

Annual pollen spectrum variations in the air of Bratislava (Slovakia): years 2002–2009

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Abstract Pollen grains in the atmosphere of Bratislava were quantitatively and qualitatively analysed during an 8-year period (2002–2009) using a Burkard volumetric pollen trap. The mean annual total pollen grain count recorded during this period was 36,608, belonging to 34 higher plant taxa (22 trees and/or shrubs and 12 herbaceous species). The maximum annual total pollen grain count (50,563) was recorded in 2003 and the minimum (14,172) in 2009. The taxa contributing the highest concentration of pollen grains were *Betula*, *Urticaceae*, *Cupressaceae*-*Taxaceae*, *Populus*, *Pinus*, *Poaceae* and *Ambrosia*. During the study period, there was a remarkable increase in the number of pollen grains from February to April, with the highest daily mean pollen counts recorded in April. Total pollen concentration began to decrease markedly in May, but there was a second increase between July and August, followed by a decrease in September. The timing and length of the pollen seasons varied. *Betula* and *Poaceae* showed a rather constant 2-year fluctuating rhythm. The relationships between airborne pollen concentration and meteorological variables were assessed. Based on these results, the first pollen calendar in Slovakia has been

constructed for the area of Bratislava, which provides a great deal of useful and important information.

Keywords Airborne pollen · Fluctuating rhythms · Meteorological parameters · Pollen calendar · Slovakia

1 Introduction

Pollen allergy belongs to the category of seasonal allergic diseases, and its occurrence is correlated to the blooming period of pollen-allergenic plants. In Central Europe, trees bloom in the spring, especially in March and April, causing health problems related to pollen released by various types of plants, including those belonging to the *Aceraceae*, *Betulaceae*, *Corylaceae*, *Fagaceae*, *Oleaceae*, *Salicaceae*, *Cupressaceae* and *Taxaceae* families (D'Amato et al. 2007). Grasses of the *Poaceae* family bloom later in the spring, from the second half of May up to the second half of June (D'Amato et al. 2007). Late summer–early autumn (August, September) is the time of year when weeds of the *Urticaceae* and *Asteraceae* families bloom (Jurko 1990). The identification of the type and time of release of pollen grains is useful information for patients suffering from allergic diseases.

A qualitative and quantitative analysis of the atmosphere of highly populated cities is essential. Many countries have constructed pollen calendars in

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order to evaluate pollen conditions in the atmosphere (Gawel et al. 1996; Giner et al. 2002; Abreu et al. 2003; Ballero and Maxia 2003; Gioulekas et al. 2004; García-Mozo et al. 2006; Docampo et al. 2007; Bilisik et al. 2008). The aim of the study reported here was to provide the first pollen calendar in Slovakia, namely, for the area of Bratislava, based on 8 years of sampling and to identify changes and fluctuations in atmospheric pollen and the main pollen seasons for the most important pollen types.

The results of our study may provide that will be data useful for research on pollen allergens, particularly in terms of healthcare and improving prophylaxis for pollen allergies.

2 Materials and methods

The study was carried out in the city of Bratislava, in the southwestern part of Slovakia (Fig. 1). Bratislava (48°10'N, 17°10'E) is bounded by the Malé Karpaty Mountain to the west, running SW–NE. To the southeast, the alluvial plains extend down to the Danube river.

Bratislava has a warm and dry lowland climate, with average temperatures ranging from -1 to -4°C in January and from 19.5 to 20.5°C in July. The

average annual rainfall varies from 530 to 650 mm, falling mostly in the summer (May–July); there is relatively less rain in the spring. There are, on average, 966 h of sunshine per year.

The daily mean pollen concentrations were monitored from February to October over eight growing seasons, 2002–2009 using a Burkard 7-day volumetric pollen trap. The sampler was situated on the flat roof of the Department of Botany, Comenius University in northwest Bratislava (Fig. 1) at a height of 10 m above ground level (183 m a.s.l.). This sampler records pollen concentrations as 2-h samples, and we converted these values to daily mean pollen concentrations for use in our analysis. We used the 12-traverse transect method to count the pollen grains in a daily sample. Pollen concentrations were expressed as the number of pollen grains in 1 m^3 of air. The pollen grains were identified according to Erdtman (1969) using an optical microscope.

The pollen calendar was constructed following the technique adopted by Spieksma (1991): daily mean pollen concentrations of 10-day periods were summed and averaged over the 8-year study period. These average sums were placed in exponential classes (Spieksma 1991) and depicted by column growth heights in the calendar.

The main pollen seasons (MPS) of selected pollen types were established according of method by Nilsson and Persson (1981), which defines the main pollen season as the period from which the sum of concentrations reaches 5% of the annual total pollen until the time when the sum reaches 95%.

Based on data collected at the meteorological station Bratislava-Mlynská dolina (Fig. 1) during the period from 2002 to 2009, we assessed what we considered to be the four most important meteorological variables affecting the quantity of pollen grains in the atmosphere pollen, namely, mean temperature ($^{\circ}\text{C}$), relative humidity (%), rainfall (mm) and mean wind speed (m/s). Pearson's correlation coefficient was used to establish the relationship between the daily pollen concentration of selected pollen types (MPS and pre-peak period were considered) and meteorological parameters. The correlations were calculated for the whole study period (2002–2009). In order to eliminate the influence of annual variations in pollen concentrations, daily mean pollen concentrations were standardised by calculating their percentage on the cumulative yearly pollen

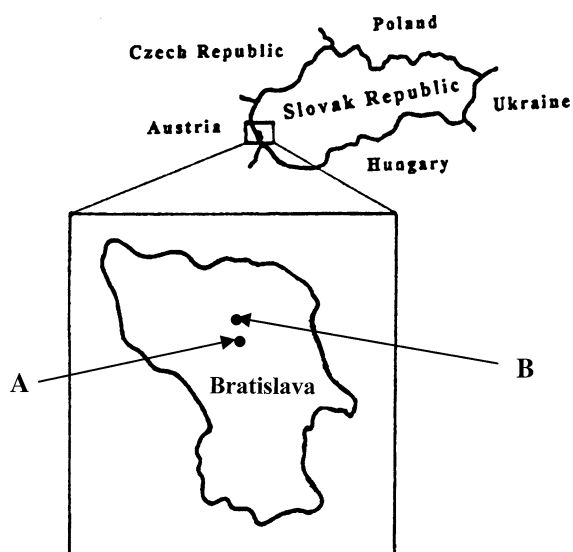


Fig. 1 Geographical localisation of pollen monitoring station and meteorological observatory in Bratislava. *A* Monitoring station, *B* meteorological observatory

concentrations according to the formula adopted by Emberlin and Norris-Hill (1991):

$$x_s = (1000 \times x) / \Sigma x$$

where x is the daily mean pollen concentration, x_s is the standardised concentration and Σx is the cumulative annual pollen concentration. A logarithmic transformation was used for both pollen concentration [$\log(x + 1)$] and for standardised pollen concentration [$\log(x_s + 1)$] in order to normalise their distributions. The 2004 SPSS software package (SPSS, Chicago, IL) was used for all statistical analyses.

3 Results

The total number of sampled pollen grains (sum of the daily mean pollen concentrations for the 8-year period) in the atmosphere of Bratislava was 292,823, of which 189,707 (65% of the total) originated from arboreal plant types and 103,116 (35%) from non-arboreal plant types (Table 1). The identified pollen grains belong to 34 taxa, including 22 tree and/or shrub and 12 herbaceous species (Table 1). All of the pollen types are individually reported in the pollen calendar (Table 2). Most pollen types appeared every year, except for *Aesculus* (appeared from 2002 to 2007 and in 2009), *Ailanthus* (appeared in 2002, 2003 and 2004), Apiaceae (from 2002 to 2007), *Castanea* (from 2002 to 2005 and in 2007), Cyperaceae (2002, 2003, 2008 and 2009), *Juniperus* (2002 and 2003), *Larix* (2002, 2003, 2004, 2006 and 2007) and Rosaceae (from 2002 to 2005). The average annual total pollen count (2002–2009) was 36,608 pollen grains, with the maximum annual total pollen grain count (50,563) recorded in 2003 and the minimum (14,172) in 2009 (Table 1).

On the basis of the mean annual total pollen counts for the 8-year period (Table 1), we identified the most abundant pollen types in the air of Bratislava to be: *Betula* (23.38% of the total), Urticaceae (18.84%), Cupressaceae–Taxaceae (9.93%), *Populus* (6.41%), *Pinus* (6.28%), Poaceae (5.11%), *Ambrosia* (4.51%), *Alnus* (3.76%), *Fraxinus* (3.65%) and *Artemisia* (2.18%). The mean annual total pollen count during the 8-year period for each of these pollen types was >700 grains. Pollen types from *Ailanthus*, Apiaceae, Asteraceae, *Castanea*, Cyperaceae, *Juniperus*, *Larix*,

Platanus and Rosaceae (altogether 1.65% of the total) were relatively less well represented (mean annual total pollen count <100 pollen grains) in the air of Bratislava.

Our data hint at certain seasonal differences in the concentrations of pollen grains in the atmosphere of Bratislava during the eight pollen seasons (2002–2009). Differences in the timing and severity of the pollen seasons between years were observed. The most important pollen contributors were Urticaceae, *Betula* and *Populus* in 2002 and 2005; *Betula*, Urticaceae and Cupressaceae–Taxaceae in 2004 and 2006; Urticaceae, *Betula* and *Alnus* in 2003; *Betula*, Cupressaceae–Taxaceae and Urticaceae in 2007; *Betula*, Cupressaceae–Taxaceae and *Alnus* in 2008; Urticaceae, *Pinus* and Poaceae in 2009 (Table 1).

For the taxa flowering in the spring (March and April), in particular *Alnus*, *Betula*, *Carpinus*, *Corylus*, *Fraxinus*, *Populus*, *Quercus*, *Salix* and Cupressaceae–Taxaceae, the highest level of pollen grains was recorded in 2006—a total pollen grain count of 28,757 (Fig. 2)—corresponding with the most suitable weather conditions for pollen release (from March to April 2006 there were 31 days with mean temperatures >10°C and total precipitation of 65 mm) within the whole period analysed (average: 21 days and 92 mm, respectively). The highest total pollen count for taxa optimally flowering during the summer (from May to July), such as Poaceae, *Pinus*, *Plantago* and Urticaceae, occurred in 2002—19,178 in total—corresponding with the most suitable weather conditions for pollen release (from May to July 2003 there were 52 days with mean temperatures >20°C and total precipitation of 160 mm) within the whole period analysed (average: 40 days and 202 mm, respectively). In the autumn (August, September), pollen grains of the synanthropic and ruderal plants (in particular, *Ambrosia*, *Plantago*, Urticaceae) were generally seen. In comparison with the spring and summer period, the concentration of pollen grains was much lower in the autumn and there was a smaller year-to-year variability.

There was a remarkable increase in the number of pollen grains from February to April (Fig. 3), with the highest mean concentration of pollen grains recorded in April (13,460 pollen grains, 37% of total) and arboreal taxa flowering in spring being the most important contributors. The pollen concentration began to decrease sharply in May, followed by a

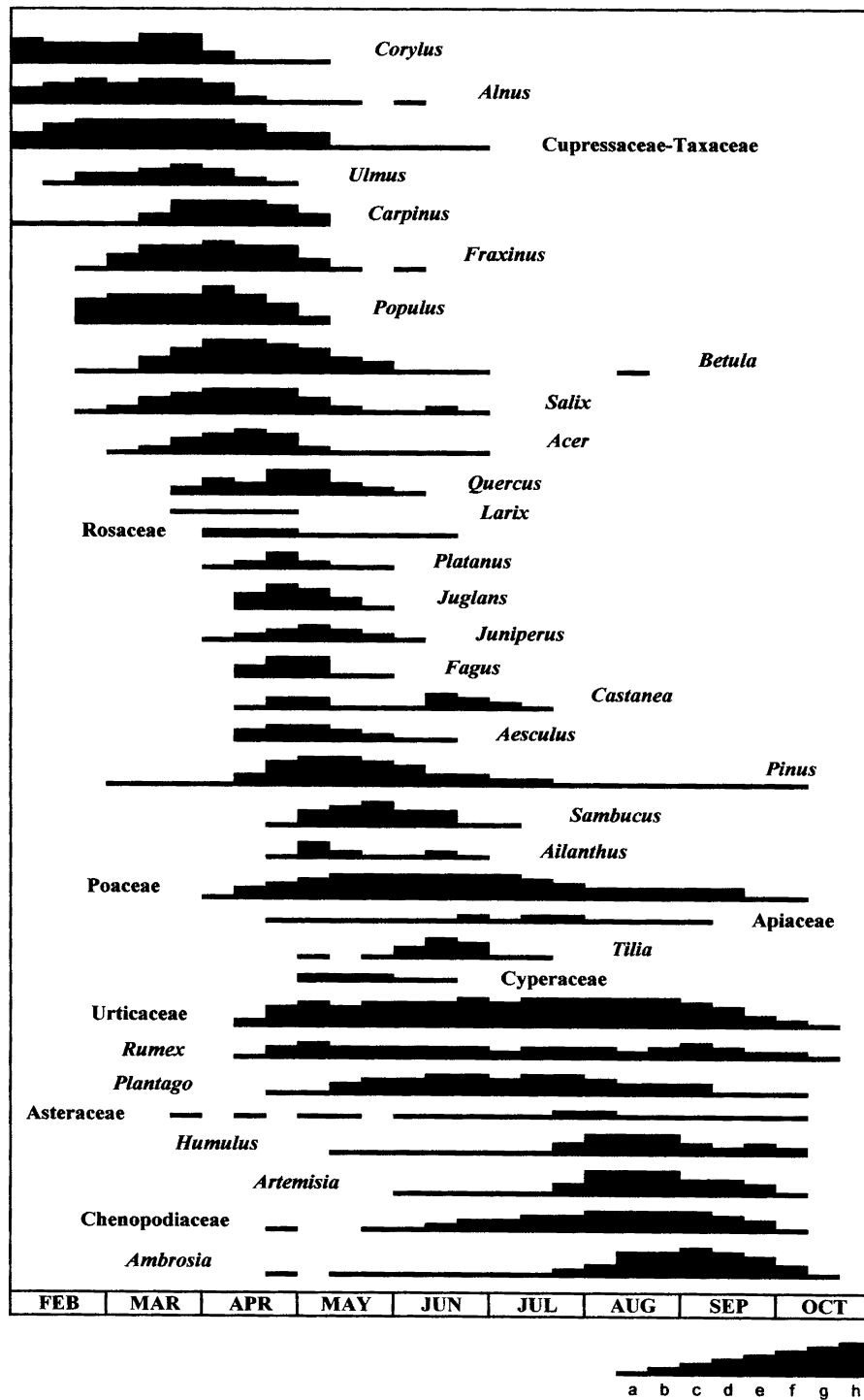
Table 1 Annual total pollen grain count of all pollen types found in the atmosphere of Bratislava, with their mean values and percentages, during the period 2002–2009

Taxa/pollen		Annual total pollen grain count								Mean (2002–2009)	Percentage of total (2002–2009)
Pollen-producing taxa	Pollen type ^a	2002	2003	2004	2005	2006	2007	2008	2009		
<i>Acer</i>	A	117	137	219	410	196	878	339	127	303	0.83
<i>Aesculus</i>	A	80	41	2	79	228	299	0	213	118	0.32
<i>Ailanthus</i>	A	177	284	7	0	0	0	0	0	59	0.16
<i>Alnus</i>	A	444	3,816	1,631	539	1,266	559	2,668	90	1,377	3.76
<i>Ambrosia</i>	NA	2,536	1,492	1,750	2,113	2,244	1,213	816	1,051	1,652	4.51
Apiaceae	NA	57	93	137	16	43	27	0	0	47	0.13
<i>Artemisia</i>	NA	941	874	885	596	542	1,004	574	954	796	2.18
Asteraceae	NA	34	44	57	10	45	74	20	42	41	0.11
<i>Betula</i>	A	4,480	7,041	11,593	5,416	18,538	8,226	12,123	1,040	8,557	23.38
<i>Carpinus</i>	A	95	538	344	662	1,052	1,037	1,711	247	711	1.94
<i>Castanea</i>	A	424	225	20	6	0	106	0	25	101	0.28
Chenopodiaceae	NA	528	900	270	369	279	486	375	417	453	1.24
<i>Corylus</i>	A	314	660	379	524	870	447	611	223	504	1.38
Cupressaceae–Taxaceae	A	1,534	2,696	4,189	3,723	3,428	7,909	4,702	891	3,634	9.93
Cyperaceae	NA	23	10	0	0	0	0	303	303	80	0.22
<i>Fagus</i>	A	10	618	184	113	150	176	122	76	181	0.49
<i>Fraxinus</i>	A	2,531	3,187	1,099	959	1,827	530	381	183	1,337	3.65
<i>Humulus</i>	NA	480	814	259	482	196	3	7	6	281	0.77
<i>Juglans</i>	A	62	186	153	239	127	636	537	436	297	0.81
<i>Juniperus</i>	A	235	382	0	0	0	0	0	0	77	0.21
<i>Larix</i>	A	1	10	17	0	48	23	0	0	12	0.03
<i>Pinus</i>	A	2,222	3,070	1,875	1,803	2,765	2,431	2,023	2,189	2,297	6.28
<i>Plantago</i>	NA	547	523	293	879	216	425	389	474	468	1.28
<i>Platanus</i>	A	32	166	45	36	34	29	11	11	46	0.12
Poaceae	NA	2,207	2,430	1,039	2,436	1,757	2,527	1,466	1,087	1,869	5.11
<i>Populus</i>	A	2,922	3,593	1,980	5,010	2,404	1,655	983	225	2,347	6.41
<i>Quercus</i>	A	853	1,875	174	693	579	185	173	74	576	1.57
Rosaceae	NA	40	20	92	45	0	0	0	0	25	0.07
<i>Rumex</i>	NA	427	517	96	472	383	284	131	158	309	0.84
<i>Salix</i>	A	1,266	842	297	321	231	620	274	141	499	1.36
<i>Sambucus</i>	A	187	451	213	385	73	698	465	294	346	0.94
<i>Tilia</i>	A	47	167	20	161	49	181	223	223	134	0.37
<i>Ulmus</i>	A	189	365	239	47	198	72	311	7	179	0.49
Urticaceae	NA	10,401	12,496	5,355	11,715	4,394	5,320	2,513	2,965	6,895	18.84
Total		36,443	50,563	34,913	40,259	44,162	38,060	34,251	14,172	36,608	

^a A arboreal plants (trees and shrubs), NA non-arboreal plants (herbs)

second increase in the number of pollen grains from July to August due to the flowering of non-arboreal taxa. In September, the pollen concentration once again started to decrease (Fig. 3).

In February and March, the most abundant pollen types in the air of Bratislava were those of Cupressaceae–Taxaceae and *Alnus* (Table 2). In April, *Betula* pollen type was dominant, partially due to the

Table 2 Pollen calendar for the pollen types collected in the Bratislava atmosphere and related 10-day means of the daily mean pollen concentrations^a

(^aConcentration of pollen grains (in pollen/m³) a: 1–5 pollen/ m³, b: 6–10, c: 11–25, d: 26–50, e: 51–99, f: 100–500, g: 501–1,000, h: > 1,000 pollen/ m³)

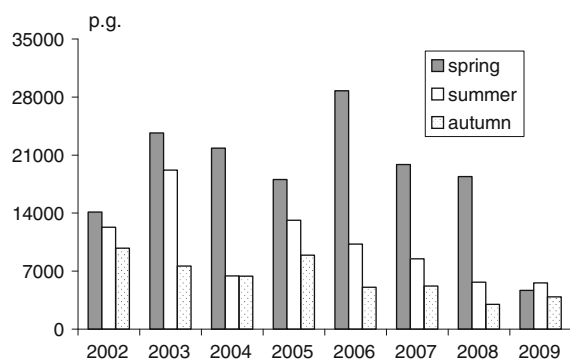


Fig. 2 Annual total pollen found in the atmosphere of Bratislava in the spring (March, April), summer (May–July) and autumn (August, September)

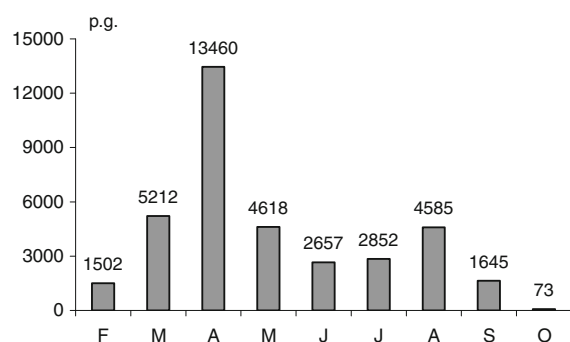


Fig. 3 Monthly pollen average counts (2002–2009) in the atmosphere of Bratislava

presence of trees of *Betula pendula* growing in the region; *Populus* and *Fraxinus* plants were also important pollen contributors in April. The very noticeable remarkable decrease in pollen concentration in May was closely related to the ending of the MPS of most trees and the fact that taxa of Poaceae and Urticaceae families did not flower optimally at this time. In May pollen grains of *Pinus* were the most abundant in the atmosphere of Bratislava. The most frequent pollen grains recorded in June were those of the Poaceae family, while in July and August the dominant pollen types were of the synanthropic and ruderal entities, such as Urticaceae and *Artemisia*. *Ambrosia* pollen reached its maximum level in September (Table 2).

We recorded some between-year fluctuations in terms of the dates of the beginning and end of the MPS, season length and daily maximum values for the ten most abundant pollen types (Table 3). For example, the Cupressaceae–Taxaceae pollen season started

on 9 February in 2007 and on 30 March in 2006. The smallest oscillations were shown by *Ambrosia* taxa, with a between-year variability in the beginning of the pollen season of less than 2 weeks. There were also some differences in the length of the pollen seasons. For example, the length of the Poaceae pollen season was 109 days in 2006 and only 63 days in 2002. The longest pollen season was that of the Urticaceae—110 days on. We noted the highest daily pollen concentrations with the following taxa: *Betula*, Cupressaceae–Taxaceae, *Populus*, *Fraxinus*, *Alnus*, *Pinus*, Urticaceae, *Ambrosia*, Poaceae and *Artemisia* (Table 3).

Variability among pollen seasons either in terms of the timing or quantitatively corresponded with the biological rhythms of the plants and meteorological conditions. The data for the annual total pollen for ten taxa with the most abundant pollen grains in the air of Bratislava are shown in Fig. 4. Visual examination of this figure reveals a 2-year cycle between 2003 and 2009 (7 years), with the exception of one small lapse in 2002 for *Betula*, and a 2-year fluctuating rhythm between 2002 and 2008 (7 years), with the exception of one lapse in 2009 for Poaceae.

Pearson's correlation coefficients between the logarithmic standardised daily mean pollen concentrations of the eight main pollen types (four arboreal and four non-arboreal) and the selected daily meteorological parameters were assessed both during MPS and pre-peak period for the whole study period (2002–2009). In both cases, negative correlations were found between the daily mean pollen concentrations and relative humidity for all these pollen types (Table 4). However, significant positive correlations were found between the daily mean pollen concentrations of all eight main pollen types and temperatures during MPS; during the pre-peak period, the correlations were also significant, with the exception of *Artemisia*. Only a few negative correlations with rainfall and wind speed were found.

4 Discussion

The average annual total pollen count in the atmosphere of Bratislava during the study period (2002–2009) was 36,608 pollen grains. The identified pollen grains were identified as belonging to 34 higher plant taxa, including 22 trees and/or shrubs and 12

Table 3 Characteristics of the main pollen seasons of taxa with the highest recorded daily pollen concentrations (2002–2009) in the atmosphere of Bratislava

Characteristics of pollen-producing taxa		Study year								
Taxa	Characteristics ^a	2002	2003	2004	2005	2006	2007	2008	2009	
<i>Alnus</i>	PS	2 March–18 April	10 March–4 April	21 Feb–21 March	17 March–1 April	19 March–1 April	10 Feb–12 March	6 Feb–2 March	10 March–3 April	
	SL	48	26	30	16	14	31	26	25	
	Max	64 (19 March)	463 (12 March)	314 (19 March)	125 (31 March)	279 (28 March)	71 (12 Feb)	457 (23 Feb)	9 (16 March)	
<i>Ambrosia</i>	PS	15 Aug–10 Sept	8 Aug–27 Sept	16 Aug–17 Sept	20 Aug–16 Sept	20 Aug–19 Sept	15 Aug–24 Sept	12 Aug–19 Sept	11 Aug–21 Sept	
	SL	27	51	33	28	31	41	39	42	
	Max	286 (27 Aug)	216 (7 Sept)	174 (10 Sept)	332 (6 Sept)	243 (7 Sept)	156 (21 Aug)	57 (21 Aug)	57 (28 Aug)	
<i>Artemisia</i>	PS	1 Aug–9 Sept	18 July–8 Sept	31 July–26 Aug	5 Aug–26 Sept	2 Aug–24 Sept	3 Aug–26 Aug	4 Aug–9 Sept	2 Aug–15 Sept	
	SL	40	53	27	53	54	24	37	45	
	Max	108 (15 Aug)	64 (9 Aug)	87 (11 Aug)	69 (19 Aug)	64 (19 Aug)	129 (14 Aug)	60 (15 Aug)	53 (15 Aug)	
<i>Betula</i>	PS	19 March–27 April	5 April–1 May	4 April–24 April	6 April–22 April	10 April–6 May	2 April–18 April	29 March–16 April	7 April–3 May	
	SL	40	27	21	17	27	17	19	27	
	max	736 (2 April)	931 (23 April)	2,326 (11 April)	1,255 (8 April)	3,087 (16 April)	1,369 (3 April)	2,447 (6 April)	81 (8 April)	
Cupressaceae—Taxaceae	PS	4 March–14 April	18 March–29 April	16 March–10 April	22 March–7 April	30 March–6 May	9 Feb–1 April	22 Feb–17 March	16 March–20 April	
	SL	42	43	26	17	38	52	25	36	
	Max	281 (5 March)	402 (27 March)	1,241 (18 March)	751 (26 March)	516 (9 April)	1,724 (6 March)	1,486 (24 Feb)	86 (23 March)	
<i>Fraxinus</i>	PS	6 March–23 April	28 March–24 April	20 March–24 April	29 March–25 April	10 April–23 April	14 March–16 April	1 March–7 April	25 March–17 April	
	SL	49	28	36	28	14	34	38	24	
	Max	321 (3 April)	496 (30 Mar)	175 (11 April)	223 (8 April)	413 (10 April)	56 (1 April)	37 (23 March)	42 (5 April)	
<i>Pinus</i>	PS	2 May–30 May	30 April–4 June	13 May–7 June	9 May–10 June	4 May–4 June	28 April–24 May	20 April–30 May	21 April–29 May	
	SL	29	36	26	33	32	27	41	39	
	Max	434 (15 May)	379 (9 May)	25 (16 May)	311 (19 May)	346 (23 May)	257 (7 May)	145 (7 May)	109 (5 May)	
Poaceae	PS	11 May–12 July	13 May–17 July	17 May–17 Aug	21 May–3 Aug	18 May–3 Sept	24 April–21 July	27 April–23 July	28 April–3 Aug	
	SL	63	66	93	75	109	89	88	98	
	Max	208 (18 May)	95 (24 May)	106 (27 May)	118 (18 June)	76 (8 June)	158 (23 May)	75 (26 May)	25 (15 May)	
<i>Populus</i>	PS	4 March–2 April	26 March–17 April	18 March–16 April	3 April–20 April	31 March–16 April	4 March–13 April	25 Feb–24 April	28 March–23 April	
	SL	30	23	30	18	17	41	60	27	
	Max	360 (15 March)	579 (1 April)	220 (21 March)	1,302 (6 April)	926 (9 April)	140 (14 March)	152 (1 March)	33 (8 April)	
Urticaceae	PS	6 June–3 Sept	7 May–26 Aug	11 June–29 Aug	4 June–3 Sept	10 May–27 Aug	27 April–1 Sept	28 April–8 Sept	28 April–9 Sept	
	SL	90	112	80	92	110	128	134	135	
	Max	297 (8 Aug)	424 (19 July)	439 (11 Aug)	408 (25 June)	320 (21 June)	158 (16 Aug)	78 (15 Aug)	60 (4 Aug)	

^a PS start and ending dates, respectively, SL length of pollen season, Max maximum daily mean pollen concentrations (pollen/ m³) and its date (in parenthesis)

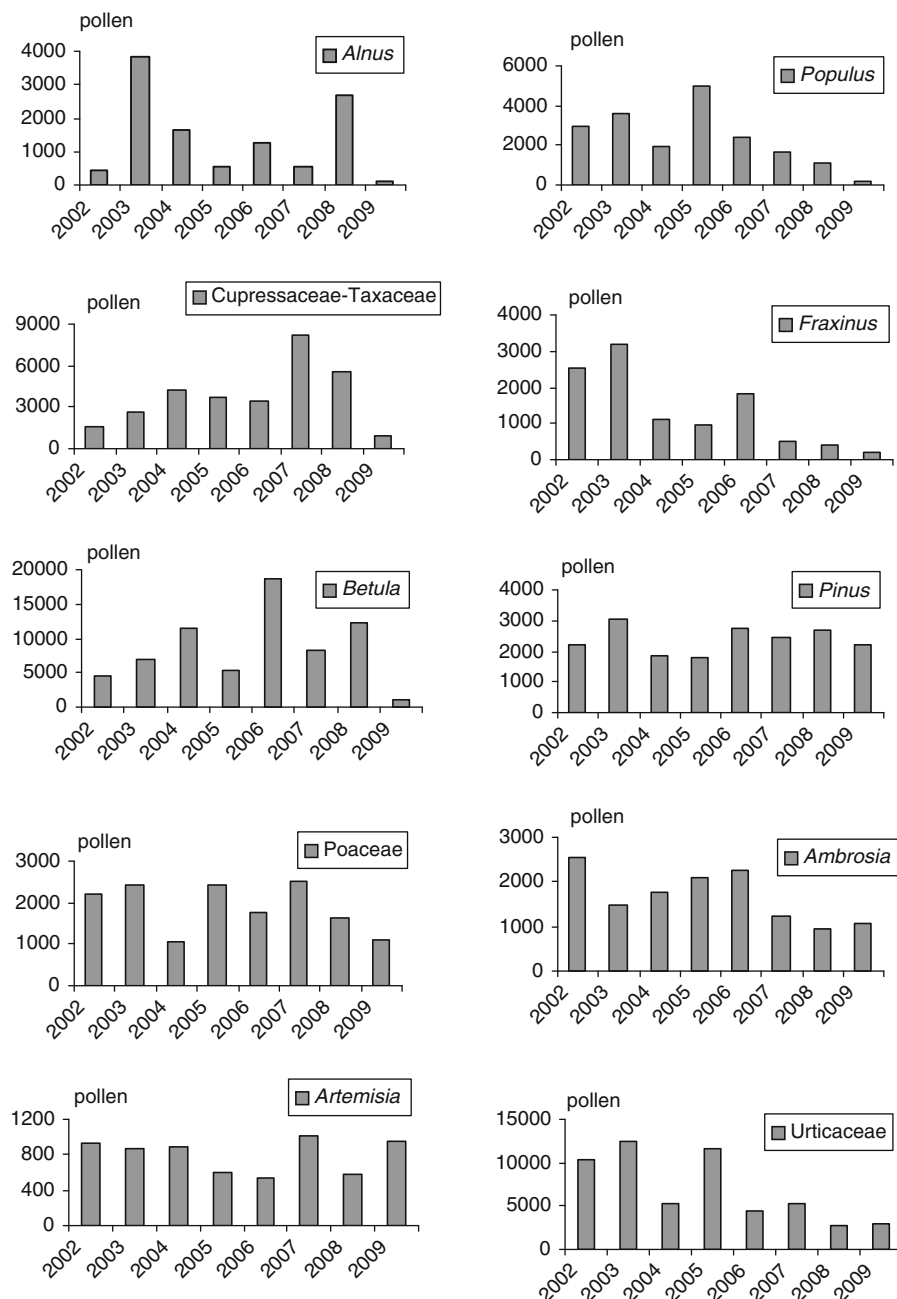


Fig. 4 Annual total pollen counts of the ten most abundant pollen types found in the atmosphere of Bratislava in 2002–2009

herbaceous species, with 65% of the total pollen produced by arboreal plants and 35% produced by non-arboreal plants. The high level of arboreal pollen is likely due to the fact that trees produce more pollen than non-arboreal plants and there was an abundance of diverse tree sorts in the area.

Based on the annual total mean for each pollen type, we identified the most common pollen types in the air of Bratislava, in decreasing order, to be: *Betula*, Urticaceae, Cupressaceae–Taxaceae, *Populus*, *Pinus*, Poaceae, *Ambrosia*, *Alnus*, *Fraxinus* and *Artemisia*. This composition broadly reflects the local vegetation,

Table 4 Pearson's correlation coefficients between logarithmic standardised daily mean pollen concentrations and daily meteorological variables both for the MPS and pre-peak period

during 2002–2009 for the eight main pollen types (four arboreal and four non-arboreal)

Taxa	Pollen season	df	T_{mean}	H_{rel}	R	WS_{mean}
<i>Alnus</i>	MPS	214	0.270***	−0.242***	−0.041	−0.003
	Pre-peak	157	0.304***	−0.185*	−0.177*	−0.059
<i>Fraxinus</i>	MPS	249	0.151*	−0.187**	−0.187	0.022
	Pre-peak	168	0.346***	−0.251***	−0.136	−0.044
<i>Populus</i>	MPS	244	0.201**	−0.345***	−0.046	0.008
	Pre-peak	103	0.346***	−0.426***	−0.147	−0.057
Cupressaceae—Taxaceae	MPS	277	0.140*	−0.126*	−0.086	−0.013
	Pre-peak	141	0.455***	−0.240**	−0.238**	−0.030
<i>Ambrosia</i>	MPS	290	0.223***	−0.171**	−0.100	0.221***
	Pre-peak	181	0.162*	−0.149*	−0.072	−0.001
<i>Artemisia</i>	MPS	331	0.334***	−0.220***	0.009	−0.032
	Pre-peak	151	0.082	−0.093	0.124	−0.133
Poaceae	MPS	679	0.129**	−0.235***	−0.112*	0.048
	Pre-peak	270	0.440***	−0.107	−0.009	0.058
Urticaceae	MPS	879	0.407***	−0.239***	0.044	−0.084*
	Pre-peak	437	0.386***	−0.355***	−0.066	−0.057

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ MPS Main pollen season, T_{mean} mean daily temperature, H_{rel} relative humidity, R daily rainfall, WS_{mean} mean wind speed, df degrees of freedom

which consists of natural woodlands surrounding the town and anthropogenic formations within the city itself. One-fifth of the annual total pollen originated from natural woodlands in general and from the Carpathian oak–hornbeam forests and fragments of softwood and hardwood alluvial forests in particular. Almost 45% of the annual total pollen was produced by trees introduced either for ornamental purposes (*Acer*, *Aesculus*, *Ailanthus*, *Betula*, *Juniperus*, *Platanus*, Cupressaceae–Taxaceae, *Tilia*) or for other economic reasons (*Castanea*, *Juglans*, *Corylus*). The main herbaceous pollen types, basically corresponding to weeds, reached almost 35% of the total airborne pollen amount, with the highest values recorded for Urticaceae, Poaceae, *Ambrosia* and *Artemisia*.

Variability among pollen seasons, either in terms of timing or quantitatively, was found to correspond with the biological rhythms of the plants and meteorological conditions. With respect to biological rhythms, several authors (Hyde 1952; Andersen 1980; Nilsson and Persson 1981; Atkinson and Larsson 1990; Emberlin et al. 1990, 1993; Jäger et al. 1991; Detandt and Nolard 2000) hint at the possibility of cyclic alternation in pollen grain production, with years of

high and low production, respectively. We recorded 2-year cycles between 2003 and 2009 (7 years), with the exception of one small lapse in 2002 for *Betula*. This finding is with consist with the results reported by most of the above-mentioned authors in different European countries. However, Detandt and Nolard (2000) observed a 3-year cycle in the pollen production of *Betula* in Belgium. We also found a 2-year fluctuating rhythm between 2002 and 2008 (7 years), with the exception of one lapse in 2009 for Poaceae. Jäger et al. (1991) observed year-to-year alternations in the production of Poaceae pollen in Leiden during a 7-year period and in Vienna during a 6-year period.

Meteorological factors, particularly mean temperature, relative humidity, rainfall and wind speed, directly influence the release of pollen from anthers and its dispersal throughout the atmosphere. Sunny and warm weather generally correspond with higher pollen production (Hyde 1950a, b; Davies and Smith 1973), although a long-lasting dry period may, conversely, have a negative effect due to stress on the plants. Cold and humid weather dampen the production of pollen as rainfall directly removes pollen grains from the atmosphere.

Based on our analysis of the eight main pollen types (Table 4), the correlations between daily mean pollen concentrations and relative humidity were always negative for both the MPS and pre-peak period, as also found by Ribeiro et al. (2003), Stennet and Beggs (2004) and Rizzi-Longo et al. (2007). Other researchers have reported significant positive correlations between the daily mean pollen concentrations and temperatures, both during the MPS and the pre-peak period (Jato et al. 2002, Rodríguez-Rajo et al. 2003, Ribeiro et al. 2003, Stennet and Beggs 2004, Angosto et al. 2005). Contrary to our findings, Ballero and Maxia (2003) and Rizzi-Longo et al. (2007) observed negative correlations between total daily pollen concentrations and temperatures during the MPS. In contrast to results reported earlier (Ribeiro et al. 2003, Stennet and Beggs 2004, Angosto et al. 2005), we often found a negative correlation between total daily pollen concentrations and wind speed. In Bratislava, the strong local winds (Konček 1979) have a dilution impact on pollen concentration, as reported by Valencia-Barrera et al. (2001) and Rizzi-Longo et al. (2007). The correlations with rainfall were more often negative, but weak, as found by Barnes et al. (2001). According to these latter authors, rainfall, with the exception of heavy and intense rain, does not markedly influence the amount of pollen in the atmosphere. The correlations may be higher if shorter time periods were to be considered, which would allow us to precisely establish the number of pollen grains during hours of rain and hours with no rain, respectively.

5 Conclusions

The results of our 8-year study contribute to our knowledge of the composition of the pollen aerosol of the city of Bratislava.

For the first time in Slovakia, a pollen calendar has been constructed for the area of Bratislava for 34 higher plant taxa. The most abundant types in the air of Bratislava were identified to be: *Betula*, *Urticaceae*, *Cupressaceae*–*Taxaceae*, *Populus*, *Pinus*, *Poaceae*, *Ambrosia*, *Alnus*, *Fraxinus* and *Artemisia*. It can be concluded that Bratislava receives a large portion of its aerosol pollen from a number of ornamental trees and shrubs introduced into the urban area.

The highest concentrations of pollen grains were recorded in April, when the climate conditions are

favourable for a large release of pollen grains. For *Betula*, *Poaceae* and *Urticaceae*, there appears to be a constant 2-year fluctuating rhythm.

Total daily pollen concentrations of the eight main pollen types in Bratislava are positively correlated with temperature and negatively correlated with relative humidity in both the MPS and pre-peak period. Rainfall and wind speed often show negative correlations with pollen counts.

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References

- Abreu, I., Ribeiro, H., & Cunha, M. (2003). An aeropalynological study of the Porto region (Portugal). *Aerobiologia*, 19, 235–241.
- Andersen, S. T. (1980). Influence of climatic variation on pollen season severity in wind-pollinated trees and herbs. *Grana*, 19, 47–52.
- Angosto, J. M., Moreno-Grau, S., Bayo, J., & Elvira-Rendueles, B. (2005). Multiple regression models for predicting total daily pollen concentration in Cartagena. *Grana*, 44, 108–114.
- Atkinson, H., & Larsson, K. A. (1990). A 10 year record of the arboreal pollen in Stockholm, Sweden. *Grana*, 29, 229–237.
- Ballero, M., & Maxia, A. (2003). Pollen spectrum variations in the atmosphere of Cagliari, Italy. *Aerobiologia*, 19, 251–259.
- Barnes, Ch., Pacheco, F., Landuyt, J., Hu, F., & Portnoy, J. (2001). The effects of temperature, relative humidity and rainfall on airborne ragweed pollen concentrations. *Aerobiologia*, 17, 61–68.
- Bilisik, A., Yenigun, A., Bicakci, A., Eliacik, K., Canitez, Y., Malyer, H., et al. (2008). An observation study of airborne pollen fall in Didim (SW Turkey): years 2004–2005. *Aerobiologia*, 24, 61–66.
- D'Amato, G., Cecchi, L., Bonini, S., Nunes, C., Annesi-Maesano, I., Behrendt, H., et al. (2007). Allergenic pollen and pollen allergy in Europe. *Allergy*, 62, 976–990.
- Davies, R. R., & Smith, L. P. (1973). Weather and the grass pollen content of the air. *Clinical Allergy*, 3, 95–108.
- Detandt, M., & Nolard, N. (2000). The fluctuations of the allergenic pollen content of the air in Brussels (1982 to 1997). *Aerobiologia*, 16, 55–61.
- Docampo, S., Recio, M., Trigo, M. M., Melgar, M., & Cabezudo, B. (2007). Risk of pollen allergy in Nerja (southern Spain): a pollen calendar. *Aerobiologia*, 23, 189–199.
- Emberlin, J., & Norris-Hill, J. (1991). Annual, daily and diurnal variation of *Urticaceae* pollen in North-central London. *Aerobiologia*, 7, 49–57.

- Emberlin, J., Norris-Hill, J., & Bryant, R. H. (1990). A calendar for tree pollen in London. *Grana*, 29, 301–309.
- Emberlin, J., Savage, M., & Woodman, R. (1993). Annual variations in the concentrations of *Betula* pollen in the London area, 1961–1990. *Grana*, 32, 359–363.
- Erdtman, G. (1969). *Handbook of palynology*. Munksgaard Copenhagen: An introduction to the study of pollen grains and spores.
- García-Mozo, H., Pérez-Badía, R., Fernández-gonzález, F., & Galán, C. (2006). Airborne pollen sampling in Toledo, Central Spain. *Aerobiologia*, 22, 55–66.
- Gawel, J., Halota, A., Pisiewicz, K., Kurzawa, R., Radliński, J., & Doniec, Z. (1996). Allergenic airborne sporomorphs calendar for Rabka (Southern Poland), 1991–1995. *Annals of Agricultural and Environmental Medicine*, 3, 87–98.
- Giner, M. M., García, J. S. C., & Camacho, C. N. (2002). Seasonal fluctuations of the airborne pollen spectrum in Murcia (SE Spain). *Aerobiologia*, 18, 141–151.
- Gioulekas, D., Balafoutis, Ch., Damialis, A., Papakosta, D., Gioulekas, G., & Patakas, D. (2004). Fifteen years' record of airborne allergenic pollen and meteorological parameters in Thessaloniki, Greece. *International Journal of Biometeorology*, 48, 128–136.
- Hyde, H. A. (1950a). Studies in atmospheric pollen. IV. A survey of pollen deposition in Great Britain. The influence of situation and weather. *New Phytologist*, 49, 398–406.
- Hyde, H. A. (1950b). Studies in atmospheric pollen. IV. A survey of pollen deposition in Great Britain. The composition of the pollen catch. *New Phytologist*, 49, 407–420.
- Hyde, H. A. (1952). Studies in atmospheric pollen. V. A daily census of pollen at Cardiff for the six years 1943–1948. *New Phytologist*, 51, 281.
- Jäger, S., Spieksma, F. T. M., & Nolard, N. (1991). Fluctuations and trends in airborne concentrations of some abundant pollen types, monitored at Vienna, Leiden and Brussels. *Grana*, 30, 309–312.
- Jato, V., Dopazo, A., & Aira, M. J. (2002). Influence of precipitation and temperature on airborne pollen concentration in Santiago de Compostela (Spain). *Grana*, 41, 232–241.
- Jurko, A. (1990). Sezonalita kvitnutia rastlín a peľové alergény v našej vegetácii/Flowering periods and pollen allergens in Slovak vegetation. *Biológia*, 45, 367–374.
- Konček, M. (Ed.). (1979). *Klíma a bioklíma Bratislavy/Climate and bioclimate of Bratislava*. Bratislava: Veda.
- Nilsson, S., & Persson, S. (1981). Tree pollen spectra in the Stockholm region (Sweden), 1973–1980. *Grana*, 20, 179–182.
- Ribeiro, H., Cunha, M., & Abreu, I. (2003). Airborne pollen concentration in the region of Braga, Portugal, and its relationship with meteorological parameters. *Aerobiologia*, 19, 21–27.
- Rizzi-Longo, L., Pizzulin-Sauli, M., Stravisi, F., & Ganis, P. (2007). Airborne pollen calendar for Trieste (Italy), 1990–2004. *Grana*, 46, 98–109.
- Rodríguez-Rajo, F. J., Jato, V., & Aira, M. J. (2003). Pollen content in the atmosphere of Lugo (NW Spain) with reference to meteorological factors (1999–2001). *Aerobiologia*, 19, 213–225.
- Spieksma, F. Th. M. (1991). Regional European pollen calendars. In G. D'Amato, F. Th. M. Spieksma, & S. Bonini (Eds.), *Allergenic pollen and pollinosis in Europe*. Oxford: Blackwell.
- Stennet, P. J., & Beggs, P. J. (2004). Pollen in the atmosphere of Sydney, Australia, and relationships with meteorological parameters. *Grana*, 43, 209–216.
- Valencia-Barrera, R. M., Comtois, P., & Fernández-González, D. (2001). Bibliography and bioclimatology in pollen forecasting. An example of grass in León (Spain) and Montréal (Canada). *Grana*, 40, 223–229.