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RESEARCH ARTICLE

Effect of stingless bee (*Tetragonula iridipennis*) pollination on onion seed yield in Rabi and Kharif seasons

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Abstract

The present study on stingless bee was carried out during Rabi and Kharif of 2022-2023 in farmers field at Oddanchatram, Dindigul district of Tamil Nadu to evaluate their efficiency in pollinating onion, cultivated for seed purpose. Two fields (10 km apart) were used, one with stingless bees (2 colonies/acre) and one without. Foraging activity was monitored every 4 days over 36 days and onion seed yield and germination were compared between open pollination and covered umbels. During Rabi, peak foraging activity occurred from 1100 to 1200 h with 23.6 outgoing bees/5min/h. Pollen and nectar foragers peaked between 1200 and 0100 h with means of 6.5 and 20.1 bees/5min/h, while resin foragers showed peaks at 1200-0100 and 0500-0600 h. Managed pollination yielded 165 kg/acre with 88% germination compared to 120 kg/acre and 77% without bees. In Kharif, similar peaks were observed, with pollen, nectar and resin foragers averaging 4.3, 19.4 and 2.0 bees/5min/h, respectively. Seed yield was 150 kg/acre with stingless bee pollination versus 110 kg/acre without bees, with germination rates of 86% and 74%. Stingless bee pollination improved onion seed yield by 37.5% in Rabi and 36% in Kharif, demonstrating their significant role in boosting crop productivity. Future studies should explore the long-term impacts of stingless bee pollination on crop yields and biodiversity.

Keywords

foraging activity; onion seed yield; pollination; stingless bee; weather factors

Introduction

Onion (*Allium cepa* L.), a widely cultivated bulbous vegetable native to Central Asia, belongs to the Liliaceae family. It has been a significant commercial and condiment crop in India for over 5000 years. India ranks second in Onion bulb production globally, following China, with an annual output of 311.29 lakh tonnes and a productivity rate of 16.26 MT/ha (1). Major onion producing states include Maharashtra, Karnataka, Madhya Pradesh, Andhra Pradesh, Rajasthan, Tamil Nadu and Haryana. Despite high production levels, India's average onion productivity remains below the global average, primarily due to the limited availability of quality seed material. The country requires approximately 9400 tonnes of onion seeds annually to cultivate 11.73 lakh hectares of land (2). Organized sectors supply about 40% of this demand, while the rest is met by seeds saved by farmers. Quality onion seed production heavily relies on effective pollination, which depends on the presence and diversity of insect pollinators (3).

Among all flora onions are oldest cultivated plants globally, encompassing

1250 species of perennial bulbous plants within the genus *Allium*. The onion, *Allium cepa* L. is a cross-pollinated crop owing to the protandrous nature of flowers and it depends upon the insects for pollination rather than wind due to wet and sticky nature of pollen grains (4). In early morning (0600-0700 h), the anthesis takes place and dehiscence of anthers starts from 0700 to 1700 h and it begins from outermost flowers and progressive to center of umbel (5). Agrometeorology, as a discipline, delves into the intricacies of weather patterns and leverages the weather and climate data to optimize agricultural practices. By harnessing insights from meteorological information, agrometeorology contributes to the enhancement of agricultural strategies, ultimately leading to increased crop production (6).

The biotic and abiotic vector pollination play key roles in ecological services by enhancing crop productivity. Mostly 80% of flora depends on arthropods for pollination. Out of that 90% of pollination is supported by *Apis,* non-*Apis* bee species of hymenopterans, descended by Diptera, Lepidoptera and Coleoptera (7, 8). The most primitive and smallest eusocial bee species that producing honey are stingless bees (*Tetragonula iridipennis* Smith) which belong to the family Apidae and subfamily Meliponinae. This bee species is most abundant in India, having high degree of floral fidelity and diversified flora for foraging (9). The stingless bees are most effective and manageable pollinators in commercial crops of families likes Leguminaceae and Cruciferae, etc where other honeybees fail to pollinate. The efficacy of insect pollinator is contingent upon three primary factors *viz.,* the contact between the anther and stigma of flower, their capacity for travel and their abundance within the region.

Generally, the foraging behaviour of honeybees has notable effect due to temperature and rainfall. From the finding of previous scientific investigation between the weather factors and foraging activity of bees, this study aims to investigate the impact of stingless bee on onion seed yield and examine how bee activity is influenced by weather conditions.

Materials and Methods

Study area and experimental design

The present study with manageable stingless bee pollination in seed onion was conducted in farmers field during two different seasons *viz.,* Rabi and Kharif at oddanchatram (10.476434°N; 77.733564°E), Dindigul district of Tamil Nadu, where the standard agronomic practices were followed. The onion seedlings (cultivar CO-6) were transplanted and maintained in an area of one acre from December 2022 to March 2023 (Rabi) and May to August 2023 (Kharif). The anthesis initiation started form outermost flowers and progressed towards centre in sequential manner, the anthesis duration of onion was approximately 30 to 35 days. With ten kilometers of isolation distance two experimental fields were selected, one with the presence of stingless bee colonies @ 2colonies/acre and another without bee colonies. An isolation distance of 10 km was maintained between the experimental fields to ensure experimental validity and prevent cross-pollination, by considering the foraging range of stingless bees, which is between 50 and 500 m.

Foraging behaviour and pollination efficiency assessment

With slight modifications, observations on the foraging behavior of stingless bees were conducted over a duration of twelve hours, from 0700 to 1900 hours (10). Four type of bee foragers and their activities were observed in terms of number of worker bees going out and coming in with their rewards for five minutes per hour from 0700 h to 1900h in a day at the hive entrance. The key interpretation attributes *viz.,* outgoing and incoming foragers were recorded at every four days interval during the blooming period that lasted for 36 days. The bees going out for collecting floral rewards were designated as outgoing bees and the incoming bees with pollen and resin in their corbicula were described as pollen and resin foragers respectively and bees without pollen in their corbicula were described as either nectar or water foragers. The total seed yield and germination rate of onion seeds under the presence and absence (umbel covered with butter paper) of stingless bee pollination were observed (11).

Meteorological data collection

The meteorological data were recorded from the AgroMet Advisory Bulletin (AAB) jointly released by Regional Meteorology Centre, Chennai - India Meteorology Department, Reddiarchathram Seed Growers Association and M.S. Swaminathan Research Foundation. Also, by following the recent studies in evaluating the performance of NASA POWER data (12), the requisite hourly weather data of five parameters *viz*., maximum and minimum temperature (°C), rainfall (cm), wind (km/h), relative humidity (%) were obtained from NASA POWER web portal (https://power.larc.nasa.gov/data-access-viewer/) with a mean of ten days were recorded with relation to bee foragers from 0700 to 1900 h of the day (Table 1) and also these factors were used for correlating the functional foraging activity of stingless bee foraging *viz*., outgoing bees, pollen, nectar and resin foragers.

Statistical analysis

The statistical analysis was performed using R Studio with the “agricolae” package for the Duncan’s Median Range Test (DMRT) to find the peak foraging time of worker bees and regression analysis to predict the foraging behaviour with respect to changing weather conditions and “psych” package for correlation matrix.

Results and Discussion

Foraging behaviour of stingless bee on Onion flowers

Bees upon landing on the individual florets of the umbel, the pollen collecting stingless bee climbed to the apex of anther to gather the pollen grains. During this activity, the stingless bees contacted the stigma which resulted in cross pollination. In disparity, nectar foragers land at the floret base, thereby avoiding the stigma apex and collected nectar (Fig. 1). These findings were in line with previous findings which noted the same behaviour of stingless bee foraging on onion flower, as the species of stingless bee and the rewards of onion flower were same in both the locations (10).

Foraging activity patterns in Rabi and Kharif seasons

The stingless bee foragers exhibited notable variations in pollen, nectar, resin collection and outgoing bees on onion across various days and hours (Table 2). The observation on foraging activity of stingless bee in Rabi season revealed that, the peak

Table 1. Meteorological data on onion in Oddanchathiram, Dindigul district: Rabi (February to March 2023) and Kharif (July to August 2023)

Time of hours	*Weather parameters									
	Maximum temperature (°C)		Minimum temperature (°C)		Rainfall (cm)		Wind (km/h)		Relative Humidity (%)	
	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif
0700 to 0800	22.9	27.6	13.1	23.5	0.0	0.04	6.1	19.8	85.9	70
0800 to 0900	24.5	29.2	15.3	24.7	0.0	0.00	9.3	22.5	83.4	64.1
0900 to 1000	26.1	30.7	17.5	26.3	0.0	0.03	11.8	23.3	80.6	60.9
1000 to 1100	27.7	32	18.7	28	0.0	0.03	13.8	23.5	72.0	57.8
1100 to 1200	28.9	33.7	20.9	29.6	0.0	0.00	12.4	23.3	65.0	50.5
1200 to 1300	30.1	34.7	22.0	30.5	0.0	0.04	14.0	21.7	57.9	48.2
1300 to 1400	31.4	35.3	22.4	31.4	0.0	0.03	13.0	21.2	52.5	44.8
1400 to 1500	32.1	36.3	23.3	32.3	0.0	0.03	14.9	22.7	51.1	42.6
1500 to 1600	30.8	36.8	21.5	32.7	0.0	0.13	15.4	22.8	48.7	39.1
1600 to 1700	30.6	36.4	21.3	32.1	0.0	0.04	17.1	20.8	47.2	39.8
1700 to 1800	30.1	35.4	20.8	31.5	0.0	0.12	17.4	20.8	46.4	41
1800 to 1900	29.9	34.2	19.5	29.8	0.0	0.33	15.1	19.7	50.5	45

*Mean of ten observations of weather data, during onion flowering period of two seasons.

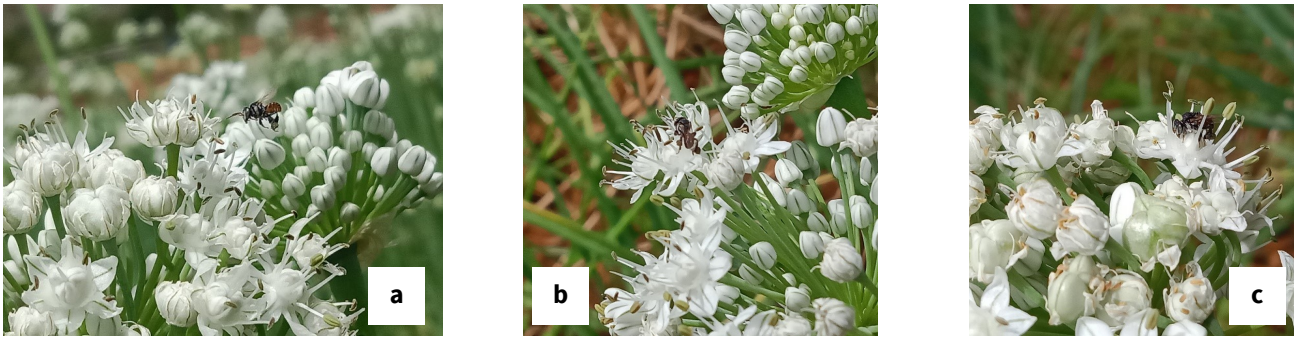

Fig. 1. Foraging behaviour of stingless bee in onion. (a) foraging flight towards the onion inflorescence, (b) collection and loading of pollen grains from anthers and (c) nectar collection from base of the stigma.

Table 2. Foraging activity of *Tetragonula iridipennis* in onion across Rabi and Kharif seasons

Time of hours	Number of bees*/ 5 min							
	Outgoing		Pollen carrying		Nectar carrying		Resin carrying	
	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif
0700 to 0800	1.5 (1.22)^{f}	0.8 (0.89)^{g}	0.7 (0.84)^{f}	0.0 (0.00)^{d}	0.8 (0.89)^{f}	0.3 (0.55)^{d}	0.6 (0.77)^{e}	0.4 (0.63)^{d}
0800 to 0900	3.0 (1.73)^{de}	2.1 (1.45)^{f}	1.2 (1.09)^{e}	0.4 (0.63)^{d}	1.6 (1.26)^{e}	0.9 (0.95)^{d}	1.0 (1.00)^{d}	0.7 (0.84)^{bcd}
0900 to 1000	7.2 (2.68)^{c}	5.8 (2.41)^{e}	3.9 (1.97)^{b}	2.8 (1.67)^{bc}	7.9 (2.81)^{c}	6.7 (2.59)^{bc}	1.6 (1.26)^{c}	1.4 (1.18)^{abc}
1000 to 1100	14.7 (3.83)^{b}	12.6 (3.55)^{bc}	3.7 (1.92)^{bc}	2.9 (1.70)^{bc}	10.3 (3.21)^{bc}	9.2 (3.03)^{bc}	1.5 (1.22)^{c}	1.0 (1.00)^{abcd}
1100 to 1200	23.6 (4.85)^{a}	23.6 (4.86)^{a}	4.4 (2.10)^{b}	4.3 (2.07)^{a}	9.8 (3.13)^{bc}	19.4 (4.40)^{a}	1.8 (1.34)^{bc}	1.9 (1.38)^{a}
1200 to 1300	22.7 (4.76)^{a}	13.3 (3.65)^{bc}	6.5 (2.55)^{a}	3.4 (1.84)^{ab}	20.1 (4.48)^{a}	9.1 (3.02)^{ab}	2.9 (1.70)^{a}	1.3 (1.14)^{abc}
1300 to 1400	12.9 (3.59)^{bc}	11.2 (3.35)^{c}	4.5 (2.12)^{ab}	3.6 (1.90)^{ab}	8.8 (2.97)^{c}	7.7 (2.77)^{ab}	1.3 (1.14)^{d}	0.6 (0.77)^{cd}
1400 to 1500	15.9 (3.98)^{b}	14.5 (3.81)^{b}	3.7 (1.92)^{bc}	2.7 (1.64)^{bc}	12.4 (3.52)^{b}	9.9 (3.15)^{bc}	2.2 (1.48)^{b}	1.7 (1.30)^{b}
1500 to 1600	10.1 (3.17)^{bc}	8.5 (2.92)^{d}	3.9 (1.97)^{bc}	2.7 (1.64)^{bc}	6.4 (2.53)^{d}	5.1 (2.26)^{bc}	1.5 (1.22)^{c}	1.1 (1.05)^{abcd}
1600 to 1700	7.5 (2.73)^{d}	5.9 (2.43)^{e}	3.3 (1.82)^{d}	2.3 (1.52)^{c}	5.4 (2.32)^{e}	3.5 (1.87)^{c}	2.2 (1.48)^{b}	1.8 (1.34)^{ab}
1700 to 1800	13.9 (3.72)^{bc}	12.6 (3.55)^{bc}	4.1 (2.02)^{b}	3.4 (1.84)^{ab}	9.8 (3.13)^{bc}	12 (3.46)^{ab}	1.7 (1.30)^{bc}	2.0 (1.41)^{a}
1800 to 1900	1.1 (1.04)^{f}	0.4 (0.63)^{g}	0.4 (0.63)^{f}	0.3 (0.55)^{d}	4.9 (2.21)^{e}	4.4 (2.10)^{d}	0.9 (0.95)^{e}	0.7 (0.84)^{bcd}

*No. of bees going out and coming in with rewards for five minutes in an hour. Each value is a mean of ten observations. Figures in parentheses are square root transformed values; Means followed by same alphabet(s) are on par by DMRT (p=0.05).

activity of outgoing bees was observed in the time interval of 1100 to 1200 h and 1200 to 0100 h with a mean of 23.6 and 22.7 bees/5min/h, respectively and least activity recorded between 1800 to 1900 h with a mean of 1.1 bees/5min/h. The peak foraging activity of pollen, nectar and resin foragers were recorded between 1200 to 0100 h with a mean of 6.5, 20.1 and 2.9 bees/5min/h and the least activity of bee with nectar and pollen rewards were observed between 0700 to 0800 h with a mean of 0.8 and 0.6 bees/5min/h; and least pollen foragers activity during 1800 to 1900 h with a mean of 0.4 bees/5min/h. Significant peak of pollen foraging occurred during the noon hours, which was in line with previous reports which stated that peak pollen foragers were at 12 noon (13). Whereas inconsistent with a few findings which stated that peak pollen foraging activity is in early morning hours, this contradiction might be due the floral rewards availability and microclimate suitability (14, 15). The fallouts of the present study are contradictory with the findings which reported that the peak activity of *Tetragonula* sp. is during 1000 to 1100 h and the contradictory might be due to the different agroclimatic factors affecting the crop and bees (16). It was observed that the maximum number of outgoing bees (88.74 foragers/10 min), pollen foragers (30.55 foragers/10 min), nectar foragers (69.44 foragers/10 min) and resin foragers (5.93 foragers/10 min) occurred during the month of March (14). During Kharif season, the foraging performance annotations revealed that, the maximum number of outgoing bees was recorded in the late morning hours from 1100 to 1200 h with a mean of 23.6 bees/5min/h and least number from 1800 to 1900 h with a mean of 0.4 bees/5min/h. The pollen and nectar foragers were found enhanced during the late morning hours between 1100 and 1200 h with a mean of 4.3 and 19.4 bees/5min/h. Later the least activity of pollen foragers was noted from 0800 to 0900 h. The peak number of resin foragers occurred between 1700 and 1800 h, with an average of 2.0 bees/5min/h, followed by 1100 to 1200 h, with a mean of 1.9 bees/5min/h. The lowest foraging activity for nectar and resin foragers was observed between 0700 and 0800 h, with a mean of 0.3 and 0.4 bees/5min/h, respectively. The fallouts of the present investigation are analogous with previous research which recorded the highest outgoing bee activity during 1200 to 1300 h as well as peak nectar and pollen foragers during 1300 to 1400 h coinciding with monsoon weather (17). The present contentions are inconsistent with the previous findings which stated that the peak nectar and pollen foraging activity was during 1600 to 1700 h and 0800 to 0900 h, respectively (10). These inconsistencies might be due to the changes in weather factors of specific locality.

Correlation between weather parameters and foraging activity

The association between weather factors and foraging activity of *T. iridipennis* during the Rabi season, the temperatures and wind speed shows the moderate and weak positive correlation, respectively, with outgoing bees and incoming foragers with floral rewards. Whereas the relative humidity shows weak negative correlation to the bee foragers and there is no rainfall during the crop flowering period. The results of kharif season, revealed that the temperature (maximum and minimum) and wind speed showed a moderate positive correlation to the outgoing and incoming foragers with rewards. However, the relative humidity and rainfall exhibited a moderate to weak negative correlation to the foragers going out and coming in (Fig. 2). These results are inconsistent with previous observations indicating that stingless bees exhibited a weak negative correlation (r = -0.24) and a weak positive correlation (r = +0.01) with maximum temperature, a moderate negative correlation with minimum temperature (r = -0.69) and a weak negative correlation with wind speed (r = -0.07) (18). Nevertheless, the relative humidity and rainfall showed negative correlations, respectively r = -0.35 and r = -0.40, which are analogous in our investigation. These incomparable results might be due to the seasonal variations between the study locations (Fig. 3).

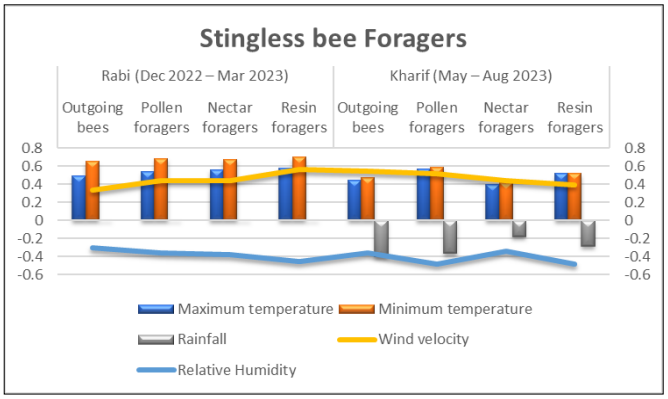

Fig. 2. Correlation matrix between weather parameters and foraging activity of *Tetragonula iridipennis* in onion during Rabi and Kharif season.

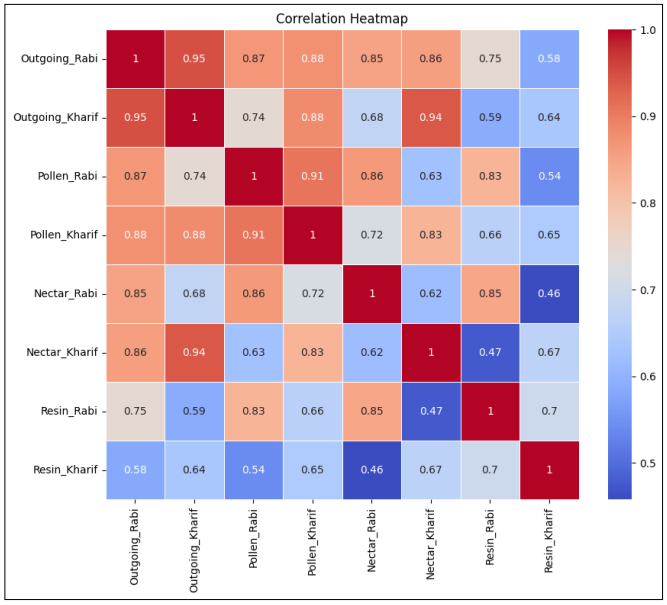

Fig. 3. Correlation heatmap of foraging efficiency on two seasons over time.

Variability in foraging activity: Boxplot and Pairplot analysis

The boxplots (Fig. 4) for outgoing activities during Rabi and Kharif seasons show some outliers in the data (the circles above the box), especially in the Kharif season. Both seasons have a wide interquartile range (IQR), meaning high variability. The median values are higher in Rabi but relatively close. Both pollen activities show small IQRs, meaning less variability. However, some outliers exist, particularly in the Rabi season. Nectar activity shows moderate variability, with the Kharif season displaying a wider IQR compared to Rabi. There are some outliers in the data as well. Resin activity shows the smallest variability and IQR. There are no significant outliers and the activities are consistently low across both seasons.

The pairplot (Fig. 5), which is used to visualize the pairwise relationships between multiple variables in a dataset. Diagonal KDE Plots represent the distribution (probability

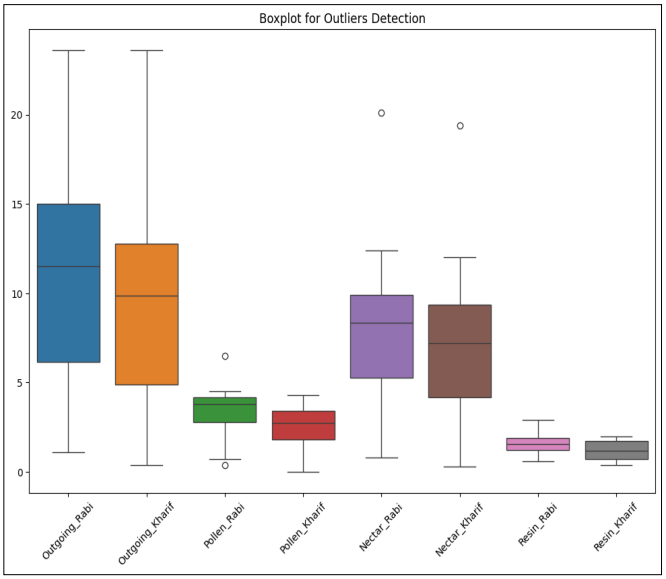

Fig. 4. Outlier detection using box plot analysis of different foragers.

density) of each variable. The smoother and taller the plot, the more concentrated the data around certain values. Scatter Plots (Off-Diagonal) depict the relationship between every pair of variables. Some patterns can be interpreted to identify trends or correlations: Outgoing_Rabi & Pollen_Rabi and Outgoing_Rabi & Nectar_Rabi: There is a slightly positive linear trend, suggesting that as the outgoing rates increase, the pollen and nectar production in the Rabi season also increase. Pollen_Rabi & Nectar_Rabi: A clear positive correlation, indicating a strong relationship between pollen and nectar in the Rabi season. Pollen_Kharif & Nectar_Kharif: Like the Rabi season, these also show a positive relationship in the Kharif season. Outgoing_Kharif with other Kharif variables (e.g., Pollen_Kharif, Nectar_Kharif): These seem to have a less pronounced trend but may still show slight positive associations. Due to their unique properties of honey and vital pollination services enhance crop productivity and biodiversity, supporting the adoption of stingless bee colonies for resilient and sustainable agroecosystems.

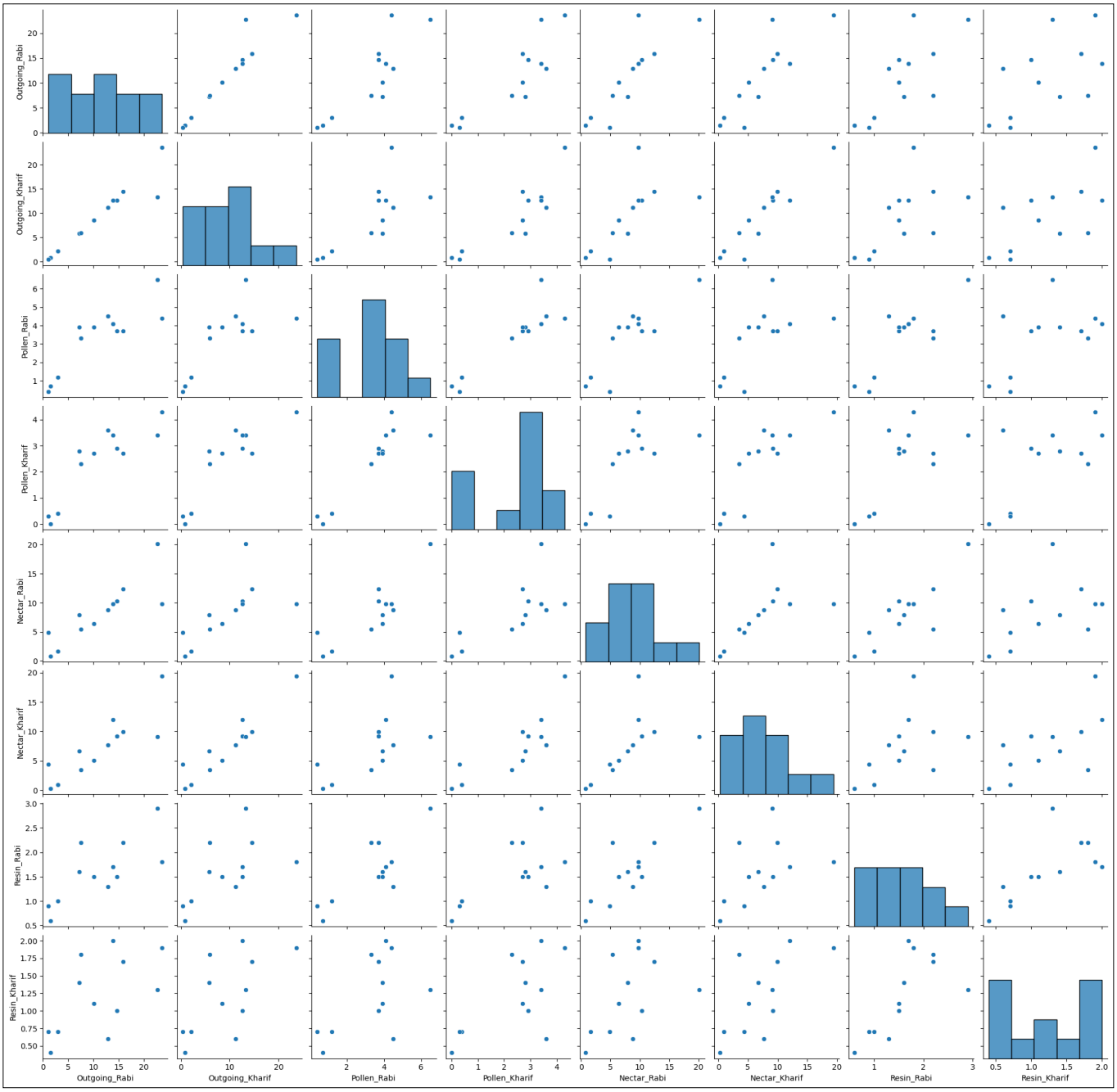

Fig. 5. Pairwise relationship between the number of different stingless bee foragers over time.

Multiple regression analysis of weather's impact on foraging activity

Multiple regression analysis illustrated that how each weather parameters had contributed to the foraging activity of stingless bees. The foraging activity versus weather factors during Rabi season depicted that the maximum temperature shows negative regression coefficient to outgoing foragers (a = -10.24), pollen collectors (a = -2.35), nectar foragers (a = -3.60) and resin foragers (a = -0.81); minimum temperature depicted positive regression coefficient to the outgoing bees (b= +10.14), pollen foragers (b = +2.28), nectar foragers (b = +4.50) and resin foragers (b = +0.74) during February to March. Manageable stingless bee pollination during Rabi season illustrated that 1 °C increase in maximum temperature would lead to 10.24 decrease in outgoing bees, 2.35 pollen foragers, 3.60 nectar foragers and 0.81 resin collectors. During Kharif season, the maximum temperature depicted negative regression coefficient to the outgoing bees (a = -13.57), pollen foragers (a = -2.03), nectar collectors (a = -12.86) and resin foragers (a = -0.35) and minimum temperature drew positive regression coefficient to outgoing bees (b= +13.93), pollen foragers (b= +2.18), nectar collectors (b= +11.37) and resin foragers (b= –0.10) and wind speed illustrated positive regression coefficient to the outgoing bees (c = +2.71), pollen foragers (c = +0.39), nectar collectors (c = +2.17) and resin foragers (c = +0.16) during July to August (Table 3). Pollination during Kharif season by stingless bees clearly depicted that the 1°C increase in maximum temperature would lead to 13.57 number decrease in outgoing, 2.03 pollen foragers, 12.86 nectar collectors and 0.35 resin foragers and similarly for the rest of weather parameters also. This prediction aligned with previous findings indicating that the number of bees going out for foraging was negatively influenced by maximum temperature (r = -0.72) (19). However, it contrasted with other studies that suggested maximum and minimum temperatures positively influenced the activity of outgoing and pollen foragers among stingless bees (18). Additionally, it was comparable with observations showing that stingless bee foraging activity tended to be lower during winter months, as flight activity decreased compared to warmer days (20, 21).

Effect of stingless bee pollination on onion seed yield

The onion field with the existence of stingless bee colonies during Rabi and Kharif season yielded a seed harvest of 165 and 150 kg/ac respectively, whereas the field in the absence of stingless bee pollination yielded about 120 and 110 kg/ac respectively. Which is revoked as 37.5% and 36% increase in seed yield due to stingless bee manageable pollination. The results are comparable with findings reporting that pollination by bees resulted in a higher percentage of fruit set in crops compared to open pollination, self-pollination and hand pollination (10). They also align with observations of a 31% increase in seed production of coriander through stingless bee-managed pollination (22). Additionally, a 25.74% yield increase was recorded with bee pollination compared to mechanical pollination, consistent with these findings (23). The germination rate (mean value of 100 seeds) of onion seeds harvested from Rabi and Kharif cropping with bagged (77% and 74%) and unbagged (88% and 86%) inflorescence correspondingly and the seedling vigour of Rabi and Kharif cropped seeds showed the root length from bagged (8.62 and 8.53cm); unbagged (9.64 and 9.78 cm) and with seedling shoot length of bagged (3.45 and 3.79 cm); unbagged (3.39 and 3.77 cm) respectively (Fig. 6). This finding was consistent with reports of a significant increase in the germination rate in uncaged inflorescences (11). It also aligned with observations showing that onion umbels pollinated by stingless bees exhibited maximum root and shoot lengths of 9.59 cm and 11.02 cm, respectively (16).

Conclusion

In the present study, the impact of climatic factors such as temperature, rainfall, wind speed, relative humidity on stingless bee foraging the onion was investigated and it was found that the weather factors such as relative humidity and rainfall negatively affected the foraging activity of stingless bees while the provision of stingless bee colonies to the onion field significantly increased the pollination thereby boosting onion seed yield and germination rates. These findings support the inclusion of stingless bee populations in agricultural practices to enhance crop yields and promote biodiversity. They also highlight the importance of conducting further research on the long-term advantages of managed bee pollination in different crops.

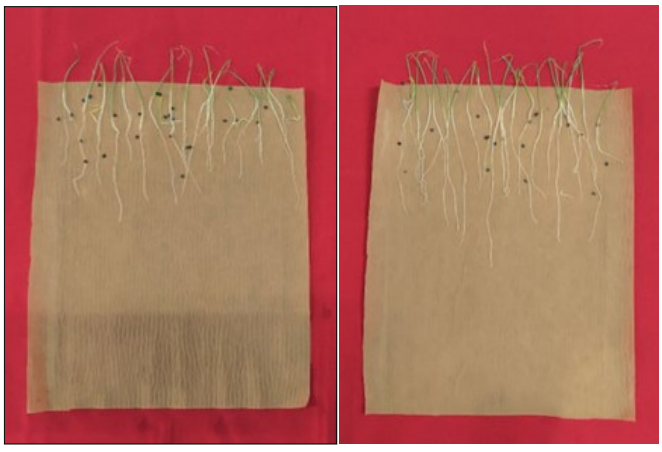

Fig. 6. Influence of stingless bee pollination in the germination of onion seeds. (a) seedlings from bagged inflorescence (b) seedlings from unbagged inflorescence.

Table 3. Multiple linear regression equations for foraging performance of stingless bees with weather parameters during Rabi and kharif season, 2023

Cropping seasons	Type of Foragers	Multiple regression equation	R^2 values
Rabi	Outgoing bees	$Y = 125.38 - 10.24 X_1 + 10.14 X_2 - 0.24 X_4 - 0.26 X_5$	0.85
	Pollen	$Y = 27.77 - 2.35 X_1 + 2.28 X_2 + 0.08 X_4 - 0.05 X_5$	0.86
	Nectar	$Y = 14.98 - 3.60 X_1 + 4.50 X_2 + 0.28 X_4 + 0.07 X_5$	0.69
	Resin	$Y = 10.38 - 0.81 X_1 + 0.74 X_2 + 0.08 X_4 - 0.02 X_5$	0.79
Kharif	Outgoing bees	$Y = 14.43 - 13.57 X_1 + 13.93 X_2 - 14.67 X_3 + 2.17 X_4 - 0.11 X_5$	0.69
	Pollen	$Y = -0.42 - 2.03 X_1 + 2.18 X_2 - 4.08 X_3 + 0.39 X_4 - 0.02 X_5$	0.75
	Nectar	$Y = 84.78 - 12.86 X_1 + 11.37 X_2 + 1.34 X_3 + 2.17 X_4 - 0.54 X_5$	0.49
	Resin	$Y = 21.51 - 0.35 X_1 - 0.10 X_2 - 3.08 X_3 + 0.16 X_4 - 0.17 X_5$	0.54

Where, X_1 - Maximum temperature; X_2 - Minimum temperature; X_3 - Rainfall; X_4 - Wind velocity; X_5 - Relative humidity.

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Authors' contributions

BSV developed the research questions and designed the experimental setup, data collection methods and data analysis, and drafting the manuscript. JJ, RN, KK and MRS as the advisor for the research work, data analysis and for drafting the manuscript. MJ performed the manuscript drafting. KS contributed by make arrangement of selection of research field.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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