POLLINATION ACTIVITY OF BEES (*Apoidea: Apiformes*) VISITING THE FLOWERS OF *Tilia cordata* MILL. AND *Tilia tomentosa* MOENCH IN AN URBAN ENVIRONMENT

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Received 25 August 2010; Accepted 15 October 2010

S u m m a r y

The pollination activity of bee communities was studied on the flowering linden trees *Tilia cordata* and *Tilia tomentosa* in the urban environment of the city of Toruń, Poland. In 2002, the activity of bees while visiting the flowers of *Tilia cordata* and *Tilia tomentosa* was similar. During 2002, there was a cooler flowering period for the *Tilia cordata* species and a bit warmer period for the *Tilia tomentosa* species. In 2003, during the warmer season with thermally similar flowering periods, flowers of *Tilia tomentosa* were visited twice as often as compared to flowers of *Tilia cordata*. It was found that toxic properties of *Tilia tomentosa* nectar are stronger for bumblebees than for *Apis mellifera*. During the warmer flowering period, bumblebees were being intoxicated almost twice as often compared to the cooler period. The contribution of intoxicated bumble bees did not significantly increase (from 5% to 8%) even though there was a tenfold increase in the contribution of all bumblebees visiting the flowers during the studied seasons from 2002 to 2003.

Keywords: *Apiformes*, bees, *Tilia cordata*, *Tilia tomentosa*, pollination activity.

INTRODUCTION

Flowers of *Tilia cordata* and *Tilia tomentosa* are regarded as nutritionally very attractive for bees (Jabłoński et al., 2000; Demianowicz, 1979). Linden trees of these species are often planted in urban areas of Central Europe. Their flowering periods complement each other, so when flowering of *Tilia cordata* ends, the flowering of *Tilia tomentosa* begins (Jabłoński et al., 2000). These species also differ from each other in the abundance of blooming flowers, and at the same time in the abundance of nectar and pollen (Jabłoński and Kołtowski, 1999; Szklanowska and Teper, 1999; Szklanowska et al., 1999). During the same season, density of flowers on *Tilia cordata* might be several times higher than density of flowers on *Tilia tomentosa* (Jabłoński et al., 2000).

The other characteristic that differentiates the attractiveness of these linden species are the toxic properties of the nectar of *Tilia tomentosa* (Crane, 1977; Dreyer and Dreyer, 2001; Sikora, 2002) and its hybrids with *Tilia cordata* (e.g. Fellenberg and Wolf, 1991). More frequent intoxications were observed among bumblebees than among specimens of *Apis mellifera*. It was found that the mechanism of intoxication consists in blocking the phosphorylation of glucose by mannose (contained in nectar, apart from other monosaccharides) in the process of glycolysis. Since bees and wasps do not have phosphomannose isomerase (enzyme), they cannot metabolize mannose. Consequently, they accumulate mannose-6-phosphate, which induces paralysis of the body (Harborne, 1993; Sols at al., 1960). Lavish consumption

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of *Tilia tomentosa* nectar leads to lethal intoxication of an organism (Madel, 1977).

In the previous studies, less attention was paid to the multi-seasonal activity of bees that pollinate *Tilia cordata* and *Tilia tomentosa*. The aim of the present paper was to investigate the extent of bee activity during their visiting trips to the flowers of two linden species during two subsequent flowering seasons. Furthermore, an attempt was undertaken to evaluate the *Tilia tomentosa* flower'sintoxication intensity on bees.

MATERIAL AND METHODS

The research was conducted during the seasons coinciding with the height of the blooming of *Tilia cordata* (180-270 flowers per m^2) and *Tilia tomentosa* (80-100 flowers per m^2) during two periods: from June 10th till July 8th, 2002 and from June 16th till July 18th, 2003 in the city area of Toruń. Two streets in Toruń were chosen. From the trees lining Gagarina street, which is next to the university campus, 25-year-old *Tilia cordata* trees were selected. Chosen trees were those with a height of 7 m, and a crown diameter of 5-6 m. The other street chosen was called Grudziądzka street, next a cemetery. Grudziądzka street is lined with 40-year-old *Tilia tomentosa* trees. Tree heights were 9-10 m, the crown diameters were 8-9 m. The research was performed along a line of 5 trees. It consisted in observations of bees visiting the flowers within the lower part of the tree crown at a height of 1.50-3.00 m from the ground. The observations were conducted on each of the five trees during all (5-6) sunny, warm days (the air temperature of 19-25°C), at the height of florescence of the linden trees.

Flowering range for both linden tree species were determined (Fig. 1). In 2002, the average temperature for June was 16.8°C and for July 20.2°C. The height of the *Tilia cordata* flowering range covered a period of 18 days (from June 10th till June 28th), and *Tilia tomentosa* - 8 days (from July 1st till July 8th). In 2003, the average temperature for June was 18.2°C, and for July 19.3°C. The height of the *Tilia cordata* flowering range covered a period of 14 days (from June 16th till June 30th). The flowering range for *Tilia tomentosa* covered 12 days (from July 6th till July 18th).

At the height of the *Tilia tomentosa* flowering season, all dead and intoxicated specimens were collected every morning under the five trees selected for this research. During this period, almost 100% of all intoxicated bees were collected under the linden trees. Of these specimens 95% were recorded after warm and sunny days.

A calculation unit (a sample) was defined as the number of bees recorded and caught alive (there were few solitary bees) while nectar and pollen gathering during 5 min observations of the lower crown part of one tree. During that time, observations were done on the whole zone around the crown area (25 m^2) of trees with a crown diameter of 8 m, or almost the entire area (90% of 28 m^2) if the trees had a crown diameter of 9 m. Questionable identifications of bumblebees in the field were checked with the use of a hand-held magnifying glass (x20), afterwards such specimens were released. The total number of bees determined in samples and collected under the trees are presented in Table 1. All the samples were used to define basic parameters of the structure of pollinating bee communities from *Tilia cordata* and *Tilia tomentosa*.

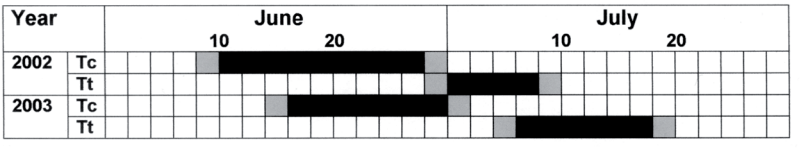

Fig. 1. Flowering seasons of *Tilia cordata* (Tc) and *Tilia tomentosa* (Tt) in the urban environment of Toruń in 2002-2003: black colour - the height of florescence

Honey bee workers were flying in from 20-30 single hives distributed in allotment gardens. These gardens were located 0.8-1 km from the studied sites with linden tree sites.

The structure of each community was described by the number of species (S), the density expressed as an average number of specimens recorded during a 5 min walk around the lower area of the crown zone (D), the index of species diversity (H') and the index of potential species diversity (J). Differences between D values from particular years were statistically assessed with the t-test. The formula of the species diversity index was calculated after Shannon and Weaver (1963): $\mathbf{H' = \sum p_i \log_2 p_i}$, where $p_i = n_i / N$. The index denotes a fraction of the i^{th} species in a community that consists of S species, n_i stands for the count of the i^{th} species in a community with the total count of N individuals. The potential species diversity index, which is also known as the evenness index of quantitative distribution of species in a community, was accepted after Pielou (1966): $\mathbf{J' = H'/ \log_2 S}$, where $\log_2 S$ denotes the maximum possible value of the H' index (H'max). The J' index assumes values within the range of $0 < J' < 1$; when a value drops to 0, it reflects the increasing tendency of superdomination. When a value increases to 1, it reflects the increasing tendency of codomination. Statistical significance of differences between values of the H' index was assessed according to Hutcheson (1970). Formulas of the variance of an estimate and degrees of freedom of an estimate of differences between H' values (t-test) were applied. In all statistical comparisons, the significance of the difference (P) was accepted at the level equal and not higher than 0.05. Statistical calculations were performed with the software Statistica v6.

RESULTS

Pollinating bee communities

In 2002 on *Tilia cordata*, 1420 bees and 9 species were recorded, and in 2003 - 2185 specimens and 8 species. Among them, *Apis mellifera* was a definite superdominant, and constituted 91% of all specimens in the first season and 89% in the second season of the research. In 2002 bumblebees comprised 6 species, which constituted 9% of all specimens, and in 2003 - 5 species, which constituted 11% of all specimens. The remaining species of bees were merely a trace contribution in the structure of communities (Tab. 1).

In 2002, 6 species among 1684 specimens were recorded on *Tilia tomentosa*, and in 2003 - 6 species among 3440 specimens of bees. Also in this case, *Apis mellifera* was a definite superdominant and made up 94% in the first season and 85% in the second season. Bumblebees comprised 5 species, which in 2002 constituted ca. 6% of all bees, and in 2003 - more than 15% of all specimens.

Thus, both communities of pollinating bees included nearly exclusively honey bee workers and bumblebees. For *Tilia cordata*, the ratio of specimens from the genera *Apis* and *Bombus* was 10 : 1 in 2002, and 8 : 1 for 2003; whereas for *Tilia tomentosa* - 15 : 1 in 2002, and 6 : 1 in 2003 (Tab. 1).

During the first season, the density of specimens in bee communities for *Tilia cordata* and *Tilia tomentosa* was similar. The density ranged from 37.4-39.4 specimens, per a 5 min observation of a tree crown. During the second season, the density was significantly different. This time, the density was within the range of 89.7 specimens for *Tilia cordata* and 178.9 specimens for *Tilia tomentosa*, i.e. in the second season, density was two times higher as compared to the first season. As a consequence of the domination distribution of species in communities from 2002 was a significant drop ($P \leq 0.05$) in their species diversity (H'), and a significant drop in communities from 2003. A similar pattern of species diversity was observed, despite the fact that the density of bees on *Tilia tomentosa* was two times higher (Tab. 2).

Table 1

Number of specimens of *Apiformes* recorded and collected during the flowering seasons of *Tilia cordata* and *Tilia tomentosa* in an urban environment of the Toruń in 2002-2003

Species	2002						2003					
	Tilia cordata			*Tilia tomentosa*			*Tilia cordata*			*Tilia tomentosa*		
	Nl [n=30]	%ΣNl	Nd[1]	Nl [n=30]	%ΣNl	Nd[2]	Nl [n=25]	%ΣNl	Nd[1]	Nl [n=25]	%ΣNl	Nd[2]
Andrena haemorrhoa (F.)	1	0.07										
Halictus rubicundus (Christ)							2	0.09				
Lasioglossum albipes (F.)							5	0.23				
Lasioglossum calceatum (Scop.)	1	0.07										
Bombus hypnorum (L.)	1	0.07		12	0.67	6	2	0.09		1	0.02	18
Bombus lapidarius (L.)	13	0.91		6	0.37		22	1.01		1	0.02	7
Bombus lucorum (L.)				13	0.73	7				2	0.05	42
Bombus pascuorum (Scop.)	5	0.35		3	0.17		3	0.14				
Bombus pratorum (L.)	3	0.21								1	0.02	1
Bombus ruderarius (Müll.)	3	0.21					2	0.09				
Bombus terrestris (L.)	102	7.18	2	67	3.78	14	209	9.56	6	615	15.15	182
Apis mellifera (L.)	1291	90.91	3	1684	94.34	21	1940	88.78	6	3440	84.73	50
Total *Apiformes* (Σ)	1420	100	5	1785	100	48	2185	100	12	4060	100	300

n - number of samples, Nl - number of live specimens in n samples, Nd - number of dead specimens during flowering seasons of lindens
1) - after nights with precipitation or a storm
2) - intoxicated

Table 2

Characteristics of bee communities for *Tilia cordata* and *Tilia tomentosa* during flowering seasons, in an urban environment of the Toruń in 2002-2003

Parameters	2002		2003	
	T. cordata	*T. tomentosa*	*T. cordata*	*T. tomentosa*
Number of species [S]	9	6	8	6
Density [D]	37.4	39.4	89.7	178.9
Tendency of D values [TD]*	ns		↑*	
Diversity [H']	0.38	0.28	0.42	0.43
Tendency of H'values [TH']*	↓*		ns	
Evenness [J']	0.17	0.16	0.20	0.24
Tendency of J'values [TJ']	=		=	

D - mean number of specimens recorded per 5 min on one linen-tree;
TD - tendency of D value changes with the significance level
H' - Shannon index; TH' - tendency of H' value changes with the significance level
J' - Pielou index; TJ' - tendency of J' value changes
Value changes: ↓ - decrease, ↑ - increase, = - equal
*) significance level $P \leq 0.05$, ns - not significant

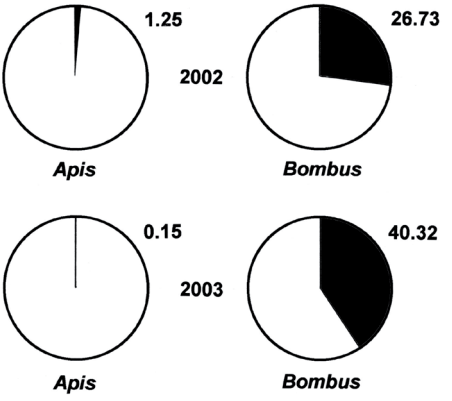

Fig. 2. Percentage contribution of dead bees during the flowering season (the black coloured part) in relation to all observed bees (the total number of bees in n samples = 20% of all bees) that visited flowers of *Tilia tomentosa* within the lower 1.5 m to 3 m part of the tree crown

Intensity of intoxication by *Tilia tomentosa*

Dead specimens, which were collected under *Tilia tomentosa* trees were not only from the lower observation zone of linden crowns (up to 3 m height), as it is presented in Fig. 2, but from the entire crown. Despite this simplified picture, it should be noted that honey bee workers collected beneath these linden trees constituted a trace contribution (1.25-0.25%) in relation to all honey bees visiting the flowers.

When trying to assess the extent of poisoning of bumblebees per one tree, it is necessary to note certain methodological points:

1) the total number of observed bumblebees from all samples was representative for all bumblebees visiting the flowers during the flowering season of *Tilia tomentosa*;

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2) bumblebees were evenly distributed over the whole cylindrical surface area of a linden tree crown;

3) the total number of dead bumblebees beneath the crowns of all five linden trees (and attributed to the lower 1.5 m observation zone) were equivalent to a crown of one 9 m high linden tree.

This is the way the percentage contribution of dead bumblebees was assessed in relation to all bumblebees visiting the subsequent 5 crown zones, up to the height of 9 m (Fig. 3). From the graphs presented in Fig. 3, it appears that during the first season of 2002, dead bumblebees constituted 5% of all bumblebees flying around the flowers on one tree, and during the second season of 2003 - 8% of all bumblebees on one tree.

to *Tilia cordata*. Regarding the seasonal variability, the density on both species of linden trees were two times higher on *Tilia cordata* and four times higher on *Tilia tomentosa* during the warmer season as compared to the cooler season.

Toxic properties of *Tilia tomentosa* nectar were nearly insignificant for *Apis mellifera* and most evident for bumblebees. However, the contribution of intoxicated bumblebees constituted only a few per cent of all bumblebees visiting the flowers. This contribution did not significantly increase (from 5% to 8%) though there was a tenfold increase (Tab. 1), in the contribution of all bumblebees visiting the flowers during the studied seasons of 2002 and 2003.

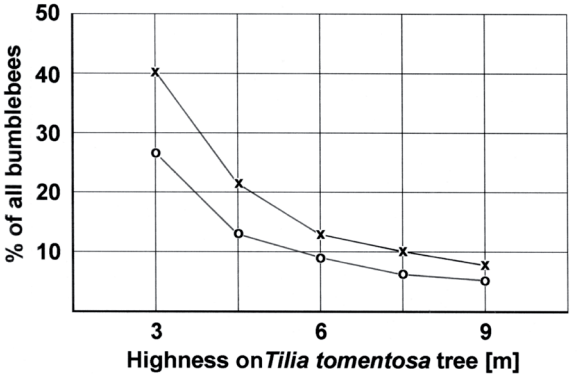

Fig. 3. Estimation of the percentage contribution of dead bumblebees to all bumblebees that visited a crown of *Tilia tomentosa* (diameter of 8-9 m) at different heights of a tree in 2002 (o) and 2003 (x)

DISCUSSION

Both species of linden trees were visited almost exclusively by honey bees and bumblebees. The number of visiting honey bees in relation to the number of bumblebees was several times higher during the cooler season of 2002 and a few times higher during the warmer season of 2003.

General density of *Apiformes* during the cooler season was similar for both linden species. Whereas during the warmer season, density of *Apiformes* was twice as high ($P<0.05$) on *Tilia tomentosa* as compared

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AKTYWNOŚĆ PSZCZÓŁ (*Apoidea: Apiformes*) ODWIEDZAJĄCYCH KWIATY *Tilia cordata* MILL. I *Tilia tomentosa* MOENCH W ŚRODOWISKU MIEJSKIM

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

Badano aktywność zapylających zespołów pszczół na kwitnących lipach *Tilia cordata* i *Tilia tomentosa* w środowisku miejskim Torunia. Aktywność pszczół w odwiedzaniu kwiatów *Tilia cordata* i *Tilia tomentosa* była podobna w sezonie (2002 r.) z chłodniejszym okresem kwitnienia pierwszego gatunku i nieco cieplejszym okresem drugiego gatunku. W cieplejszym sezonie (2003 r.) o podobnych termicznie okresach kwitnienia, kwiaty *Tilia tomentosa* były dwa razy częściej odwiedzane niż kwiaty *Tilia cordata*. Stwierdzono większe właściwości trujące nektaru *Tilia tomentosa* dla trzmielowatych niż dla *Apis mellifera*. Trzmielowate truły się prawie dwukrotnie częściej w cieplejszym okresie kwitnienia niż w chłodniejszym okresie. Udział ten nie wzrastał jednak znacząco (z 5% do 8%) pomimo dziesięciokrotnego podwyższenia udziału ogółu trzmielowatych odwiedzających kwiaty w badanych sezonach z 2002 r. do 2003 r.

Słowa kluczowe: *Apiformes*, pszczoły, *Tilia cordata*, *Tilia tomentosa*, aktywność zapylania.