Journal of Applied Horticulture, 26(1): 37-40, 2024

https://doi.org/10.37855/jah.2024.v26i01.07

Journal of Applied Horticulture

ISSN: 0972-1045

Pollination efficiency and foraging activity of stingless bee (*Tetragonula* "*iridipennis*" sp. group) in open field coriander cropping

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Abstract

In this study, we investigated the efficiency of *Tetragonula iridipennis* Smith, India's prevalent stingless bee, as a pollinator during the Rabi season, specifically focusing on coriander, cultivated for seed production. Our findings revealed several key insights during the peak blooming period of coriander. The highest activity of outgoing bees occurred between 1000-1200 hrs, with the peak number of pollen foragers recorded between 1100-1200 hrs, averaging 3.83 bees/5min/hour over six days. Nectar-foraging bees were most active between 1100 and 1400 hrs, while resin-foraging bees were observed at their peak between 1400 and 1500 hrs. Incorporating stingless bees in open-pollinated coriander crops resulted in a substantial yield of 130 kg of seeds per acre per 10 colonies, accompanied by 130 g of honey production within 28 days. Comparatively, this represented a 31 percent increase in seed production when compared to fields without bee colonies. These findings underscore the valuable role of *T. iridipennis* in enhancing coriander seed production, with potential implications for crop productivity and honey production.

Key words: *Tetragonula* sp.*,* foraging, pollination, coriander seed yield

Introduction

Beekeeping with stingless bees is called Meliponiculture, which has been practiced for many centuries, where these bees are considered very valuable domestic species. Meliponiculture has been managed at varying levels by traditional societies throughout the equatorial range of stingless bees. Currently, it is most widely practiced in Neotropical realms, including Asia, with many species (Chuttong *et al.*, 2016). *Tetragonula iridipennis* Smith is the most abundant stingless bee in India. This bee species forages in diverse flora with high floral fidelity (Layek and Karmakar, 2018). Stingless bees were more efficient and manageable pollinators than Apis bees, and effective pollinators in economic crops of families like Cruciferae and Leguminaceae, etc., where honeybees failed to pollinate. Only a few people used this bee species to pollinate crops like cucumber (Tej *et al.*, 2017). Therefore, utilizing this bee colony to pollinate crops could be very effective. Unfortunately, the management and utilization of this bee species for pollination are minimal.

Stingless bees are polylectic (collect pollen from various floral species) and manageable pollinators as they can adapt to extreme conditions and various nesting habits. The foraging activity of *T. iridipennis* varies significantly at different hours of the day and the month of the season and also depends on weather parameters (wind, humidity, temperature) and the body size of the bee (Danaradi *et al.*, 2011; Layek and Karmakar, 2018). Bees are involved in pollen collection only in the early morning, whereas they collect nectar, resin, or mud during noon and afternoon (Santos *et al.*, 2012).

Stingless bees play a crucial role in the pollination of various horticultural and agricultural crops by visiting these plants for nectar and pollen, which subsequently enhances pollination and increases crop yields (Roubik, 1995). According to Wayakar and Baviskar (2015), seven agro-horticultural plants—*Citrus aurantifolia* (lime), *Coriandrum sativum* (coriander), *Lagernaria siceraria* (bottle gourd), *Moringa oleifera* (drumstick tree), *Citrus aurantium* (bitter orange), *Cucumis sativus* (cucumber), and *Cucurbita pepo* (pumpkin)—provide both pollen and nectar as food sources for stingless bees. These bees are highly effective, pollinating approximately 20 crop species and contributing to the pollination of 60 other crop species.

Stingless bees are particularly important for the pollination of several economically and ecologically significant crops. These include annatto (*Bixa orellana*), known for its natural food coloring; coconut (*Cocos nucifera*), vital for its oil, water, and other products; cupuaçu (*Theobroma grandiflorum*), related to cacao and prized for its fruit; macadamia (*Macadamia integrifolia*), valued for its nuts; mango (*Mangifera indica*), a popular fruit globally; carambola or star fruit (*Averrhoa carambola*), known for its unique shape and flavor; chayote (*Sechium edule*), a type of squash; and mapati (*Pourouma cecropiifolia*), a lesser-known fruit tree (Heard, 1999).

Further research by Devanesan *et al.* (2009) identified 142 plants that stingless bees forage on, encompassing a wide range of plant types such as vegetables, oilseeds, spices, plantation crops, ornamental plants, forest trees, medicinal plants, and wild plants. Their pollination activities have been shown to significantly enhance crop yields, increasing vegetable yields by 25% and coconut yields by 20-40%.

In the present study, the pollination efficiency of stingless bees on coriander (*Coriandrum sativum*) was assessed. The study aimed to evaluate the quantitative improvements in coriander production due to stingless bee pollination. The results were compared with coriander plants subjected to open pollination with and without the presence of stingless bees. This comparison helps in understanding the specific contributions of stingless bees to coriander crop yields and highlights their importance in agricultural practices.

Table 1. Foraging activity of *Tetragonula* sp. in coriander crop

Time	Number of bees*			
	Outgoing	Collecting pollen	Collecting nectar	Collecting resin
0700 – 0800	0.5 (0.96)^{f}	0 (0.70)^{d}	0.33 (0.85)^{e}	0 (0.70)^{d}
0800 – 0900	1.33 (1.31)^{f}	0 (0.70)^{d}	0.5 (0.96)^{e}	0 (0.70)^{d}
0900 – 1000	5.33 (2.28)^{de}	1.83 (1.51)^{ab}	5.67 (2.46)^{cd}	0.83 (1.08)^{bcd}
1000 – 1100	10 (3.16)^{bc}	1.83 (1.47)^{ab}	8.5 (2.97)^{bc}	0.5 (0.93)^{cd}
1100 – 1200	21 (4.54)^{a}	3.83 (2.01)^{a}	18.67 (4.24)^{a}	1.67 (1.42)^{ab}
1200 – 1300	11.5 (3.45)^{bc}	2.33 (1.55)^{ab}	10 (3.19)^{bc}	0.83 (1.07)^{bcd}
1300 – 1400	10.83 (3.34)^{bc}	2.16 (1.48)^{ab}	8.83 (2.85)^{bc}	0 (0.70)^{d}
1400 – 1500	13.33 (3.65)^{b}	1.83 (1.40)^{bc}	9 (2.84)^{bc}	2.33 (1.61)^{a}
1500 – 1600	7.33 (2.70)^{cde}	1.83 (1.46)^{abc}	12.83 (3.62)^{ab}	1 (1.11)^{bcd}
1600 – 1700	5.33 (2.22)^{e}	1.16 (1.25)^{bcd}	5.5 (2.21)^{cd}	1.66 (1.36)^{abc}
1700 – 1800	10.67 (3.10)^{bcd}	2.33 (1.55)^{ab}	10 (2.98)^{bc}	2 (1.53)^{ab}
1800 – 1900	0 (0.70)^{f}	0.33 (0.88)^{cd}	2.67 (1.66)^{de}	0.17 (0.79)^{d}

*numbers of bees going out /coming in for five minutes in an hour. Figures in parentheses are square root transformed values; means followed by same alphabet(s) are on par by DMRT (*P*=0.05)

Materials and methods

The pollination efficiency of stingless bees in an open coriander field during the Rabi season was studied. The standard agronomic package of practices was followed, and the fieldwork was conducted at a farmer's field in Sattur from December 2020 to February 2021. The coriander crop was sown by the farmers for seed production.

Stingless bee foraging behavior was observed and documented with slight adjustments, following the methodology outlined by Ramesh *et al.* (2016). Observations were made at random intervals, with a frequency of once every five minutes, spanning from 6:00 AM to 6:00 PM. These observations were conducted on foragers located both at the hive entrance and on the coriander plants. This data collection process was repeated a total of six times, covering the period from flowering to seed set, with intervals of three days between each observation session. Two separate coriander fields were selected that were two kilometers apart and one served as open-field pollination with stingless bees and another as open-field pollination without stingless bees. Weather data were also gathered from the meteorological observatory of Agricultural Research Station, Kovilpatti. The total seed yield from both fields was recorded and expressed in kilograms. Descriptive statistics, Duncan's Median Range Test (DMRT) of the data was done in IBM_SPSS_26.0 package.

Results and discussion

Foraging activity in coriander field: The foraging behaviors of *Tetragonula* sp. on coriander exhibited significant variations on different days and at different hours of the day, as summarized in Table 1. The highest number of outgoing bees was observed during the period from 10:00 AM to 12:00 PM, while the lowest activity levels were recorded between 7:00 AM to 9:00 AM and 6:00 PM to 7:00 PM. Specifically, during the flowering period of coriander, the peak pollen foraging activity occurred between 11:00 AM and 12:00 PM, with an average of 3.83 bees per 5 minutes per hour over six days. Conversely, the lowest pollen foraging activity was observed between 7:00 AM to 9:00 AM and 6:00 PM to 7:00 PM, with 0.00 and 0.33 bees per 5 minutes per hour, respectively. The highest nectar foraging activity was also observed between 11:00 AM and 12:00 PM, while the lowest occurred between 7:00 AM and 9:00 AM.

In the case of resin foragers, their maximum activity was noted between 2:00 PM and 3:00 PM, while the lowest activity levels were recorded during several time slots: 7:00 AM to 9:00 AM, 1:00 PM to 2:00 PM, and 6:00 PM to 7:00 PM.

These findings align with those of Roopa *et al.* (2017), who observed peak outgoing bee activity between 12:00 PM and 1:00

Table 2. Foraging activity versus weather parameters in coriander crop at Sattur, Virudhunagar district (Dec-Feb)

Timing	Weather parameters						Number of bees		
	Max. Temp. °C	Min. Temp. °C	Rainfall (cm)	RH (%)	Wind (km/hr)	Outgoing	Pollen foraging	Nectar foraging	Resin foraging
0700-0800	26.17	21.67	0.02	89.50	9.00	0.5	0	0.33	0
0800-0900	28.17	21.67	0	84.34	9.67	1.33	0	0.5	0
0900-1000	27.00	22.00	0	78.84	9.84	5.33	1.83	5.67	0.83
1000-1100	26.67	23.00	0.02	82.50	9.17	10	1.83	8.5	0.5
1100-1200	28.00	24.00	0	70.34	12.00	21	3.83	18.67	1.67
1200-1300	29.17	26.67	0.04	66.50	13.50	11.5	2.33	10	0.83
1300-1400	29.50	26.67	0.02	68.50	12.00	10.83	2.16	8.83	0
1400-1500	28.50	25.50	0.25	74.17	9.34	13.33	1.83	9	2.33
1500-1600	27.34	23.34	0.24	77.67	9.84	7.33	1.83	12.83	1
1600-1700	27.84	23.34	0.04	74.17	10.34	5.33	1.16	5.5	1.66
1700-1800	26.34	22.17	0.18	72.50	10.84	10.67	2.33	10	2
1800-1900	24.17	20.50	0.40	71.84	10.17	0	0.33	2.67	0.17

Table 3. Correlation between weather factors and foraging activity of *Tetragonula* sp. in coriander crop

Weather parameters	Outgoing bees	Pollen foraging	Nectar foraging	Resin foraging
Maximum temperature	+0.522	+0.428	+0.364	+0.169
Minimum temperature	+0.649*	+0.572*	+0.518	+0.239
Rainfall	-0.188	-0.181	-0.020	-0.207
Relative humidity	-0.567	-0.633*	-0.579*	-0.383
Wind velocity	-0.526	-0.597	-0.510	-0.083

PM and the highest pollen and nectar foraging activity between 1:00 PM and 2:00 PM during the monsoon season. Similarly, Cervancia *et al.* (1982) reported increased foraging activity during the summer period.

Weather parameters versus foraging activity: The six-day mean data of weather parameters, including maximum and minimum temperatures, rainfall, relative humidity, and wind velocity, were analyzed in relation to the number of foraging bees observed from 0700 to 1900 (Table 2). The correlation matrix between these weather factors and the foraging activity of *Tetragonula* sp. during the Rabi season revealed that both maximum and minimum temperatures had a significantly positive correlation with foraging activity. In contrast, rainfall and relative humidity showed a negative correlation with foraging activity, although the negative correlation with rainfall was not significant. Wind velocity also negatively correlated with foraging activity (Table 3).

The multiple regression equation fitted with weather factors predicted that the foraging activity of *Tetragonula* sp. was $y= 54.855+1.66X_1+2.18X_2 - 20.74X_3-0.46X_4-1.36X_5$ where X1= maximum temperature, X2= minimum temperature, X3= rainfall, X4= relative humidity, X5= wind (Table 4).

Table 4. Multiple regression between weather factors and foraging activity of *Tetragonula sp.* in coriander crop

Activity	Variables	Partial regression coefficient	Standard error	't' value	r^2
Outgoing bees	X1= Max. Temp.	1.668	3.751	0.444	0.465
	X2= Min. Temp.	2.187	2.776	0.787	
	X3= Rainfall	-20.744	25.545	-0.812	
	X4= RH	-0.468	1.023	-0.457	
	X5= Wind	-1.360	3.798	-0.358	
Pollen foraging	X1= Max. Temp.	0.295	1.416	0.208	0.550
	X2= Min. Temp.	0.618	1.048	0.590	
	X3= Rainfall	-9.033	9.644	-0.936	
	X4= RH	-0.307	0.386	-0.795	
	X5= Wind	-0.801	1.434	-0.558	
Nectar foraging	X1= Max. Temp.	1.741	3.608	0.482	0.294
	X2= Min. Temp.	1.786	2.670	0.669	
	X3= Rainfall	-7.442	24.571	-0.302	
	X4= RH	-0.080	0.984	-0.081	
	X5= Wind	0.331	3.654	0.090	
Resin foraging	X1= Max. Temp.	0.313	0.588	0.532	0.316
	X2= Min. Temp.	0.176	0.435	0.404	
	X3= Rainfall	-1.315	4.010	-0.328	
	X4= RH	-0.205	0.160	-1.276	
	X5= Wind	-0.763	0.596	-1.279	

RH= Relative Humidity, Temp. = Temperature

The regression equation indicated that a 1°C increase in the maximum temperature would lead to 0.44 number increase in outgoing bees, 0.20 pollen foragers, 0.48 nectar foragers and 0.53 resin foragers. However, a 1°C increase in the minimum temperature would lead to 0.78 number increase in outgoing bees, 0.59 pollen foragers, 0.66 nectar foragers and 0.40 resin foragers. An increase in one mm of rainfall will decrease 0.81 number of outgoing bees, 0.93 pollen foragers, 0.30 nectar foragers and 0.32 resin foragers. However, a percent increase in relative humidity would lead to 0.45 number decrease in outgoing bees, 0.55 pollen foragers, 0.08 nectar foragers and 1.27 resin foragers. Similarly, an increase in wind velocity by 1kmph would decrease 0.35 number of outgoing bees, 0.55 pollen foragers, 0.09 nectar foragers and 1.27 resin foragers during the rabi season in coriander. Further, the values of the coefficient of determination (r^2) indicated that there were 46.5 (r^2= 0.465), 55.0 (r^2= 0.55), 29.4 (r^2= 0.29) and 31.6 (r^2= 0.316) percent variation in the foraging activity of *Tetragonula sp.,* due to meteorological factors (Fig. 2). The present results are in confirmation with the findings of Roopa *et al.* (2017) who reported that the foraging activity was positively correlated with higher temperature and negatively correlated with relative humidity and low temperature.

Seed and honey yield: Open-pollinated coriander fields with stingless bees yielded 130 kg of seeds/acre/10 colonies, whereas in the absence of stingless bee colonies, it yielded about 90kg/acre. About 31% increase in seed yield was observed due to stingless bee pollination. Normal seed yield was reduced by crop lodging due to unseen rainfall during the present study. The honey yield obtained during the pollination service in coriander was about 130 g within the flowering period of 28 days (Table 5). The honey was harvested only once at the end of the flowering period from 10 colonies.

Table 5. Comparison of coriander seed yield in presence and absence of stingless bee pollination

Coriander field	Number of stingless bee colonies per acre	Isolation distance	Seed yield (kg/ac)	Yield increase over control (%)	Honey yield per 10 colonies (g)
With stingless bee pollination	10	Two km	130	31	130
Without stingless bee pollination	-		90	-	-

This study investigated the efficiency of *T. iridipennis* Smith, a prevalent Indian stingless bee, in pollinating coriander during the Rabi season. Notably, we observed peak bee activity between 10:00 AM and 12:00 PM, with the highest pollen foragers (average of 3.83 bees/5min/hour) between 11:00 AM and 12:00 PM. Nectar and resin foragers were most active from 11:00 AM to 2:00 PM and 2:00 PM to 3:00 PM, respectively. Integrating stingless bees into coriander fields increased seed production by 31% (130 kg/acre/10 colonies) compared to fields without bees, accompanied by 130 g of honey production. These findings underscore the valuable role of *T. iridipennis* in enhancing coriander seed production and honey yield, with potential implications for agriculture.

Acknowledgements

The authors express their sincere gratitude to the localfarmers who generously contributed by allowing access to their cropping areas for the pollination studies.

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Received: September, 2024; Revised: December, 2023;
Accepted: January, 2024