of outgoing foragers were observed between 1200-1300 and 1600-1700 h. Similarly, Ghazi *et al.* (2014) noted that the effective time for foragers to go out was early in the morning between 0800 to 1100 hrs and the peak of activity was 1000 and 1200 h.

Foraging activity of incoming pollen foragers: The activity of incoming foragers with pollen was highest in between 0900 and 1000 h in the north-east monsoon, the dry season and 1100-1200 h during the south-west monsoon season. The second

peak was later in the afternoon during 1500-1600 h in all three seasons (Fig. 2). This is in accordance with the study conducted by Layek and Karmakar (2018) in West Bengal where they obtained two distinct peaks occurring between 0900-1100 and 1500-1600 h and also Devanesan *et al.* (2002) who reported two distinct peaks at 1200 and 1500 h respectively.

Foraging activity of incoming forgers without pollen: The activity of incoming non-pollen foragers showed only one distinct peak between 1000-1200 h except in south-west monsoon which had three peaks viz., 1000-1100 h (first peak), 1300-1400 h (slight second peak) and 1500-1600 h (third peak) (Fig. 3). Foraging activity that had a single peak was also obtained by Danaraddi *et al*. (2011) in Karnataka. The variations in the activity might be due to difference in colony health, climatic aspects and flora of the area. The study provides information on the foraging activity pattern of *T. travancorica* which is higher during morning hours from 0800-1200 h and late afternoon 1500-1600 h. It can be concluded that the foraging activity is highest during the summer months and lowest during the winter months. The change in the pattern of foraging behaviour with seasons suggests a strong influence of weather and flora on the bee colony.

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