

ASSESSMENT OF THE FLYING ACTIVITY OF THE BUFF-TAILED BUMBLEBEE (*Bombus terrestris* L.) ON GREENHOUSE-GROWN TOMATOES

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Received 21 April 2008; accepted 29 May 2008

S u m m a r y

The objective of the study was to assess the flying activity of the buff-tailed bumblebee (*Bombus terrestris* L.) on greenhouse-grown tomatoes.

The field study was performed in a greenhouse which was 1 ha in area. Inside the greenhouse the tomatoes were being grown. The bumblebees working in the greenhouse were purchased in Belgium, Holland, Italy and Great Britain. Bumblebee flight intensity was evaluated from March to August, 2006, from 7:00a.m. to 7:00p.m. Bumblebees flying out of the hives were counted for 15 min. The results were converted to counts per 1 h. Pollination effectiveness was measured based on 10 tomato shoots picked at random.

The optimum ambient temperature for the foraging flights of 11-42 bumblebees per 1h, averaged from 19.6 to 24°C. The lowest flying activities were recorded at greenhouse indoor temperatures below 19.6°C and above 24°C. The work of the bumblebees in the greenhouse was affected by ambient temperatures ranging from 2 to 24°C. The optimum light intensity was 19,6 klx (kilo-lux). Too low or too high light intensity decreased the activity of the bumblebees. The highest visitation rates by the bumblebees were recorded from 7:00a.m. to 7:00p.m. This was a rate of from 10 to 22 bumblebees per 1 h. The data on the pollination efficacy of the tomato crop show that each flower on a shoot was pollinated and developed into a fruit.

The Belgium bumblebees were the most active visitors averaging 17.5 bumblebee flights per 1 h. Those from Holland averaged 13 flights per 1 h. Those from Great Britain, 12. The least active were the Italian bumblebees with 9.5 flights per 1 h.

Keywords: *Bombus terrestris*, flight activity, polination of tomato.

INTRODUCTION

The buff-tailed bumblebee (*Bombus terrestris*) is practically a social insect belonging to the Apoidea superfamily. It forms colonies, which are not continuous, as they occur only from spring to autumn. For the wintertime, only young inseminated females remain in the environment and they give rise to a colony in the spring (Alford 1969, Fliszkiewicz and Wilkaniec 2007). The queen starts building a nest on her own. She gets provisions to the nest and raises the first generation of workers

unassisted (Duchateau and Velthuis 1988). The lifespan of a queen is one year. The lifespan of the workers working in the field is 36 days. The lifespan of those workers working in the nest is 72 days. That means that in a bumblebee colony, 30% of the workers work in the field and the remaining ones work in the nest (Free and Butler 1959). Most of the time the workers perform their functions throughout their lifetimes. Bumblebees have higher demand for pollen with which their larvae are fed, than for nectar. This is the reason that about 75% of the workers are out collecting pollen and the remaining ones



are busy harvesting nectar. They are therefore, eager visitors of polliniferous plants, and not necessarily of nectar yielders, e.g. the tomatoes. The colonies of the buff-tailed bumblebee reach an average population of ca. 500-600 workers (Dylewska 1996, Biliński 2003). However, under natural conditions, the size of their populations is to a large extent dependent on the weather in a particular year. Population size also depends on the supply of forage plants in the environment. In cool and rainy years the colony size seldom exceeds 150 individuals but when a year is warm and forage plants are in good supply, it can be as high as 1000 individuals or more (Banaszak 1993).

The morphology of bumblebees to a high degree affects the way in which pollen is collected and transported. Pollen is transported on the legs and frequently on the whole body since bumblebees are furry insects. For that reason they are regarded as one of the best pollinators. The buff-tailed bumblebee is increasingly employed as a pollinator of under cover crops. In Holland, towards the end of the 20th century bumblebees pollinated an area of 500 ha of tomato crop (Eijnde and Ruijter 1991). At present, nearly 100% of greenhouse crops are pollinated by bumblebees. They proved to be ideally suited to pollinate tomatoes in greenhouses and plastic-covered tunnels. Their activity depends on environmental conditions, forage quality, and on the conditions in the colony itself including the quality of the queen. The bumblebees visit tomato flowers when they are correctly expanded. They are also systematic pollinators, as they do not visit the same flower twice (Wysocka-Owczarek 2006c). Bumblebee activity is most strongly effected by air temperature and humidity, rainfall, cloud cover, light intensity, as well as by the concentration of CO₂ with which plants in the greenhouse are treated.

Elevated CO₂ concentration may cause drowsiness in the workers.

Contemporary techniques allow the bumblebees to be raised throughout the year without even a pause-period (Röseler 1985). This is the reason they can be employed to pollinate greenhouse crops in any season.

The objective of the study was to assess the flight activity of the buff-tailed bumblebee (*Bombus terrestris*) used to pollinate a greenhouse-grown tomato crop.

MATERIAL AND METHODS

A field study was performed at a horticultural farm in Siechnice. It is in the Wrocław area of Poland. Observations were carried out in a single greenhouse of 10,000 m² in area in which tomatoes were grown.

The experiment material were bumblebee colonies and tomato plants observed in greenhouse culture. The hives with bumblebees came from cultures originating in Holland, Belgium, Italy and Great Britain. At the start there were 50-60 bumblebee in each hive. There were 625 for 1000 m² of the tomato crop for each colony working for 10 weeks. Throughout its use, each hive was provided with a container of sugar water solution as a carbohydrate food. In the greenhouse there were four stands placed between tomato rows to protect the hive flight hole from direct sunlight, without blocking the way to the hive. Hives with bumblebees were placed on each stand. During the first few observations there were 2 hives on each stand. As the number of expanded tomato flowers increased, new hives were successively added. This was done until the full stocking rate of 16 colonies was obtained.

Flight intensity of bumblebees was assessed from 3rd March to 1st August 2006, once every two weeks on average (a total of 10 days) from 7:00a.m. to 7:00 p.m.

The observations consisted of counting individuals flying out of the hives to forage for 15 min. The number was converted to 1 h. During the observation time records of current microclimatic conditions inside and outside the greenhouse were taken: ambient temperature, momentary light intensity, relative air humidity and outdoor temperature. The greenhouse was ventilated during the day. The data on current microclimatic and weather conditions were collected from a weather station in the greenhouse and from one on the farm.

Pollination effectiveness was measured on ten tomato shoots picked at random. The selected shoots were marked with colored ribbons. On each shoot records were taken of expanding flowers, pollinated flowers and developing fruits. Pollinated flowers were recognized from the brown marks on petals and necrotic spots on the stigma and the anther cone. The number of shoots per plant was reduced according to tomato management principles. The investigations of pollination effectiveness were terminated once the mature fruits were picked.

The field study data were processed statistically. Mean values, standard deviations, correlation coefficients between the number of flying-out bumblebees and the factors under investigation were calculated. ANOVA and Duncan's test was used to validate the differences in bumblebee activity as influenced by their origin

RESULTS AND DISCUSSION

The bumblebee is one of the most important pollinating insects. However, its activity is not the same throughout the tomato blooming season. The study into its flight intensity and pollination efficacy showed that there are several factors, which affect bumblebee activity. It must be stressed that the literature on the subject is

rather scarce. Many papers which deal with the intensity with which bumblebees forage in tomatoes contain but very general statements. There is also a lack of data on pollination efficacy which adds to the difficulty of the interpretation of the results of this study.

According to Banaszek (1993) the most populous bumblebee colonies number 500 or more individuals in Polish conditions. A colony of 150 individuals is considered to be of medium strength and a weak colony to about 50 individuals. At the beginning of summer an average colony is 20 to 100 workers strong. In this study in which the records were taken in the greenhouse, the colonies numbered 50 to 60 individuals at the beginning of the experiment. Banaszek (1993) maintains that bumblebees chiefly pollinate plants, which cannot be pollinated or are poorly pollinated by the honeybee. The tomato is one of such plants. Bumblebees are eager visitors of a tomato crop since it yields substantial amounts of pollen which is the main forage harvested by those insects (Flaga 2003). It is usually quite different in other crops. According to Bożek (2003) bumblebees accounted for 2 to 20% of insects pollinating blueberries, the remaining pollinators being primarily honeybees. However, bumblebees prefer not all plant species. Żuraw (2005) stated that blooming *Petasites* was not attractive to bumblebees since she was not able to find a single foraging bumblebee on the flowers of that species. Borisov et al. (2005) demonstrated that there was a close relationship between the tongue length of the bumblebee and the species that the insect visited. It is related to flower morphology and to the availability of pollen and nectar to bumblebees. During the day each bumblebee worker can visit 1,500 – 2,000 tomato flowers. It means that, theoretically, 10 bumblebee workers should be sufficient to pollinate 1000m² of a tomato crop. Such a number of insects

guarantees stable yields, good crop quality and a yield increase by even 30-90% (Koide and Hayashi 1993, Banaszak 1996). Teper (2004, 2005) while investigating food preferences of the buff-tailed bumblebee found that the food plants of choice were those of the genera *Fagopyrum*, *Hypericum*, *Plantago*, *Tilia* and of the Rosaceae family as well as the papilionaceous fodder crops such as *Trifolium*, *Vicia*, *Medicago*. Ruszkowski and Biliński (1969) evaluated the activity of bumblebees on leguminous crops as well. In this study the choice of food for the bumblebees was restricted to tomato flowers. Biliński (2002) says that when the greenhouse is being ventilated some bumblebees leave the greenhouse. This is considered beneficial since pollen from other plants makes a family stronger. It also activates the workers to pollinate more tomato flowers. Such bumblebee behavior was also observed in this study.

This study demonstrated that there are many factors, which influence bumblebee flight activity. An air temperature of 30°C or more causes the intensity of foraging flights to drop substantially. In such hot conditions bumblebees begin intensively ventilate the nest to protect it against overheating (Flaga 2003). Likewise, at such a high temperature tomato flowers stop pollen releasing and bumblebees do not forage. According to Biliński (2002) and Wysocka-Owczarek (2006c) bumblebees forage at an ambient temperature of 10-35°C. The optimum temperature at which they work most intensively and most effectively is 27-28°C. In this study it was shown that the most foraging flights were recorded at indoor greenhouse temperatures which ranged from 19.6 to 24.0°C. Under such temperature conditions there were 11 to 42 flights per hour per colony. The range of external temperatures, at which the intensity of foraging flights was the highest, was from to 24°C. At such

temperatures 8 to 42 bumblebees were recorded flying out of the hive in one hour (Table 1). Woyke et al. (2003) maintain that in other bee species activity is also strongly related to ambient temperature. The honeybee commences its activity at 10°C and a rise in temperature causes the activity to increase.

Momentary light intensity was another parameter that turned out to be of consequence regarding foraging intensity of bumblebees. Foraging flights were at their highest when light intensity ranged from 17.2 to 49.7 klx. In these light conditions from 17 to 42 workers flying out of the hive were recorded within the space of an hour. The optimum light intensity was 19.6 klx. At that intensity 42 individuals per hour flew out of the hive (Table 1). When light intensity was either too low or too high, it lowered the foraging activity of the bumblebees.

The results of this study made in the greenhouse confirmed that air humidity level greatly affects intensity of foraging flights. The bumblebees were most active at an air humidity of 57.0 to 80.5% with a flight rate of 16 to 25 individuals per 1 h. The optimum air humidity level can be put at 76% since the highest number of foraging flights was then recorded (Table 1). Wysocka-Owczarek (2006a, 2006b) reports that the optimum greenhouse air humidity for optimum pollination should be 55-60%. Excessive humidity causes pollen to become sticky which makes it difficult for the insects to form pollen loads. Therefore, at high air humidity bumblebees did not willingly visit the flowers, a fact confirmed in this study (Table 1). Conversely, air humidity that is too low causes pollen not to adhere to the pistil and pollination is likewise prevented. In this case pollination efficacy is also reduced (Wysocka-Owczarek 2006a and 2006b).

Banaszak (1993) claims that bumblebees are better adapted to changing

Table 1

Effect of selected factors on flight activity of bumblebees.

Item	Date	Mean indoor greenhouse temperature (°C)	Mean outdoor temperature (°C)	Mean intensity of momentary light (klx)	Mean relative air humidity (%)	Number of hives in the greenhouse	Mean number of bumblebees flying out of hive
1	2	3	4	5	6	7	8
1.	03.03	20.2	2.0	19.6	76.0	2	42
2.	17.03	22.2	1.5	58.4	86.0	6	7
3.	31.03	19.6	12.2	17.2	80.5	8	25
4.	21.04	21.9	19.6	47.8	57.0	10	16
5.	04.05	22.6	19.2	49.7	67.0	12	17
6.	19.05	21.4	18.3	31.2	73.5	16	23
7.	01.06	22.9	13.0	25.8	67.5	16	21
8.	16.06	29.7	31.8	48.5	77.0	16	19
9.	14.07	24.1	23.3	12.7	82.0	16	11
10.	01.08	24.2	21.3	14.4	84.0	16	8
Mean		22.9	16.2	32.53	75.05	12	19
r		-0.254	-0.221	-0.139	-0.116	-	-
Column numbers		3 and 8	4 and 8	5 and 8	6 and 8	-	-

r – correlation value between average number of bumble bees flying out of hive and some environmental factors.

Table 2

Mean number of bumblebees flying out of hive at a given time of day.

Item	Time of day	Number of recorded foraging flights
1.	7:00a.m - 8:00a.m.	10
2.	8:00a.m. - 9:00a.m.	10
3.	9:00a.m. - 10:00a.m.	17
4.	10:00a.m. - 11:00a.m.	18
5.	11:00a.m. - 12:00p.m.	24
6.	12:00p.m. - 1:00p.m.	24
7.	1:00p.m. - 2:00p.m.	28
8.	2:00p.m. - 3:00p.m.	27
9.	3:00p.m. - 4:00p.m.	11
10.	4:00p.m. - 5:00p.m.	22
11.	5:00p.m. - 6:00p.m.	3
12.	6:00p.m. - 7:00p.m.	0

Table 3

Mean number of bumblebees flying out of hive within 1 h depending on country of origin.

Country of origin	Parameter	Number of bumblebees
Belgium	\bar{x}	17.5 ^B
	SD	16.5
Holland	\bar{x}	13.0 ^A
	SD	12.9
Italy	\bar{x}	9.5 ^A
	SD	9.1
Great Britain	\bar{x}	12.0 ^A
	SD	13.8

A, B – differences statistically valid at $p \leq 0.01$

weather conditions than the honeybee. For this reason bumblebees can work for longer hours than honeybees. They can work when the wind is stronger. They can work when the temperatures are lower. They can even work in rainy weather. Bumblebees are hard at work foraging in the early morning hours and continue working until late evening. However, this study showed that foraging intensity of bumblebees varies during the day (Table 2). It was the highest from 9:00a.m. to 5:00p.m. The number of bumblebees flying-out was then from 10 to 22 individuals per 1h. From 3:00p.m. to 4:00p.m., up to 5 bumblebees per 1h were recorded. Foraging flights stopped at ca 6:00p.m. The data were confirmed by those reported by Wysocka-Owczarek (2006c) and Biliński (2002). From the observations made by Dylewska (1996) it appears that the most bumblebees; from 20 to 30 individuals per 1h, flew out from 10:45a.m. to 1:00p.m.

It appears from this study that the Belgian bumblebees were the most active. Their foraging flight-rate averaging 17.5 individuals per 1h. The bumblebees originating from Dutch and British cultures showed an intermediate foraging flight intensity of 13 and 12 individuals per 1h,

respectively. The least active were the Italian bumblebees, averaging 9.5 individuals per 1h (Table 3).

The results relating to bumblebee pollination efficacy of tomatoes turned out to be very good. After the removal of redundant shoots on the plants all expanded flowers were pollinated. According to Wysocka-Owczarek (2006c), Banaszek (1993) and Biliński (2002) bumblebees visit an average of 20-30 tomato flowers within 1 minute. Given the number properly suited to the area to be pollinated, bumblebees are able to pollinate all the flowers in the greenhouse. The leading horticultural crop producing countries use bumblebees to pollinate entomophilous crops. These are mainly tomatoes and cucumbers grown under cover, in greenhouses and plastic tunnels. Thanks to natural pollination, higher yields and a better quality fruit crop are obtained. According to Wysocka-Owczarek (2006b) the outcome of the use of bumblebees for pollination, is good fruit set. The rate averaging 95% of developed and expanded flowers. The investigator also claims that insufficient pollination and inadequate fruit set are the result of too small a number of bumblebees per unit area of the greenhouse. From the results of this

Table 4
Pollination efficacy of bumblebees in
the tomato crop.

Observation date	Development stage of tomatoes	after shoot removal treatment
03.03.2006	expanding flowers	7
	pollinated flowers	5
	fruits	0
17.03.2006	expanding flowers	9
	pollinated flowers	7
	fruits	4
31.03.2006	expanding flowers	8
	pollinated flowers	9
	fruits	9
21.04.2006	expanding flowers	12
	pollinated flowers	9
	fruits	5
04.05.2006	expanding flowers	6
	pollinated flowers	8
	fruits	12
19.05.2006	expanding flowers	10
	pollinated flowers	7
	fruits	10
01.06.2006	expanding flowers	5
	pollinated flowers	11
	fruits	11
16.06.2006	expanding flowers	4
	pollinated flowers	4
	fruits	5
14.07.2006	expanding flowers	1
	pollinated flowers	2
	fruits	3
01.08.2006	expanding flowers	1
	pollinated flowers	2
	fruits	5
Total	expanding flowers	64
	pollinated flowers	64
	fruits	64

study it appears that the pollination efficacy was 100% (Table 4). It also indicates that the greenhouse area was properly stocked with bumblebees.

The results of this study showed that the foraging flight intensity and pollination efficacy by bumblebees in the tomato crop varied according to many external factors. Flight activity of the bumblebees was also related to their origin. It could be caused by

differences in the quality of the colonies resulting from different rearing conditions. It could also be caused by the different management of newly-formed colonies. No significant relationships were found between flight activity and individual environmental factors. The correlation coefficient between those traits was low and negative (Table 1).

CONCLUSIONS

1. Bumblebees showed the highest flight activity at greenhouse temperatures within a range of 19-24°C and at outdoor temperatures of 2-20°C. The lowest flight activities occurred at indoor temperatures above 24°C and outdoor temperatures of 21-32°C.

2. The optimum light intensity for bumblebee flights came within a range of 17-49 klx.

3. High relative air humidity above 82% negatively affected foraging flight intensity of bumblebees.

4. During the day the highest flight intensity was recorded from 9:00p.m. to 5:00p.m.

5. Pollination efficacy on the shoots selected for the test reached 100%.

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**OCENA AKTYWNOŚCI LOTNEJ TRZMIELA
ZIEMNEGO (*Bombus terrestris* L.)
W WARUNKACH SZKLARNIOWEJ UPRAWY POMIDORA**

R o m a n A . , S z c z ę s n a N .

S t r e s z c z e n i e

Celem pracy była ocena aktywności lotnej trzmiela ziemnego (*Bombus terrestris* L.) w warunkach szklarniowej uprawy pomidora.

Badania terenowe wykonano w szklarni o powierzchni 1 ha, w której uprawiane były pomidory. Trzmiele pracujące w szklarni były zakupione: w Holandii, Belgii, Włoszech oraz Wielkiej Brytanii. Intensywność lotów trzmieli była oceniana od marca do sierpnia 2006 r., w godzinach od 7.00 do 19.00. W ciągu 15 minut w kolejnych rodzinkach liczono trzmiele wylatujące z ulików, a następnie wyniki przeliczono na 1 godzinę. Efektywność zapylania mierzono na podstawie dziesięciu losowo wybranych pędów pomidorów.

Optymalna temperatura otoczenia, w której zanotowano najwięcej wylotów trzmieli 11-42 szt./h, wynosiła średnio od 19,6°C do 24°C. Natomiast najmniejszą aktywność lotną, 1-7 szt./h zanotowano, gdy temperatura w szklarni była poniżej 19,6 i powyżej 24°C oraz przy zbyt wysokiej wilgotności powietrza. Na pracę trzmieli w szklarni najlepiej wpływały temperatury zewnętrzne w granicach od 2 do 24°C. Optymalne natężenie światła wynosiło 19,6 klx. Zbyt niskie i zbyt wysokie natężenie światła obniżało aktywność trzmieli. Największą intensywność wylotów trzmieli na pożytek obserwowano w godzinach 9.00-17.00 - od 10 do 22 szt./h. Wyniki dotyczące efektywności zapylania pomidorów dowodzą że każdy kwiat na pędzie został zapylony i rozwinął się z niego owoc.

Najaktywniejsze okazały się trzmiele „belgijskie” - średnio 17,5 szt./h, następnie „holenderskie” i „brytyjskie” – odpowiednio średnio 13 i 12 szt./h, a najmniej aktywne „włoskie” - 9,5 szt./h.

Słowa kluczowe: *Bombus terrestris*, aktywność lotna, zapylanie pomidorów.