EFFECT OF VOLCANIC ASH CLOUD OVER POLAND ON FLIGHT ACTIVITY OF HONEY BEES

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S u m m a r y

Changes in light intensity effect flight intensity of honey bees. The ash cloud of the volcano Eyjafjallajökull covered the sky over Poland from 17 till 20 April 2010. We investigated whether the volcano cloud affected the flight intensity of foraging worker bees. We determined the flight intensity of bees during the two days of 17 and 20 April when the sky was covered by the cloud, and during the two days of 28 and 29 April when the cloud disappeared. We did seven counts on the number of bees returning to each of the 10 colonies studied. Each count lasted 5 min. The counts were done on the hour, from 10:00 to 16:00. The frequency distribution of the number of flights/5 min performed by bees differed significantly between different colonies, as well as between different days. High significant correlation was found between the number of combs covered by bees in different colonies and the flight activity. No significant correlation was found between the number of brood combs in the colonies and the flight activity. The daily mean number of flights/5 min performed by bees, differed significantly between different colonies, as well as between different days. The number of flights differed significantly on each of the four days. The flight activity decreased by 9%, during the first two days when the volcanic ash cloud covered the sky.

Keywords: volcanic cloud, Eyjafjallajökull volcano, honey bee flights, flight activity of bees.

INTRODUCTION

Honey bee foragers react very noticeably to meteorological changes. Bees respond to variations in solar radiation and temperatures as well as other changes (Burrill, 1981). Every beekeeper knows, that bees return to the colony en mass, when a dark rainy cloud appears in the sky. Small changes in sky light intensity also affect flight activity. During an eclipse of the sun changes in flight activity were recorded, shortly after the start of the eclipse (Woyke, 1955; Woyke et al., 2000), when the human eye was not able to detect changes. Other papers concerning reactions of bees to solar eclipse are referred by Woyke et al. (2000).

According to the information from the Institute for Earth Sciences, Nordic Volcanological Center at the University of Iceland (2010), the Eyjafjallajökull volcano erupted on March 20, 2010. (Eyja-fjalla-jökull, means islands' fells' ice cap). There was more lava flow than ash at the initial eruption. The initial phase of the eruption stopped on April 12, 2010. The second phase of the eruption begun on April 14th (Fig. 1). It was 10 to 20 times stronger than the first one. The ash plume reached 10 km in the height and more volcanic matter was ejected. On 15 April explosive eruptions of the volcano continued and the ash cloud reached mainland Europe (Fig. 2 and 3). Animation of the volcanic cloud travel over Europe was made (Mackey, 2010). Air travel across much of Northern Europe was prevented. According to the Polish Geological Institute (2010), the volcanic ash cloud reached Poland 17 April 2010 (Fig. 2) and stayed until 20 April.

Fig. 1. Eruption of the volcano Eyjafjallajökul 14 April 2010. Photo Árni Sæberg, Icelandic Coast Guard, National Geographic.

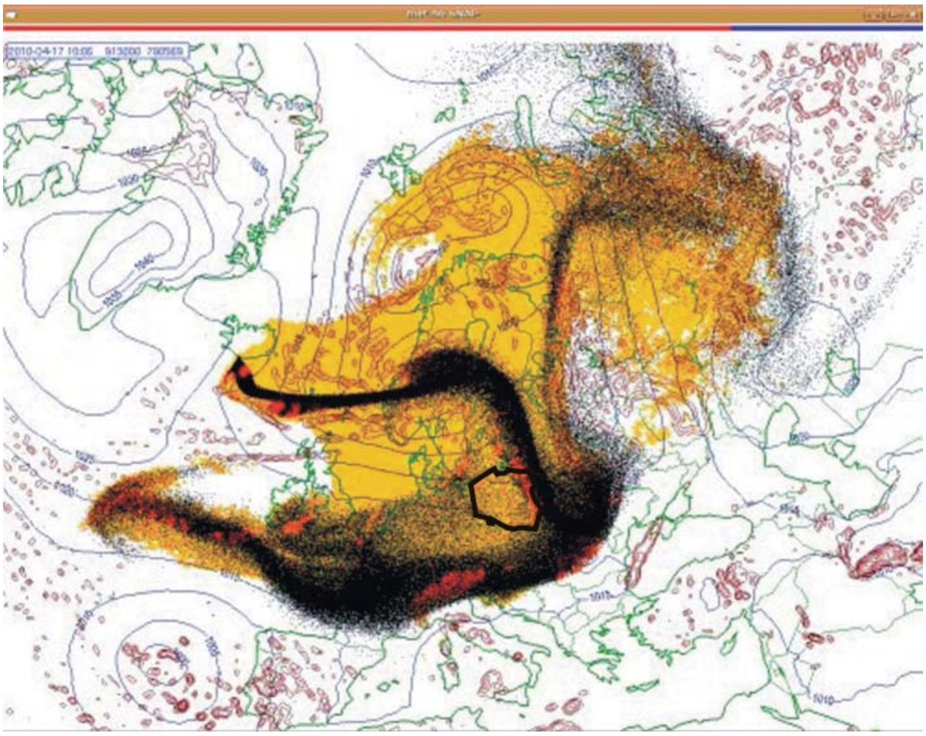

Fig. 2. Volcanic ash cloud over Europe 17 April 2010. *Norwegian Meteorological Institute. Black - ice crystals, gray (orange-yellow on line) volcanic ash. Borders of Poland in bold lines.*

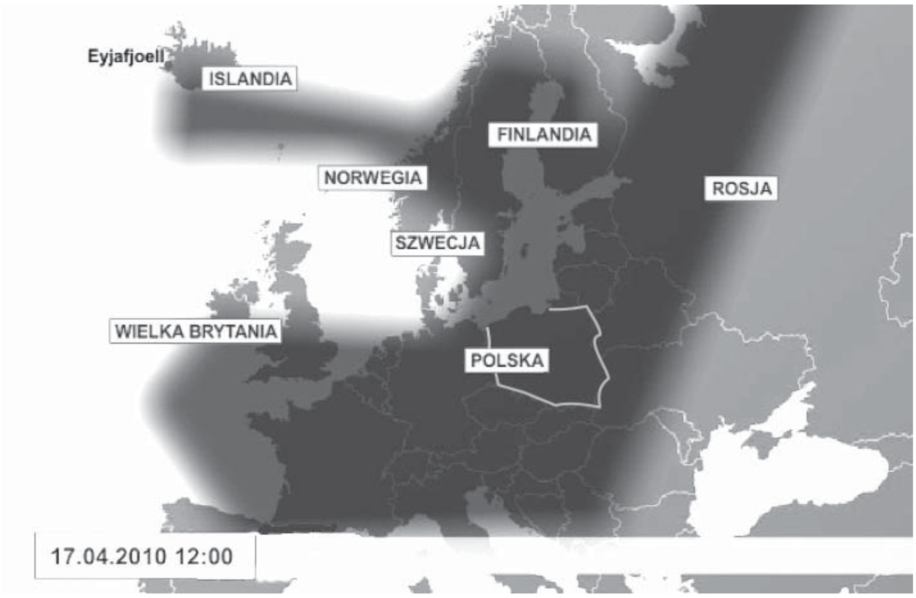

Fig. 3. Volcanic ash cloud over Europe 17 April 2010. Country names are in Polish (Polska - Poland). Gazeta.pl.

The volcanic cloud over Poland was 6 to 11 km above the ground.

Airborne volcanic fragments known as pyroclasts are of different sizes. Particles smaller than 2 mm in diameter make up the ash. The ash can often travel for thousands of km. When large amounts of ash accumulate in the atmosphere, they can reflect light and heat from the sun back to the atmosphere. In some cases, this reflection causes the temperature to drop resulting in a climate change.

We did not find any report in the internet about the effect of the volcanic ash cloud on the activity of honey bees. Therefore, we investigated whether the flight activity of foraging worker bees was effected by the volcanic ash cloud over Poland. Probably, this is the first report concerning this matter. Because, we examined flight activity of worker bees from 10 colonies, we also compared same-day flight activity of bees from different colonies, as well as flight activity of bees from particular colonies, which took place on different days.

MATERIAL AND METHODS

We observed the flight activity of foraging worker bees in the apiary of the Division of Apiculture, University of Life Science, Warsaw, for four days in April 2010. The volcanic cloud covered the sky the first two days; 17 and 20 April and was absent during the two last days; 28 and 29 April. Unfortunately, 11 days passed between the counts conducted under the clouded and clear sky. Between those counts rained and the bees did not fly.

Worker bees returning to the colony during a 5 min period were counted. The counts were repeated on the hour 7 times from 10:00 to 16:00. Each day the flight activity of 10 colonies was determined.

The strength of the colonies was examined. The colonies occupied the so called great-Polish hives (ul wielkopolski), with frames of 360 × 260 mm. The number of combs covered by the bees, as well as the number of combs with brood were determined.

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The Chi^2 test was used to compare the frequency distribution of the daily flight activities of bees. Two variations were applied. The goodness-of-fit test for equal distribution, or the R (row) × C (column) test of independence (contingency tables). Together the frequency distribution of 252 data pairs were compared. One-way and two-way analysis of variance ANOVA was applied. The LSD multiple range test $P < 0.05$ was used to detect significant differences between the means. The Statistica and the Statgraphic statistical programs were used.

RESULTS

Strength of colonies used for observations

The bees in the weakest colony, No. 3, covered 6 combs (Tab. 1). In 2 other colonies, they covered 7 combs and in the majority of the 7 colonies, the bees covered 8 combs. The lowest number of 5 brood combs was present in 2 colonies; No. 3 and 10. Six brood combs were present in half of the number of bee colonies (5). Seven brood combs were present in 3 colonies. Thus, in the majority of the 7 colonies, the bees covered 8 combs and in half of the number of colonies, there were 6 brood combs.

Frequency distribution of flight activities performed by bees from different colonies the same day

The frequency distribution of daily hourly flight activities of bees from 10 colonies showed enormous variation (Fig. 4). It was difficult to follow the flight activity of particular colonies, in one diagram. For this reason, individual diagrams for all 10 colonies of bees flying 17 April 2010 are presented (Fig. 5).

Table 1

Strength of colonies used for observations from 17 - 29 April 2010

Colony No.	1	2	3	4	5	6	7	8	9	10
No. combs covered*	8	8	6	8	7	8	8	8	8	7
No. brood combs	7	6	5	7	6	6	6	6	7	5

* Number of combs covered by bees

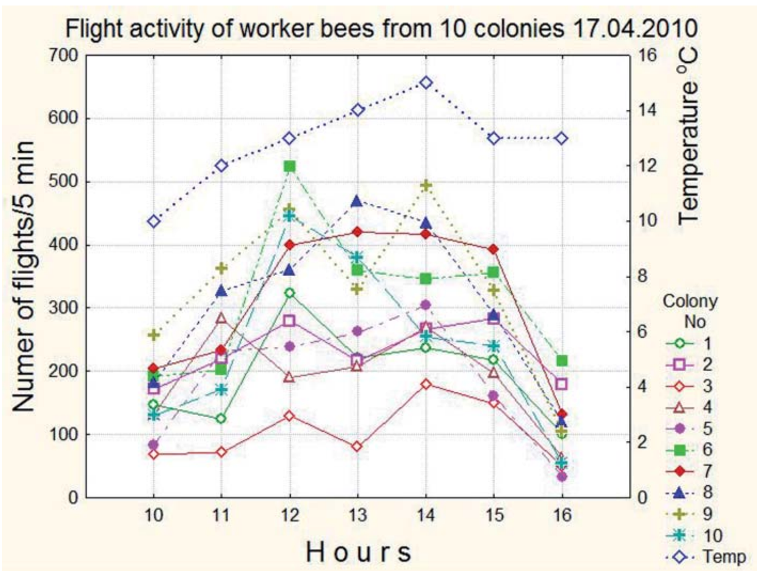

Fig. 4. Frequency distribution of the number of flights/5 min performed by bees from 10 colonies 17. 04. 2010, when the volcanic cloud was over Poland.

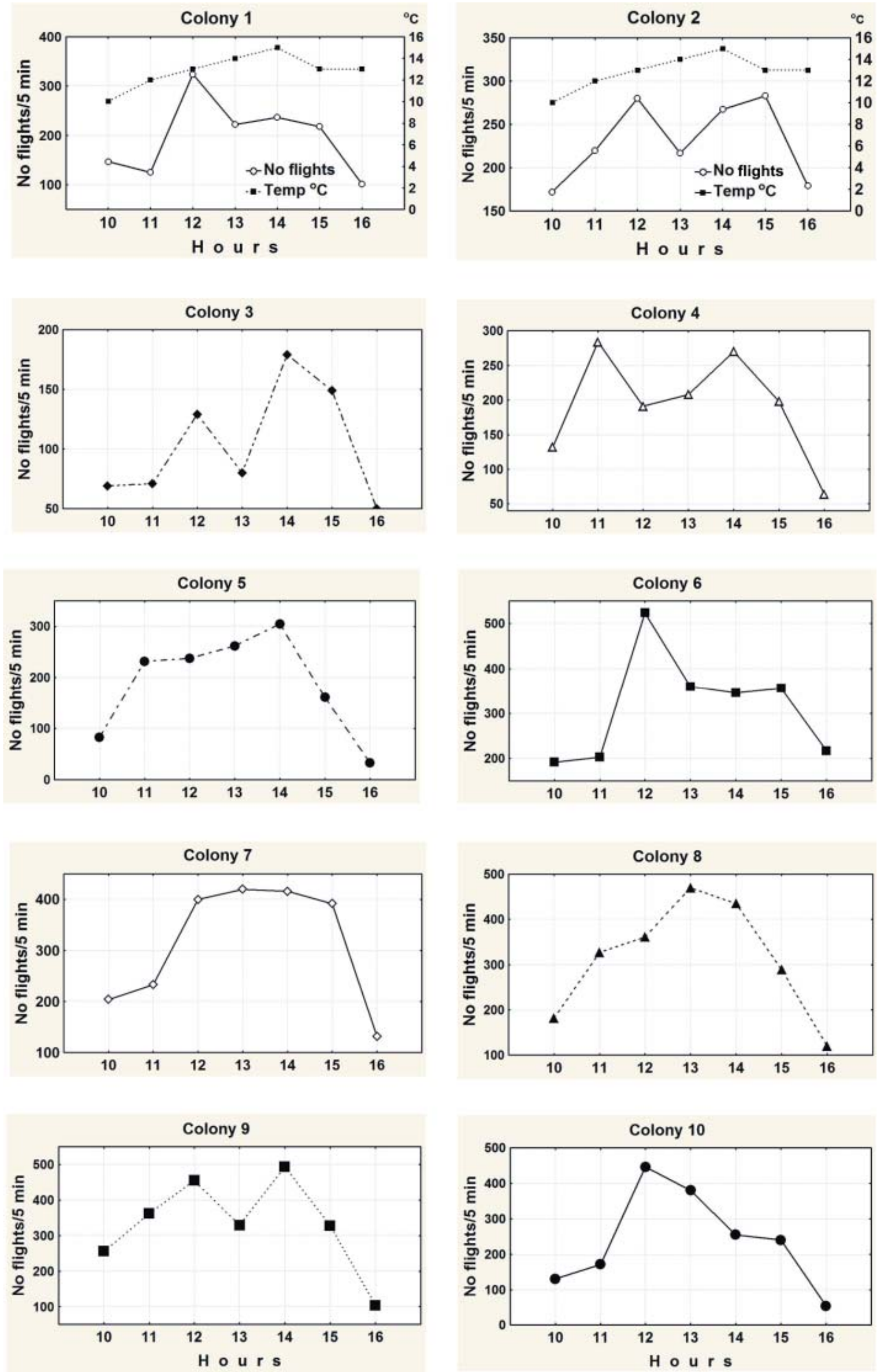

Fig. 5. Frequency distribution of the number of flights/5 min performed by bees from particular 10 colonies 17. 04. 2010, when the volcanic cloud was over Poland.

The highest temperature of 15°C appeared at 14:00. However, the daily frequency distribution of the number of flights/5 min performed by bees from different colonies showed one or two peaks. The highest peak occurred in different colonies between 11:00 and 15:00.

The distribution of the daily number of flights/5 min performed the same day, in 7 hourly counts, by bees from each of the 10 colonies was statistically compared with that from each of the other selected colonies. For the 10 colonies, this resulted in 45 pairs of comparisons for one day. Together, for all the 4 days, frequency distribution of the flight activity of 180 pairs of daily flights were compared. The applied Chi^2, **R** × **C** test of independence (7 **R** × 2 **C**) concerned the 7 **R**ows of hourly counts × the 2 **C**olumns of the 2 colonies being compared.

The Chi^2 value for the 45 pairs showed highly significant differences between different colonies in hourly frequency distribution of daily flight activities. The df for all compared pairs = 6.

17. April - 44 pairs; Chi^2 = 25.38 - 167.58, P < 0.001, and 1 pair; Chi^2 = 10.78, P > .0.05.

20. April - 43 pairs; Chi^2 = 27.12 - 197.72, P < 0.001, 1 pair P < 0.005, and 1 pair; Chi^2 = 16.24, P < 0.05.

28. April - 44 pairs; Chi^2 = 24.43 - 396.85, P < 0.001, and 1 pair; Chi^2 = 8.49, P > 0.05.

29. April - 29 pairs; Chi^2 = 16.98 -58.25, P < 0.01, 6 pairs; Chi^2 =12.73 - 16.47, P < 0.05 and 10 pairs; Chi^2 = 5.90 - 11.66, P > 0.05.

Thus, in the two first days, out of the 45 pairs compared each day, the frequency distribution of 1 pair was not found to differ significantly. However, on the last day, 10 pairs were not found to differ significantly. Hence, out of the 180 pairs of the daily hourly frequency distribution of flight activity of 10 colonies during the 4 days, only 12 pairs were not found to differ significantly.

Frequency distribution of flight activity performed by bees on different days

The frequency distribution of daily hourly number of flights/5 min performed by bees from the same colony varied considerably on different days (Figs 6 and 7, example colonies No. 1, and No. 5). Flight activity of bees from a particular colony was compared with flight activity of the same colony on the 4 days. Thus, 6 pairs of comparisons were made for each colony. Together, 60 pairs of flight activity of the 10 colonies in 4 days were compared. The independence R × C test (R=7 hourly counts × 2 colonies) showed statistically very highly significant differences between all 60 compared pairs; Chi^2 = 25.63 - 571.06, df = 6, P < 0.001. Thus, frequency distribution of flight activity performed by the same colony differed significantly between the 4 days.

Correlation between the strength of the colonies and the flight activity

The correlations between the number of combs covered by the bees in the 10 colonies (Tab. 1) and the daily mean number of flights/5 min performed by bees from those 10 colonies (Tab. 2) were statistically highly significant for all 4 days; r > 0.60, df = 9, P < 0.05 (Tab. 3). The correlation for the overall mean of the 4 days was also very highly significant; r = 0.82, df= 9, P = 0.004.

However, the correlations between the number of brood combs (Tab. 1) and the daily mean number of flights/5 min (Tab. 2) were low, and were not found to be significant in the 4 days; r < 0.5, df = 9, P > 0.2 (Tab. 3). The correlation for the overall mean of the 4 days was also low and was not found to be statistically significant; r = 0.31, df = 9, P = 0.38.

This means that correlations between the number of combs covered by the bees and the number of flights/5 min were statistically significant. However, those between the number of brood combs and the number of flights/5 min were not found to be statistically significant.

Table 2

Daily hourly mean number (of 7 hourly counts) of flights/5 min performed by bees from 10 colonies over the 4 day period. During the first 2 days volcanic cloud was over Poland.

Colony No.	17. April	20. April.	28. April	29. April	Overall
1	196 a AB*	167 a ABC	323 b CD	354 b B	261 BC
2	231 a BC	202 a BC	331 b C	432 b E	310 C
3	104 ab A	78 a A	174 a AB	273 c A	157 A
4	192 ab AB	117 ab AB	222 b ABC	407 c CDE	234 B
5	188 a AB	150 a ABC	172 a A	357 b BC	217 AB
6	314 ab C	204 a BC	332 b CD	363 b BCD	303 C
7	314 ab C	214 a C	304 ab ABCD	412 b DE	311 C
8	312 ab C	226 a C	316 ab BCD	421 b E	319 C
9	333 ab C	201 a BC	321 ab CD	430 b E	321 C
10	239 a BC	208 a BC	260 a ABCD	397 b BCDE	276 BC
Overall	242 ab	177 a	279 b	385 c	271

* different letters indicate significant differences between means, small letters concern comparison between columns (days), capitals concern comparison between rows (colonies).

Table 3

Correlation (r) between the strength of the colony (Tab. 1) and the daily mean number of flights/5 min (Tab. 2). All df = 9, Probability (P).

17 April		20 April		28 April		28 April		Overall mean	
r	P	r	P	r	P	r	P	r	P
r and P, for No. of combs covered by bees and No. flights/5 min									
0.71	0.021	0.64	0.048	0.80	0.006	0.77	0.009	0.82	0.004
r and P, for No. of brood combs and No. flights/5 min									
0.27	0.44	0.07	0.848	0.37	0.297	0.41	0.229	0.31	0.380

Mean number of flights performed by bees from individual colonies

The daily means (of 7 hourly counts) of the number of flights/5 min performed by bees from the 10 colonies during the 4 days were compared (Tab. 2). The two way analysis of variance showed that both factors; the day and the colony, highly significantly effected the mean number of flights; F_{279}, day = 54.87, df = 3, P < 0.001 and colonies = 8.47, df = 9, P < 0.001. No interaction between the day and the colony number was found; $F_{27, 279} = 0.83$, P = 0.734.

Table 2 shows that statistically significant differences were found in the mean number of flights performed by bees flying the same day from different colonies. The lowest number of flights (78/5 min) performed bees from colony No. 3, the 20 of April, although it was not found to differ significantly from the flight numbers performed by bees from 3 other colonies. The highest number of flights (432) performed bees from colony No. 2, the 29 April, although it was not found to differ significantly from that of 5 other colonies.

The overall mean number of flights/5 min also differed significantly between different colonies. The lowest number of bees flew from colony No. 3 (157/5 min), although it was not found to differ significantly from the overall of colony 5 (217/5 min). The highest overall mean numbers of flights (261 - 321), which was not found to differ significantly, performed bees from 7 different colonies (1, 2, 6 - 10). Thus, the overall mean number of flights/5 min was not found to differ significantly between the majority of the colonies.

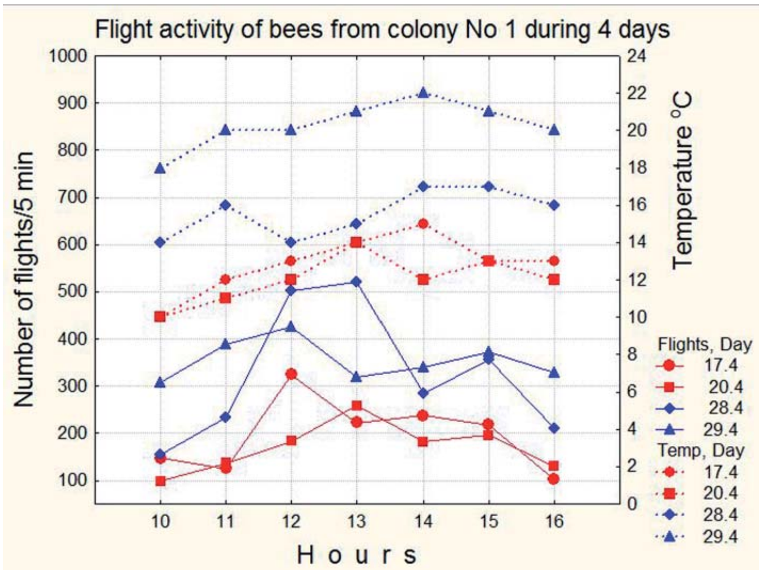

Fig. 6. Frequency distribution of the number of flights/5 min performed by bees from colony No. 1 over a 4 day period.

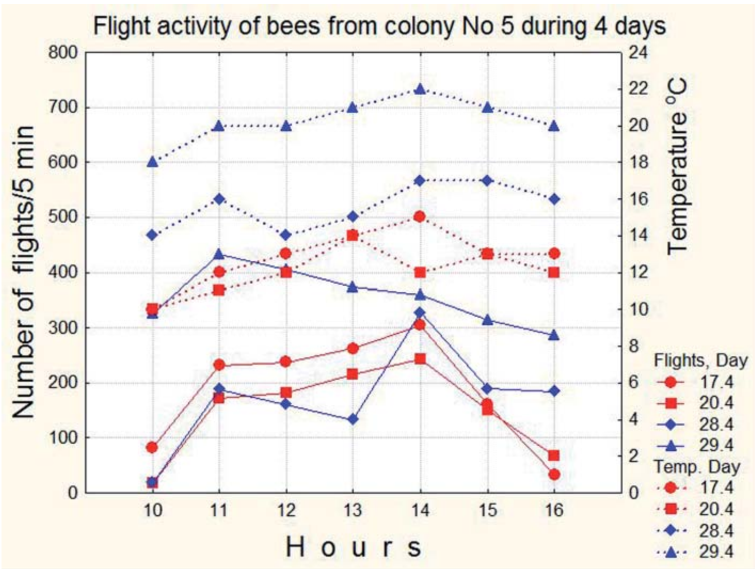

Fig. 7. Frequency distribution of the number of flights/5 min performed by bees from colony No. 5 over a period of 4 days.

Significant differences were found also between the daily mean number of flights/5 min performed by bees from the same colony on different days. The lowest number of flights (78/5 min) performed bees from colony No. 3, the 20 April, although it did not differ significantly from the means of those one day earlier and one day later. The highest number of bees (432/5 min) returned to colony No. 2, the 29 April, although it did not differ significantly from that of one day earlier.

The overall mean number of flights/5 min performed by bees from all the 10

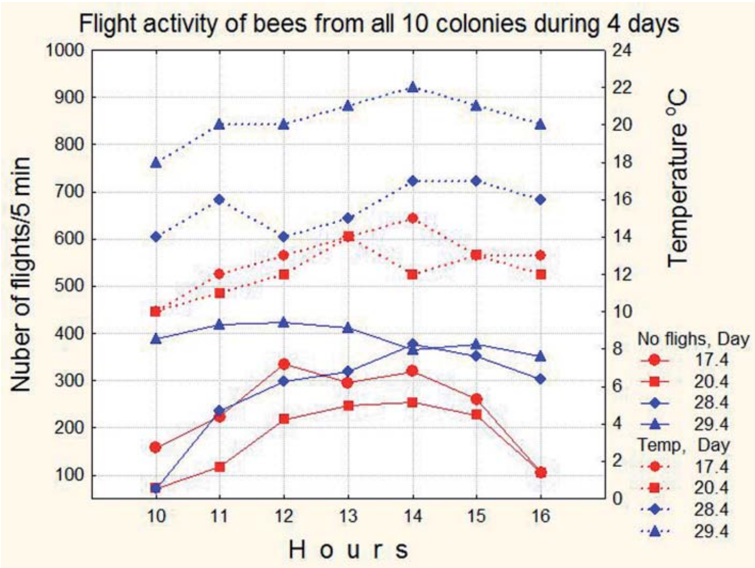

Fig. 8. Frequency distribution of the mean number of flights/5 min performed by bees from all 10 colonies over the 4 day period.

colonies differed significantly between the 4 days. The lowest number of flights (177/5 min) took place the second day, when the cloud still covered the sky, and the highest (385/5 min) the last day.

Frequency distribution of daily temperatures and daily hourly mean number of flights during the four days.

The frequency distributions of the 7 hourly measurements of **temperature** over the day varied (Fig. 8). Hourly distribution over one day was compared with that over each of the other 3 days. This created 6 pairs of comparison. No significant differences were found in the frequency distribution of daily hourly temperatures between the 4 days (6 pairs), $Chi^2 = 0.17 - 0.52$, $df = 6$, $P > 0.9$.

To synthesize the flight activities of individual colonies, the distribution of daily hourly mean **number of flights**/5 min performed by bees from all the 10 colonies during a day were compared (Fig. 8). Highly significant differences were found in the frequency distribution of the daily mean number o flights between the 4 days (6 pairs); $Chi^2 = 33.46 - 185.43$, $df = 6$, $P < 0.001$.

Daily temperatures and the daily overall mean number of flights performed during the four days

One way analysis of variance showed, that the mean **temperatures** in the 4 days (Tab. 4) differed very highly significantly; $F_{3, 27} = 53.11$, $P = 0.0000$. The mean daily temperatures during the first two days, when the volcanic cloud covered the sky (12.9 and 12.0 °C) were not found to differ significantly ($P > 0.05$). However, daily mean temperatures during the two next days, when the volcanic cloud disappeared (15.6 and 20.3°C), were significantly higher ($P < 0.05$) Thus, the daily mean temperatures differed significantly for the three days.

The daily overall mean number of **flights**/5 min (Tab. 4) indicates the mean of the sum of all 7 hourly counts performed by bees of all 10 colonies a day = 70 counts a day. One way analysis of variance showed that daily overall mean number of flights/5 min differed very highly significantly between the 4 days; $F_{3, 279} = 44.73$, $P = 0.0000$. All the daily overall means differed significantly (Tab. 4). The means for the first two days when the volcanic cloud covered the sky (242/5 min

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Table 4

Daily temperature and daily number of flights/5 min performed by bees from all 10 colonies in the 4 day period. The overall means concern 7 hourly counts of 10 colonies = 70 counts. During the two first days, volcanic cloud covered the sky.

Day	Temperature °C		No. flights			
	Min. - Max.	Mean ± se *T	Min. - Max.	Overall mean ± se, **N_O	Overall mean transformed, ***N_t	
17 April	10 - 15	12.9 ± 0.6 a	105 -335	242 ± 14 b	225	201 91%
20 April	10 - 14	12.0 ± 0.5 a	72 - 253	177 ± 11 a	177	
28 April	14 - 17	15.6 ± 0.5 b	70 - 377	279 ± 17 c	215	222 100%
29 April	18 - 22	20.3 ± 0.5 c	352 - 424	385 ± 8 d	228	

* T =temperature, **N_O = No. original mean, ***N_t = No. transformed mean, $N_t = N_O/T \times 12$. (12 = the 12°C to which the N_O were transformed).

and 177/5 min), were significantly lower than those for the two next days. It is worth noting that a significant difference was found in the mean number of flights between 28 and 29 April, when the cloud had already disappeared (279/5 min and 385/5 min). The number of flights was the highest the last day (385/5 min) when the daily mean temperature was also the highest (20.3°C). This suggests that the significantly higher number of flights the last day was affected by the significantly higher temperature.

Highly significant correlation was found between the 4 daily mean temperatures and the 4 daily overall mean number of flights; r = 0.99, df = 3, P = 0.0052. Thus, it was difficult to conclude, whether the higher number of flights the last day resulted from the absence of the volcanic cloud or from the higher temperature.

The distribution of the four daily overall mean number of flights (Tab. 4, N_o) differed highly significantly from the equal (270.75) 1 : 1 : 1 : 1 distribution, Chi^2 = 83.98, df = 3, P = 0.000. To overcome the effect of different daily mean temperatures, on the daily overall mean number of flights, the original mean numbers of flights (N_O) were proportionally transformed to the value of 12°C. The following equation was used to calculate the transformed overall mean number of flights; $N_t = N_O / T_O \times 12$. The N_t = transformed mean No. of flights, N_O = original mean No. of flights, T_O = original mean temperature, 12 = the 12°C to which the N_O were transformed. The obtained transformed mean numbers of flights (N_t) are presented in Table 4. Distribution of those 4 new overall mean numbers of flights also differed significantly from the equal (211.25) 1 : 1 : 1 : 1 distribution; Chi^2 = 7.84, df = 3, P = 0.049. This suggests, that the lower number of flights during the first two days was not caused only by lower temperatures, but also by the volcanic cloud in the sky.

The transformed overall mean number of flights/5 min for both first days, when the cloud covered the sky, was (225 + 177)/2 = 201, while for both last days it was (215 + 228)/2 = 221.5. Taking into account the mean number of 221.5/5 min during the last two days (when the sky was clear) as 100%, the mean number of 201/5 min for the two first days (when the cloud covered the sky presents 90.74%. This shows, that the mean number of flights decreased by 9.26% (rough 9%), during the first two days, when the cloud covered the sky.

DISCUSSION

The high variation in the frequency distribution of flight intensity performed by bees from different colonies was similar to that during an eclipse of the sun as reported by Woyke et al. (2000).

The frequency distributions of the daily hourly temperatures were not found to differ statistically significantly between the four days. However, unfortunately, the mean daily temperatures were significantly lower during the two first days when the volcanic ash cloud covered the sky, then during the two last days when the cloud disappeared. Highly significant correlation was found between daily mean temperatures and daily overall mean number of bee flights. Therefore, the daily mean number of flights was proportionally transferred to the temperature of 12^{o}C. The transformed mean number of flight suggests that the bees performed an 9% lower number of flights when the volcanic cloud covered the sky.

Due to the rain, the flight activity of bees under the clear sky was conducted 11 days later, then that under the volcanic cloud. Probably, the number of worker bees in the colonies increased in the meantime. Thus, the higher number of bees flying during the two last days was also partly caused by the higher number of bees in the colonies. When this increase is subtracted, then the lower number of 9% of bees flying under the volcanic cloud would be relatively lower.

CONCLUSIONS

1. The frequency distribution of daily hourly flight activity performed by bees from different colonies differed significantly during the same day, as well as between different days.
2. The daily mean number of flight performed by bees from different colonies differed significantly during the same day as well as between different days.
3. The frequency distribution of daily hourly temperatures was not found to differ significantly between the four days. However, the daily mean temperatures differed significantly between the days.
4. The overall daily mean number of flights/5 min differed significantly between the 4 days.
5. The overall mean number of flights decreased by 9%, during the days, when the volcanic ash cloud was over Poland.
6. Probably, this is the first report on the effect of volcanic ash cloud on the activity of honey bees.

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WPŁYW CHMURY PYŁU WULKANICZNEGO NAD POLSKĄ NA AKTYWNOŚĆ LOTNĄ PSZCZÓŁ MIODNYCH

W o y k e J., G ą b k a J.

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

Pszczoły reagują na zmiany meteorologiczne. Aktywność lotna pszczół zbieraczek zleży między innymi od temperatury i oświetlenia. Lot pszczół zmienia się na początku zaćmienia słońca, gdy oko ludzkie nie wyczuwa jeszcze zmian. Chmura pyłu wulkanicznego po wybuchu wulkanu Eyjafjallajökull na Islandii, znajdowała się nad Polską w dniach 17 do 20 kwietnia 2010 r. (Eyja-fjalla-jökull, znaczy wyspiarska turnia czapy lodowej). Badaliśmy czy zjawisko to wywiera wpływ na aktywność lotną pszczół. Badania prowadziliśmy w pasiece Pracowni Hodowli Owadów Użytkowych SGGW, w ciągu 2 dni, 17 i 20 kwietnia, gdy pył wulkaniczny znajdował się nad Polską i w ciągu 2 następnych dni 28 i 29 kwietnia, gdy pyłu nie było nad Polską. Obserwowaliśmy lot pszczół z 10 rodzin pszczelich. W ciągu 5 minut liczyliśmy pszczoły przylatujące do ula. Liczenia powtarzaliśmy 7 razy dziennie, w jednogodzinnych odstępach od godz. 10:00 do 16:00. Zwracaliśmy uwagę nie tylko na wpływ pyłu wulkanicznego na loty pszczół, lecz staraliśmy się również zbadać różnice aktywności lotnej pszczół z różnych rodzin w tym samym dniu jak i z tych samych rodzin w różnych dniach.

Stwierdziliśmy, że dzienny rozkład częstotliwości liczby lotów/5 min w ciągu dnia różnił się statystycznie istotnie między poszczególnymi rodzinami. Również dzienny rozkład częstotliwości liczby lotów/5 min w ciągu dnia wykonywany przez pszczoły z tych samych rodzin różnił się statystycznie istotnie między kolejnymi dniami.

Średnia liczba lotów/5 min wykonywanych przez pszczoły tego samego dnia różniła się statystycznie istotnie między poszczególnymi rodzinami. Również średnia liczba lotów/5 min wykonywanych przez pszczoły z tych samych rodzin różniła się statystycznie istotnie między kolejnymi dniami.

Ogólna średnia dzienna liczba lotów pszczół wykonywanych w różnych dniach różniła się statystycznie istotnie. Aktywność lotna pszczół, w czasie dwu dni, kiedy niebo pokrywała chmura wulkanicznych pyłów zmniejszyła się o 9%.

Słowa kluczowe: chmura wulkaniczna, wulkan Eyjafjallajökull, loty pszczół, aktywność lotna pszczół.