



E-ISSN: 2320-7078

P-ISSN: 2349-6800

www.entomoljournal.com

JEZS 2020; 8(4): 2264-2268

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Received: 10-04-2020

Accepted: 12-05-2020

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Foraging activities of bumble bee (*Bombus haemorrhoidalis* Smith) on Tomato (*Solanum lycopersicum* Mill.) under protected conditions and its correlation with weather parameters

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Abstract

The bumble bee (*Bombus haemorrhoidalis* Smith) is an effective pollinator in the cultivation of polyhouse tomato *Solanum lycopersicum* Mill. The foraging activity of bumble bees in tomato crop was recorded and observed that maximum (8.33 bumble bees/5min) activity of bumble bees (*B. haemorrhoidalis*) was during 1800-1900 day hours. Foraging rate was peaked during 1000-1100 day hour (4.74 flowers/min). Foraging speed was recorded to be maximum time spent /flower (6.82 sec/flower) during 0800-0900hr and minimum was during 1200-1300hr (3.19 sec/flower). Number of *B. haemorrhoidalis* per m²/5min was maximum during 1600-1700hr of the day (11.12 bumble bees/m²/5min). While number of bees were significantly higher (9.55 bumble bees/m²/5min) during full bloom followed by (8.61 bumble bees/m²/5min) during onset of bloom. Bumble bee foragers preferred to visit tomato bloom during morning and evening time than mid day with more abundance, foraging rate and foraging speed during these hours of the day.

Keywords: *Bombus haemorrhoidalis*, foraging activities, tomato, weather parameters

Introduction

Tomatoes grown in greenhouses need special attention to ensure successful pollen transfer to the stigma, as fruit set is generally poor under conditions when natural pollination agents such as wind and insects are withdrawn. In numerous countries, several bumblebees species are used for tomato pollination in greenhouses (Velthuis and Doorn, 2006) [1]. These large bees buzz the flowers through vibration of the thoracic muscles, which causes a large number of pollen grains to be released onto the stigma. Bumblebees are more efficient and reliable pollinators of greenhouse crops helping in fruit production of high quality due to their high speed of pollination, buzzing behaviour and efficiency at low temperature and sunlight (Paydas *et al.*, 2000) [2]. Use of insect pollination within greenhouse, especially bumblebees gave cost effective and attractive substitute of manual pollination (Velthuis and van Doorn, 2006) [1]. An external and internal environmental condition along with foraging efficiency of bumblebees has impact on required pollination of tomato cultivation. Activity of bumblebees foraging was important to serve as successful pollinators under these greenhouse conditions when compared with honeybees (Wolf and Moritz, 2008) [3]. They have better adaptive qualities for pollen and nectar collection near their hives and preference increases in small patches with flower abundance (Sheikh *et al.*, 2014) [4]. The foraging behavior of pollinators can influence their efficiency in pollinating a particular plant species and understanding of foraging behavior of pollinators can help in pollination management. Activity of bumblebees foraging was important to serve as successful pollinators under these greenhouse conditions when compared with honeybees. Bumblebees can fly and pollinate flowers under cool conditions due to their better thermoregulatory abilities (Corbet, 1996) [5]. They have better adaptive qualities for pollen and nectar collection near their hives and preference increases in small patches with flower abundance (Sowig, 1989 [6]; Sheikh *et al.*, 2014) [4]. Abak *et al.*, (2000) [7] conducted an experiment on eggplants grown in unheated plastic houses and observed that bumble bee's activity on eggplants was increased between 9:00 and 11:00 a.m., the peak activity was observed between 10:00 and 11:00 a.m. then decreases gradually and they stopped between 13:00 and 14:00 p.m.

They started foraging again in the afternoon between 15:00 and 18:00 p.m. Spivak (2000) [8] found that bumble bees are more efficient foragers than honey bees on cranberry flowers because they are capable of buzz-pollination. Bumble bees hang on to the flower and buzz it by vibrating their muscles that control flight. Bumble bees are the most efficient pollinators not only for the wild plants, but also for pollination services, used in both outdoor and greenhouse horticulture and orchards. Foraging behavior studies conducted on four species of bumble bee in England revealed that the high foraging activity occurs at 1000-1100h. The pollen collection was also high till noon hours (Free, 1955) [9]. Garfalo (1978) [10] observed in tomato greenhouse that larger workers have a great tendency to become foragers and pollinate the crop while the smaller workers tend to guard the entrance and later on became foragers. Honey bees do not work on cold days when temperature is less than 12°C however, bumble bees can forage the crops efficiently (Ahn *et al.*, 1988) [11]. Dasgan *et al.*, (1999) [12] found that the bumble bees were more robust, furrer and have long tongues which allow them to visit and forage on flowers which have long deep tubular corollas. The average traffic of *B. terrestris* in the morning, noon and afternoon was 39.2, 23.5 and 14.4 bees/colony with foraging activity being 10.1, 3.1 and 2.1 bees/unit time (Kwon and Saeed, 2003) [13]. In strawberries, bumble bees were used for the pollination under greenhouse conditions with honey bees and it was found that bumble bees foraging rate was more than honey bees and the number of flower visited by one bumble bee was comparatively higher than honey bees. Bumble bees started foraging in the morning and foraged on flowers till evening (Zaitoun *et al.*, 2006) [14]. Hines *et al.*, (2007) [15] studied the foraging activity of *B. pullatus*. The foraging rate ranged from 2.6-9.5 bees per minute across different time periods, with the highest activity in the morning (07:00-10:00 am). Pollen collection was highest from 07:00-10:00 am and declined throughout rest of the day, while the foraging rate for nectar foragers remained relatively constant. The per cent of incoming foragers that carried pollen in a sample period ranged from 2.4 to 44.2%. There was no significant relationship between ambient temperature and number of overall foragers. Foraging trips lasted from 30-70.5 minutes, with a mean of 51 and a median of 49.5 minutes. Kashyap (2007) [16] recorded the bumble bee activity in greenhouse condition on cucumber plant. They observed that bumble bee visited maximum number of flowers/5min to the extent of 59.5 and 45.6 during 0600-0700 and 1600-1700 hours. Bee started visiting the flower from 0600-1900 hours. Minimum flowers visited by bees during 1200-1300 hours (19.5 flowers/5min). The maximum time spent/flower i.e. 66.50, 64.50 and 53.00 seconds was observed during 0600-0700, 1700-1800 and 0800-0900 hours. The minimum time spent / flower during 1200-1300 hours was recorded to be 39.00 seconds and also observed that bumble bee start visiting the flowers from 0600-1900 hours. Ahmad *et al.*, (2015) [17] conducted a study on Grandella and cherry cultivar of tomato and reported that bumble bees spent 1-4 seconds per flower with mean value of 2.2 ± 0.8 seconds and 1.1-2.2 seconds with mean value of 1.4 ± 0.3 on cherry flowers, showing more variation in time spent per flowers on Grandella than cherry flowers. Flowers visitation was comparatively more frequent on cherry flowers than that of Grandella, 10.6 ± 3.5 flowers per minute and 22.6 ± 3.2 flowers per minute, respectively. Visitation marks on Grandella and cherry flower pistils showed more visits per flower on Cherry

(1.2 ± 0.4) than that on Grandella (2.7 ± 0.9).

Keeping in view all this, present studies were undertaken to investigate the foraging activity, abundance and flower visitation rates of *B. haemorrhoidalis* Smith in the polyhouse environment.

Materials and Methods

Seedling of the tomato (*Solanum lycopersicum*) were transplanted to a polyhouse at the experimental farm (Pandah) of the Department of Seed Science and Technology, Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni-Solan, Himachal Pradesh in the last week of April, 2015. The total area of the polyhouse has been divided into two by using insect proof net in the middle. Bumble bees, *Bombus haemorrhoidalis* Smith were reared in the laboratory from the overwintered spring queens in the department of Entomology, Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni-Solan. In one of the portion of polyhouse, laboratory reared bumble bee colony was introduced in flowering tomato crop at 5% flowering of the crop in polyhouse by placing it inside a big box to which a plastic tube was attached which served as a passage for entry and exit for bumble bee foragers while second portion was control plot (without bumble bee). Foraging behaviour of bumble bees in terms of foraging activity at nest entrance, foraging speed, foraging rates, abundance was recorded on tomato grown inside polyhouse from early morning hours (0600h) till late evening (1800h) at two hour interval daily for three consecutive sunny during three stages of the crop i.e. onset of bloom, full bloom, end bloom. Agrometeorological observations were recorded by keeping thermometer and hygrometer at a height of 1m under the shade from ground level inside poly house. Foraging speed of bumble bees on three stages of bloom was recorded by observing time spent by the forager on each flower using stop watch. Foraging rate was recorded in term of number of flowers visited by a forager per minute. Counts of bumble bee visiting the tomato bloom per five minute per m² were made daily for three consecutive sunny days during onset of tomato bloom, full bloom and end bloom during 0600hr to 1800hr. Data on foraging activity of *B. haemorrhoidalis* inside tomato polyhouse were analyzed for correlation multivariate ANOVA with temperature and humidity. Data recorded on various parameters were analysed statistically with suitable transformation in C.R.D. design by Gomez and Gomez (1986) [18].

Results and Discussion

Foraging activity of bumble bees (*B. haemorrhoidalis*) on tomato: *Bombus haemorrhoidalis* started foraging activity inside tomato polyhouse from dawn to dusk (0615 hr to 1830 hr). Therefore, bumble bee has long working hours. Foraging activity was recorded to be peaked (8.33 bumble bees/5min) at 1800-1900 day hours, inside tomato polyhouse while the minimum activity was recorded at 1200-1300 hr of the day (Table 1). The activity bumble bees at nest entrance inside tomato polyhouse were observed to be maximum (8.33) during evening time (1800-1900) and minimum (4.67) during noon hours (1200-1300). These findings are in close agreement with those of Kashyap (2007) [16] and Chauhan (2011) [19] who reported the peak foraging activity of bumble bees at evening.

Table 1: Foraging activity of *B. haemorrhoidalis* inside tomato polyhouse at Pandah farm during July 2015

Number of bumble bees/5min at nest entrance		Temperature (°C)	Relative Humidity (%)
Day hours	Incoming Bumble Bees/5min	Outgoing Bumble Bees/5min	Mean
0600-0700	4.33	6.33	5.33
0800-0900	4.67	7.00	5.83
1000-1100	5.33	7.33	6.33
1200-1300	4.67	4.67	4.67
1400-1500	6.00	4.33	5.17
1600-1700	6.33	8.33	7.33
1800-1900	10.00	6.67	8.33
Mean	5.91	6.38	
CD (0.05)			
Day hours	=	0.93	

Activity	=	0.52
Day hours x Activity	=	1.32

The incoming number of bees was observed significantly maximum during 1800-1900hr (10.00 bumble bees/5min) followed by number of bees at 1600hr-1700hr (6.33 bumble bees/5min). However, the minimum number of bumble bees entered back to the nest was recorded during 0600-0700hr (4.33 bumble bees/5min) of the day.

The number of outgoing bees from the colony revealed that significantly more number of bumble bees left the domicile at 1600-1700hr (8.33 bumble bees/5min) and number of outgoing bees recorded at 1400h -1500hr (4.33 bumble bees/5min) was minimum. These findings are corroborated by the observation of Chauhan (2011) [19] reported that maximum incoming activity of bumble bees were during 1800hr whereas minimum was during 0600hr and also found that more (8.16 bumble bees/5min) number of bumble bees left the domicile at 1600hr while less number (4.66 bumble bees/5min) of outgoing.

Foraging activity of bumble bee (*B. haemorrhoidalis*) at nest entrance and its correlation with weather parameters inside tomato polyhouse

Correlation data on colony traffic i.e. incoming and outgoing bumble bees with average temperature and relative humidity inside tomato polyhouse (Fig.1) revealed that number of incoming bees was positively correlated with temperature ($r=0.0744$) and relative humidity ($r=0.1336$), though non-significant. The outgoing bees were negatively correlated with temperature ($r=-0.5729$) but statistically found to be non-significant and with relative humidity ($r=0.7620$) showed significant positive correlation. The data showed that mean bee activity was maximum at 26.9°C in the evening (1800-1900hr) and minimum at 33.4°C in the afternoon (1200-1300hr). Foraging activity decreased because of high temperature at noon and increased again at low temperature during evening hours. These investigations got support from earlier findings of Kwon and Saeed (2003) [13] who reported that foraging activity of *B. terrestris* L. was highest at 25.7°C in greenhouse and decreased to 40% at 32.7°C and suggested that the temperature is an important parameter for bumble bee foraging activity in green house. The present studies are also in line with those of Kashyap (2007) [16] who reported similar effect of temperature and relative humidity on bumble bee activity.

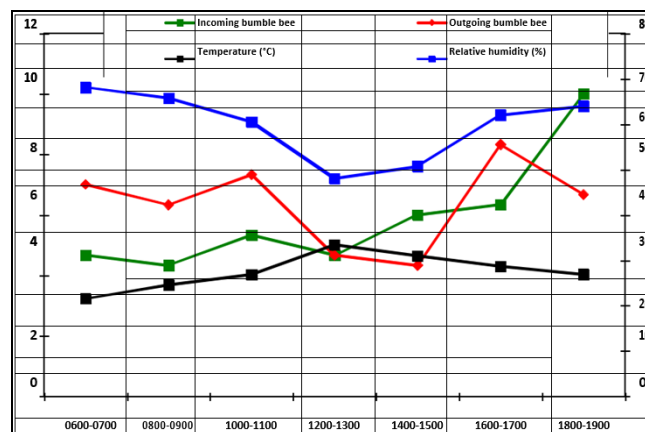


Fig 1: Correlation of *B. haemorrhoidalis* activity with temperature and relative humidity at different day hours inside polyhouse

Coefficient of linear correlation = (r)

Incoming *B. haemorrhoidalis* temperature=0.0744,
 Incoming *B. haemorrhoidalis* relative humidity=0.1336
 Outgoing *B. haemorrhoidalis* temperature=-0.5729
 Outgoing *B. haemorrhoidalis* relative humidity=0.7620

Foraging rate of *B. haemorrhoidalis*

The foraging rate of bumble bees on tomato bloom under protected condition was peaked during 1000-1100 hr (4.74 flowers/min) while minimum foraging rate was recorded during 1200-1300hr (2.37 flowers/min) Table 2.

Irrespective of day hours, the foraging rate was recorded to be significantly highest on full bloom of tomato (5.54 flowers/min) followed by at end of bloom (2.63 flowers/min) and was minimum at onset of bloom (1.86 flowers/min).

Overall foraging rate of *B. haemorrhoidalis* was maximum at morning (0800-0900hr) and minimum at noon (1200-1300hr). These findings are in close conformity with those of Ahmad *et al.* (2015) [17] who reported higher foraging rate of *B. terrestris* in morning time as compared to evening time inside tomato polyhouse.

Table 2: Foraging of rate of *B. haemorrhoidalis* inside tomato polyhouse at Pandah farm during July 2015

Day hours	Number of flowers visited by <i>B. haemorrhoidalis</i> /min during different flowering stages			Mean
	Onset of bloom	Full Bloom	End of Bloom	
0600-0700	1.31	6.41	3.39	3.70
0800-0900	2.11	7.11	3.62	4.28
1000-1100	2.42	8.15	3.66	4.74
1200-1300	1.41	4.06	1.65	2.37
1400-1500	2.26	3.67	2.09	2.67
1600-1700	1.79	3.55	1.97	2.44
1800-1900	1.70	5.83	2.03	3.19
Mean	1.86	5.54	2.63	
CD(0.05)				
Day hours	=	0.51		
Flowering	=	0.33		
Day hours x Flowering	=	0.88		

Foraging speed of *B. haemorrhoidalis*

Foraging speed of *B. haemorrhoidalis* was recorded to be maximum (6.82 sec/flower) during 0800-0900hr and minimum (3.19 sec/flower) during 1200-1300hr on tomato bloom under protected conditions (Table 3). These findings are in agreement with those of Ahmad *et al.* (2015) [17] who reported that foraging rate of *B. terrestris* was more in morning time. Irrespective of day hours, the data recorded on

time spent per flower by bumble bees during different flowering stages of tomato bloom revealed that the time spent per flower by bumble bees during onset of bloom (5.77 sec/flower) was statistically at par with time spent during full bloom (5.75 sec/flower). Whereas the minimum time spent per flower was recorded during end of bloom (4.81 sec/flowers). These findings got support from earlier work of Kashyap (2007) [16] for foraging rate and speed for *B. haemorrhoidalis* on cucumber inside polyhouse.

Table 3: Foraging speed of *B. haemorrhoidalis* inside tomato polyhouse at Pandah farm during July 2015

Day hours	Time spent by <i>B. haemorrhoidalis</i> / flower during different flowering stages(in sec)			Mean
	Onset of bloom	Full Bloom	End of Bloom	
0600-0700	6.35	6.60	5.42	6.13
0800-0900	7.60	7.07	5.80	6.82
1000-1100	5.57	6.67	5.34	5.86
1200-1300	3.94	3.93	3.87	3.91
1400-1500	4.86	4.00	3.53	4.13
1600-1700	5.87	4.45	5.41	5.25
1800-1900	6.20	7.55	4.32	6.02
Mean	5.77	5.75	4.81	
CD (0.05)				
Day hours	=		0.38	
Flowering	=		0.25	
Time X Flowering	=		0.66	

Number of loose pollen grains

The data on number of loose pollen grains adhered to the body of bumble showed that highest number of loose pollen

grains were carried during full bloom stage (1967±107.10) followed by during onset of bloom (1783.66±104.26) and end of bloom (1546.66±51.74). Chauhan (2011) [19] found that bumble bees carried more (2179±344) loose pollen grains as compared to *Apis mellifera* (1730±205) in cucumber. In the present studies, the numbers of loose pollen grains counted/adhered on the body of *B. haemorrhoidalis* were found maximum during full bloom stage of tomato crop may be due to availability of many flowers. Ravestijn and Sande (1991) [20] reported that an active worker bumble bee may visit many tomato flowers and pollinate at least 500 plants per day, i.e. 250 m² of the greenhouse area. Since the pollen grains viability of 2-5 days and the stigma receptivity of 4 days continue after anthesis (Kaul, 1991 [21]; Ho and Hewitt, 1994 [22]), bumblebees can pollinate many flowers during this period. Similarly, the foraging rate and foraging speed of bumble bee were also recorded highest at full bloom stage of tomato crop in this study.

Abundance of bumble bees on tomato bloom

Data on abundance (number /m²/5min) of *B. haemorrhoidalis* recorded at one hour interval consecutively for three days during all three bloom stages of tomato viz. onset of bloom (20-25%), full bloom (75%) and end of bloom (90%) revealed that *B. haemorrhoidalis* on tomato under protected conditions were significantly higher (9.55 bumble bees/ m²/5min) during full bloom followed by 8.61 bumble bees/ m²/5min during onset of bloom and the least abundance was recorded during end of bloom (7.15 bumble bees/ m²/5min).

Table 4: Abundance of *B. haemorrhoidalis* inside tomato polyhouse at Pandah farm during July 2015

Day hours	Number of <i>B. haemorrhoidalis</i> /m ² /5min during different flowering stages			Mean
	Onset of bloom	Full Bloom	End of Bloom	
0600-0700	7.64	6.71	5.36	6.57
0800-0900	7.64	11.07	7.71	8.81
1000-1100	9.64	11.07	8.64	9.79
1200-1300	4.93	5.36	4.36	4.88
1400-1500	8.64	8.42	6.00	7.69
1600-1700	11.36	12.64	9.36	11.12
1800-1900	10.42	11.60	8.65	10.22
Mean	8.61	9.55	7.15	
CD (0.05)				
Day hours	=	0.40		
Flowering	=	0.26		
Day hours X Flowering	=		0.69	

Irrespective of bloom stage, number of *B. haemorrhoidalis* per m²/5min was maximum (11.12 bumble bees/ m²/5min) during 1600-1700hr of the day and minimum (4.88 bumble bees/m²/5min) during 1200-1300hr (Table 4). It was observed that bumble bee foragers preferred to visit tomato grown under protected conditions during morning and evening time than midday with more abundance, foraging rate and foraging speed during these hours of the day.

Conclusion

Bumble bees have long been recognized as efficient pollinators of tomato grown under protected conditions because of their potential for long working hours, buzz pollination, presence of pollen baskets and adaptability to polyhouse conditions. From the present studies, it is clear that the tomato bloom is preferable to bumble bee, *B. haemorrhoidalis*. Hence this study concluded that bumble bees due to their longer duration of foraging, high abundance

and good pollinating efficiency will definitely enhance the quality and yield of tomato.

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