

Airborne pollen of allergenic herb species in Toledo (Spain)

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Abstract This study analysed airborne pollen counts for allergenic herb taxa in Toledo (central Spain), a major tourist city receiving over 2 million visitors per year, located in the region of Castilla-La Mancha. The taxa selected were Chenopodiaceae–Amaranthaceae, *Plantago*, Poaceae and Urticaceae, all of which produce allergenic pollen giving rise to serious symptoms in pollen-allergy sufferers. Aerobiological data were recorded over a 6-year period (2005 to 2010) using the sampling and analysis procedures recommended by the Spanish Aerobiology Network. The abundance and the temporal (annual, daily and intradiurnal) distribution of these pollen types were analysed, and the influence of weather-related factors on airborne pollen counts was assessed. Pollen from herbaceous species accounted for 20.9% of total airborne pollen in Toledo, the largest contributor being Poaceae, with 8.5% of the total pollen count; this family was also the leading cause of respiratory allergies. Examination of intradiurnal variation revealed three distinct distribution patterns: (1) peak daily counts for Chenopodiaceae–Amaranthaceae and *Plantago* were recorded during the hottest part of the day, i.e. from 1400 to 1600 hours; (2) Urticaceae displayed two peaks (1400–1600 and 2200 hours); and (3)

Poaceae counts remained fairly stable throughout the day. Two main risk periods were identified for allergies: spring, with allergies caused by Urticaceae, *Plantago* and Poaceae pollen, and summer, due to Chenopodiaceae–Amaranthaceae pollen.

Keywords Aerobiology · Herbaceous pollen · Allergy · Central Spain

Introduction

The last few years have seen an increase in the prevalence and severity of pollen-induced respiratory disorders (Ishizaki et al. 1987, D'Amato et al. 2007), prompting a marked decline in quality of life for allergy-sufferers. Rhinitis is reported to affect up to 25% of the world's population, while up to 18% is thought to suffer from asthma (Bousquet et al. 2001); pollen is the major cause of both (Muñoz et al. 2008). In Spain, pollen is responsible for 40% of cases of rhinoconjunctivitis and 27% of asthma cases (Alergológica 2005). Most spring allergies are caused by olive trees and by a relatively limited number of herbaceous plants, including Poaceae (Alergológica 2005). Pollen-count monitoring has enabled identification of the local pollen types triggering respiratory allergies in a number of geographical areas (Carracedo et al. 2008; Aira et al. 2011), and pollen calendars have been used to establish the duration and intensity of local pollen seasons (D'Amato et al. 1998; Giorato et al. 2000, Ribeiro et al. 2008; Celenk et al.

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2010). This information is essential for the study and treatment of allergies: the exposure of allergy-sufferers to pollen on peak days can thereby be reduced, preventive measures can be taken and outdoor activities can be more reliably planned.

The study of airborne pollen counts is also of considerable ecological interest, enabling the successive flowering of different wind-pollinated species to be charted (Estrella et al. 2006); the information thus obtained can be used to analyse and monitor the effects of climate change on plant species (Beggs 2004, Fernández-González et al. 2005, Galán et al. 2005).

The contribution of herbaceous species to the overall airborne pollen spectrum varies considerably, depending both on local geographical features (Kasprzyk 2006) and on the diversity of plants and flowers in the surrounding area. In central Spain, herb species produce large amounts of pollen and Poaceae pollen is particularly abundant (Pérez-Badia et al. 2010a; Sabariego et al. 2010).

This paper reports on a study of airborne herbaceous pollen counts in Toledo. The taxa selected were Chenopodiaceae–Amaranthaceae, *Plantago*, Poaceae and Urticaceae and the aims of the study were: to analyse pollen-count dynamics; to compare annual, daily and intradiurnal variations and to determine the concentrations values to inform of risk of allergies to pollen-allergy sufferers.

Material and methods

Study area

Toledo (39° 51' N, 4° 01' W) is located at 529 m above sea level, in the large Castilla-La Mancha region, in central Spain (Fig. 1). It is a World Heritage city, and a major tourist venue, with over 2 million visitors every year. It has a population of around 83,000 inhabitants.

In bioclimatic terms, Toledo lies in the Mesomediterranean belt (Rivas-Martínez 2007). Mean annual temperature is 15.4°C. January is the coldest month (mean temperature 6.4°C) and July the warmest (mean 26°C). Mean annual rainfall is 382 mm. October is the wettest month (42 mm) and July the driest (8 mm; Ministerio de Medio Ambiente 2001). In biogeographical terms, Toledo is located in the Mediterranean Region (W Mediterranean Subregion) and, according to Rivas-Martínez (2007), on the boundary between two biogeographical provinces: the Mediterranean Central Iberian Province (Castilian Subprovince, Machean Sector) and the Mediterranean West Iberian Province (Lusitan-Extremadurean Subprovince, Toledan-Taganean Sector). The city is surrounded by cropland, mainly cereals and olive groves, and natural forest vegetation comprising mostly holm-oak stands (*Quercus ilex* L. subsp. *ballota* (Desf.) Samp.), shrubs and pasturelands alternating with meadows. Major Mediterranean scrub species

Fig. 1 Geographic situation of Toledo in central Spain



include *Cistus* spp., *Erica* spp., *Rosmarinus officinalis* L., *Thymus* spp. and *Lavandula stoechas* L. subsp. *pedunculata* (Miller) Samp. ex Rozeira, among others. Grasses, Urticaceae and Chenopodiaceae are the most characteristic herbaceous species in forest, ruderal and weed communities.

Airborne pollen and allergy risk

Airborne pollen was monitored over a 6-year period, from 2005 to 2010. A Hirst volumetric spore-trap (Hirst 1952) was used for aerobiological sampling. The trap was installed at around 17 m above ground level, on the campus of the University of Castilla-La Mancha, to the west of the city of Toledo. The sampler sucks in air at a rate of 10 l/min, and pollen grains are trapped on an adhesive-coated Melinex® strip. Sampling and analysis were carried out in accordance with the procedure recommended by the Spanish Aerobiology Network (Galán et al. 2007). Slides were analysed daily under a light microscope ($\times 400$ magnification), with 4 longitudinal sweeps per slide. Results were expressed as daily average number of pollen grains per cubic meter of air (grains/m³).

The Main Pollen Season, i.e. that portion of the pollen season during which most pollen is recorded, was calculated following Andersen (1991). This method includes 95% of the seasonal total pollen count, starting on the day by which 2.5% of total pollen has been recorded and ending on the day by which 97.5 % of total pollen has been registered. Intradiurnal variations in pollen counts were analysed following Galán et al. (1991). Results were represented graphically, showing bi-hourly percentage values, using official Spanish time (UTC +1 h during autumn and winter and UTC +2 h during spring and summer).

The risk of pollen allergy was calculated in terms of the number of days on which pollen counts exceeded the risk threshold established by the Spanish Aerobiology Network (Galán et al. 2007), modified by Pérez-Badia et al. (2011) for Chenopodiaceae–Amaranthaceae pollen, a few grains of which are widely considered sufficient to trigger symptoms in patients allergic to it. The term ‘moderately allergenic levels’ was thus used to denote counts for herbaceous taxa ranging from 15 to 30 pg/m³ (Urticaceae, Chenopodiaceae–Amaranthaceae) or 25 to 50 pg/m³ (*Plantago*, Poaceae). Values higher than these were considered to constitute ‘highly allergenic levels’.

Meteorological data and statistical analysis

Meteorological data were provided by the Toledo-Buenavista weather station, located 2 km from the spore trap, using the Spanish Meteorological Agency (AEMET) database. The following meteorological variables were subjected to statistical analysis: daily mean, maximum and minimum temperature (°C), rainfall (mm), hours of sunlight, atmospheric pressure (mb) and wind speed (m/s). The SPSS 15.0® software package was used for all statistical analyses. The correlation between meteorological variables and pollen counts during the pre-peak period, i.e. the period from the start of the season up to the peak day (the day on which the maximum daily pollen count was recorded), was analysed using a non-parametric Spearman’s correlation test, since data distribution was not normal.

Results

Over the 6-year period (2005–2010), a total of 382,352 pollen grains were recorded; of these, 79,871 grains (20.9%) were from herbaceous plants. A total of 14 herbaceous pollen types were identified. The highest total annual count for herbaceous-species pollen (17,245 pollen grains) was observed in 2007, whilst the lowest total count was recorded in 2005 (3,444 pollen grains; Table 1). Pollen from Poaceae, *Plantago*, Chenopodiaceae–Amaranthaceae and Urticaceae accounted for 77.3% (61,752 pollen grains) of the total herbaceous pollen count; all these taxa are leading causes of pollen allergy in central Spain (Subiza et al. 2007). The chief contributor in terms of overall abundance was Poaceae, whose pollen (32,806 pollen grains) accounted for 41.1% of the total herbaceous pollen and 8.5% of the total pollen count. It was followed by Urticaceae (19,519 pollen grains), which accounted for 24.4% of the total herbaceous pollen count, Chenopodiaceae–Amaranthaceae (5,202 pollen grains; 6.5% of total herbaceous pollen) and *Plantago* (4,225 pollen grains; 5.3% of total herbaceous pollen; Table 2).

Herbaceous pollen counts reached highest amounts between March and June (Fig. 2); an average of 84% of total herbaceous pollen was recorded over this period (Table 1). The highest monthly pollen count was noted in May in all study years except 2008, when June values were considerably higher (4,129 vs. 2,841 pollen grains). Spring rainfall (April–June) was

Table 1 Monthly and annual total herbaceous pollen counts, mean and percentages; monthly mean temperatures, T (°C), and rainfall, R (mm), over the study period (2005–2010)

	2005	2006	2007	2008	2009	2010	Mean	%	SE	2005			2006			2007			2008			2009			2010								
										T			R			T			R			T			R			T			R		
										T	R	T	T	R	T	R	T	T	R	T	R	T	T	R	T	R	T	T	R	T	T	R	T
Jan	30	115	169	96	69	52	88.5	0.8	24.9	4.8	0.2	5.6	18.4	6.2	8.3	8.3	13.7	5.9	16.8	6.3	58.3												
Feb	40	336	432	146	351	94	233.2	2.0	80.1	5.5	29.0	7.1	15.6	10.2	27.9	9.9	17.2	8.5	29.8	7.6	86.7												
Mar	83	1732	1847	1417	2032	625	1289.3	11.3	385.4	11.2	13.5	11.8	25.7	10.6	30.5	11.5	4.9	12.2	20.4	10.1	74.5												
Apr	434	2126	2725	2674	2142	3377	2246.3	19.7	500.0	14.6	6.9	15.6	38.6	13.3	92.0	14.6	65.9	13.0	22.8	15.1	58.3												
May	1429	5516	6818	2841	3739	4722	4177.5	36.6	964.2	20.0	8.9	20.6	22.9	17.2	86.0	16.7	52.8	20.1	10.7	16.9	34.0												
Jun	512	419	3133	4129	736	2290	1869.8	16.4	778.1	26.4	1.1	24.5	32.4	21.4	35.9	22.7	24.5	24.9	7.6	22.2	64.4												
Jul	359	311	1199	962	388	800	669.8	5.9	185.4	27.8	0.0	28.9	0.7	26.0	0.6	26.2	1.2	27.5	0.0	28.2	5.5												
Aug	255	373	408	462	300	609	401.2	3.5	63.0	26.7	3.8	26.0	2.7	25.3	22.3	26.7	0.0	28.0	23.3	27.2	3.4												
Sept	175	229	382	233	295	412	287.7	2.5	46.7	21.3	0.7	23.2	11.6	22.6	3.2	21.3	8.3	22.2	15.7	22.0	19.3												
Oct	58	103	84	51	70	66	72.0	0.6	9.4	16.7	58.9	18.3	108.7	15.9	55.5	15.8	151.0	18.3	34.9	15.3	49.0												
Nov	15	57	22	34	44	41	35.5	0.3	7.6	9.2	21.4	12.8	81.2	9.1	17.1	8.6	5.2	12.6	9.0	9.7	28.2												
Dec	54	79	26	29	21	27	39.3	0.3	11.3	6.2	15.2	6.5	15.1	6.5	3.2	6.7	51.5	6.9	142.5	7.0	61.4												
Herbaceous pollen	3444	11396	17245	13074	10187	13115	11410																										
Pollen total	53874	40706	56000	59465	62422	55263	54621.7																										
% Herbaceous pollen	6.4	28.0	30.8	22.0	16.3	23.7	20.9																										

Jan January, *Feb* February, *Mar* March, *Apr* April, *Jun* June, *Jul* July, *Aug* August, *Sept* September, *Oct* October, *Nov* November, *Dec* December, *SE* standard error

Table 2 Monthly herbaceous pollen counts (mean, percentages and standard error) and mean annual pollen counts (P mean) and total pollen counts (P total) for the major herbaceous pollen types over the study period (2005–2010)

	Chenopodiaceae–Amaranthaceae			<i>Plantago</i>			Poaceae			Urticaceae		
	Mean	%	SE	Mean	%	SE	Mean	%	SE	Mean	%	SE
Jan	0	0.0	0.4	0	0.0	0.0	48	0.9	21.0	38	1.2	12.2
Feb	0	0.0	0.3	1	0.2	1.4	108	2.0	43.3	115	3.5	40.4
Mar	2	0.2	1.2	18	2.6	9.5	228	4.2	101.8	977	30.0	323.9
Apr	12	1.3	3.5	227	32.3	51.1	339	6.2	96.4	1501	46.1	495.7
May	47	5.4	12.8	284	40.3	61.9	3081	56.3	831.0	297	9.1	65.8
Jun	114	13.2	33.4	129	18.2	67.1	1173	21.5	491.2	191	5.9	86.3
Jul	202	23.3	37.6	35	4.9	17.1	299	5.5	126.4	51	1.6	15.8
Aug	262	30.2	47.1	8	1.1	1.6	72	1.3	16.0	27	0.8	7.2
Sept	203	23.4	44.2	2	0.3	0.7	60	1.1	5.4	7	0.2	2.6
Oct	18	2.1	3.4	1	0.1	0.6	32	0.6	6.3	13	0.4	4.8
Nov	5	0.6	2.0	0	0.0	0.0	10	0.2	2.2	18	0.6	6.1
Dec	2	0.2	0.5	0	0.0	0.4	17	0.3	10.3	19	0.6	3.7
P (mean)	867	100.0	106.8	704	100.0	122.7	5468	100.0	1263.1	3253	100.0	793.33
P (total)		5,202			4,225			32,806			19,519	

remarkably low in 2005, resulting in very low herbaceous pollen counts (6.4%) compared to the mean for the study period as a whole (20.9%). By contrast, the rainiest spring (2007) prompted the highest herbaceous pollen counts (17,245 pollen grains, 30.8% of total pollen; Table 1). The highest Urticaceae pollen counts were recorded in March and April (30.0% and 46.1%, respectively), whilst *Plantago* counts peaked in April and May (32.3% and 40.3%, respectively), and Poaceae counts in May and June (56.3% and 21.5%, respectively). Finally, Chenopodiaceae–Amaranthaceae counts attained maximum values in July, August and September (23.3%, 30.2% and 23.4%, respectively), as shown in Table 2.

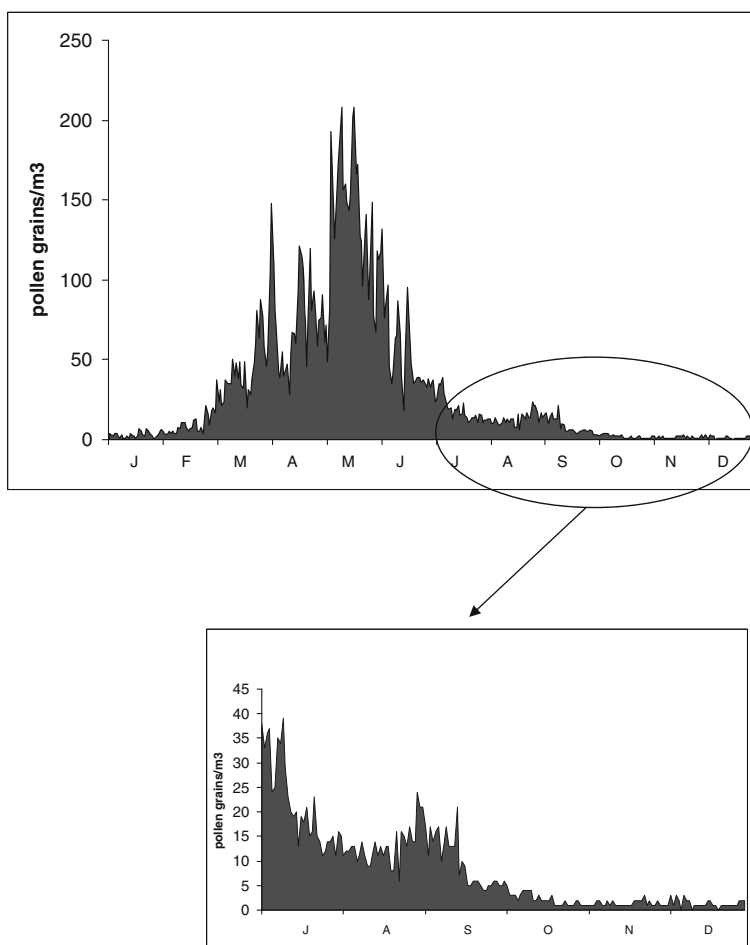
Mean maximum daily pollen counts over the study period exceeded 200 pollen grains/m³ on some days (Fig. 2); the maximum daily count was recorded for Urticaceae (620 pollen grains/m³, 03 April 2008), followed by Poaceae (557 pollen grains/m³; 13 May 2007), Chenopodiaceae–Amaranthaceae (76 pollen grains/m³; 13 September 2010) and *Plantago* (69 pollen grains/m³; 02 May 2006; Table 3, Fig. 3). The Main Pollen Season data for each pollen type analysed showed that Chenopodiaceae–Amaranthaceae, Poaceae and Urticaceae have long pollen seasons, lasting over 4 months, since they include a wide variety of species which flower consecutively over the whole pollen season.

By contrast, *Plantago* includes fewer species, and the pollen season—though relatively long—rarely exceed 4 months (Table 3).

Analysis of intradiurnal variations in pollen counts (Fig. 4) showed that the lowest levels were recorded between 0800 (*Plantago*, Poaceae) and 1000 hours (Chenopodiaceae–Amaranthaceae, Urticaceae), gradually rising thereafter. Chenopodiaceae–Amaranthaceae counts peaked between 1400 and 1600 hours; *Plantago* values peaked in the afternoon, from 1400 hours onwards, thereafter remaining fairly stable until 2400 hours. Both Poaceae and Urticaceae behaved somewhat differently: Poaceae recorded relatively uniform values throughout the day, with slight declines at 0800, 1400 and 1600 hours, while Urticaceae counts displayed two peaks: one between 1400 and 1600 hours, and the other at 2200 hours (Fig. 4).

Analysis of correlations between pre-peak pollen counts and meteorological variables—temperature, rainfall, hours of sunlight, atmospheric pressure and wind speed (Table 4)—showed a strong positive correlation between pollen counts and temperature for all taxa studied. Correlations with rainfall were negative in all cases, but only significantly so for Chenopodiaceae–Amaranthaceae. Correlations between hours of sunlight and pre-peak pollen counts were significant (positive)

Fig. 2 Seasonal fluctuations in daily average total herbaceous pollen counts. Mean values for the period 2005–2010



only for *Plantago*. A significant negative correlation of pollen counts with wind speed was observed for Chenopodiaceae–Amaranthaceae and Urticaceae. High pressure, linked to atmospheric stability, displayed a positive correlation with pollen counts in all cases.

The impact of airborne allergenic pollens on the allergic population tends to be most notable in spring and summer. Here, two distinct periods were discerned in spring: in early spring (March and April), Urticaceae pollen counts peaked and *Plantago* counts were also considerable; in late spring (May), *Plantago* and more particularly Poaceae counts attained peak values. People allergic to Poaceae pollen would continue to experience symptoms throughout May and well into June. In summer (from July to September) Chenopodiaceae–Amaranthaceae pollen counts peaked (Fig. 3).

The number of days on which pollen counts reached allergy-risk levels varied as a function of pollen type. Over the period 2005–2010, Urticaceae and Poaceae attained at least moderately allergenic levels on an

average of 43 days per year; high-risk levels were recorded for Urticaceae pollen on 29 days, and for Poaceae pollen on 24 days. Moderate allergy risk was recorded on 11 days for Chenopodiaceae–Amaranthaceae and only a few days for *Plantago* (Table 3).

Discussion

The results obtained here highlight the major contribution of herbaceous pollen to the overall pollen count (20.9%). Pollen from woody species—mainly trees—accounted for the remaining 79.1%. These results were to be expected: trees produce larger amounts of pollen than herbaceous species, and the area around Toledo is forested, while the city's parks and gardens also contain a large number of trees. Similar findings have been reported by other authors in other geographical areas (Kaya and Aras 2004a, 2004b; Bianchi and Olabuenaga 2006; Erkara 2008).

Table 3 Characteristics of the main pollen season for the herbaceous pollen types studied; number of days on which daily pollen counts exceeded allergy-risk thresholds

	2005	2006	2007	2008	2009	2010
<i>Chen-Amar</i>						
Pollen season	29Apr–28Sep	29Apr–08Oct	17May–27Sep	04May–05Oct	04May–15Oct	24May–02Oct
Season length	153	163	134	155	165	132
DMV (Date)	18 (07Jul)	42 (21Aug)	37 (24Aug)	34 (28Jun)	32 (29Aug)	76 (13Sep)
Days >15 to 30 grains/m ³	2	5	11	11	6	23
Days >30 grains/m ³	–	2	1	2	1	2
Total days >15 grains/m ³	2	7	12	13	7	25
<i>Plantago</i>						
Pollen season	09Apr–25Aug	30Mar–06Jun	05Apr–21Jun	23Mar–11Jul	01Apr–14Jul	20Apr–18Jul
Season length	139	69	108	111	105	90
DMV (Date)	22 (01May)	69 (02May)	45 (10May)	52 (21May)	54 (05Apr)	54 (30Apr)
Days >25 to 50 grains/m ³	–	2	7	3	3	7
Days >50 grains/m ³	–	1	–	1	1	1
Total days >25 grains/m ³	–	3	7	4	4	8
<i>Poaceae</i>						
Pollen season	18Feb–26Nov	12Feb–02Sept	18Feb–21Jul	15Mar–23Aug	18Feb–01Sept	22Mar–02Aug
Season length	282	203	154	235	196	134
DMV (Date)	138 (08May)	516 (15May)	557 (13May)	289 (19Jun)	226 (22May)	486 (24May)
Days >25 to 50 grains/m ³	8	16	26	24	30	14
Days >50 grains/m ³	6	24	43	32	17	23
Total days >25 grains/m ³	14	40	69	56	47	37
<i>Urticaceae</i>						
Pollen season	02Mar–04Dec	07Feb–14Nov	14Feb–09Jul	20Feb–13Jul	23Feb–19Jul	04Mar–05Aug
Season length	278	281	146	144	147	155
DMV (Date)	27 (21May)	136 (26Mar)	303 (19Apr)	620 (03Apr)	250 (28Mar)	393 (25Apr)
Days >15 to 30 grains/m ³	–	14	32	31	17	17
Days >30 grains/m ³	–	29	31	24	36	25
Total days >15 grains/m ³	–	43	63	55	53	42

Chen-Amar Chenopodiaceae–Amaranthaceae, *DMV* daily maximum value

The proportion of herbaceous-species pollen was similar to that noted for other cities in the Castilla-La Mancha region, including Cuenca (Pérez-Badia et al. 2011), but differed slightly from that reported for nearby regions such as Extremadura (González Minero et al. 1997), where herbaceous species are more abundant, and their pollen accounts for a greater percentage of the overall total (37.9%).

Poaceae accounted for 41.1% of the total herbaceous pollen count, a finding also reported for other cities in central Spain, including Aranjuez and Madrid (Gutiérrez et al. 2006; Sabariego et al. 2010), as well as in Ciudad Real (Prieto et al. 2002; García-Mozo et al.

2006b) and Extremadura (González Minero et al. 1997; Tavira et al. 1998). As in Toledo, Poaceae pollen in these areas comes mostly from pastureland, crops and ruderal vegetation surrounding these cities. Poaceae counts in Toledo were higher than those recorded for other areas of Spain such as Catalonia, but lower than those reported in some areas of northern Spanish regions such as Galicia (Fernández-González et al. 1999; Latorre and Belmonte 2004; Jato et al. 2009).

Urticaceae was the second most abundant herbaceous pollen type (24.4% of total herbaceous pollen). Counts recorded in Toledo were higher than those reported in neighbouring cities, such as Ciudad Real and Madrid,

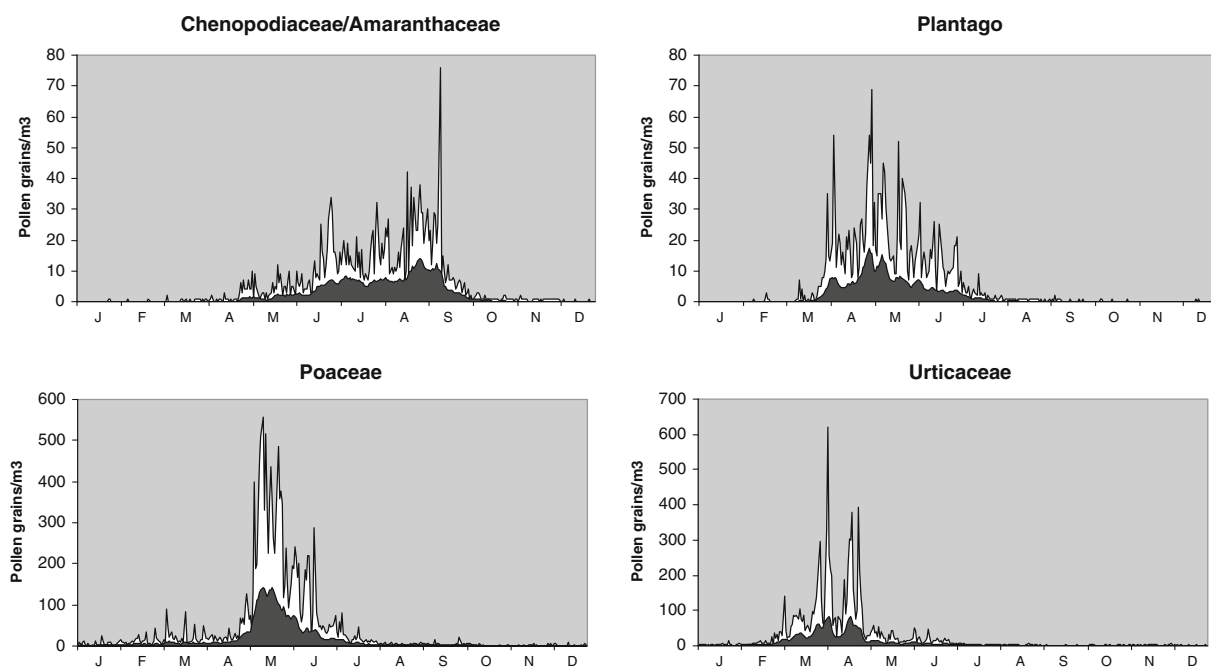


Fig. 3 Five-day running mean (black area) and maximum daily mean (line) values over the study period (2005–2010) for the herbaceous pollen types studied. Note different scales

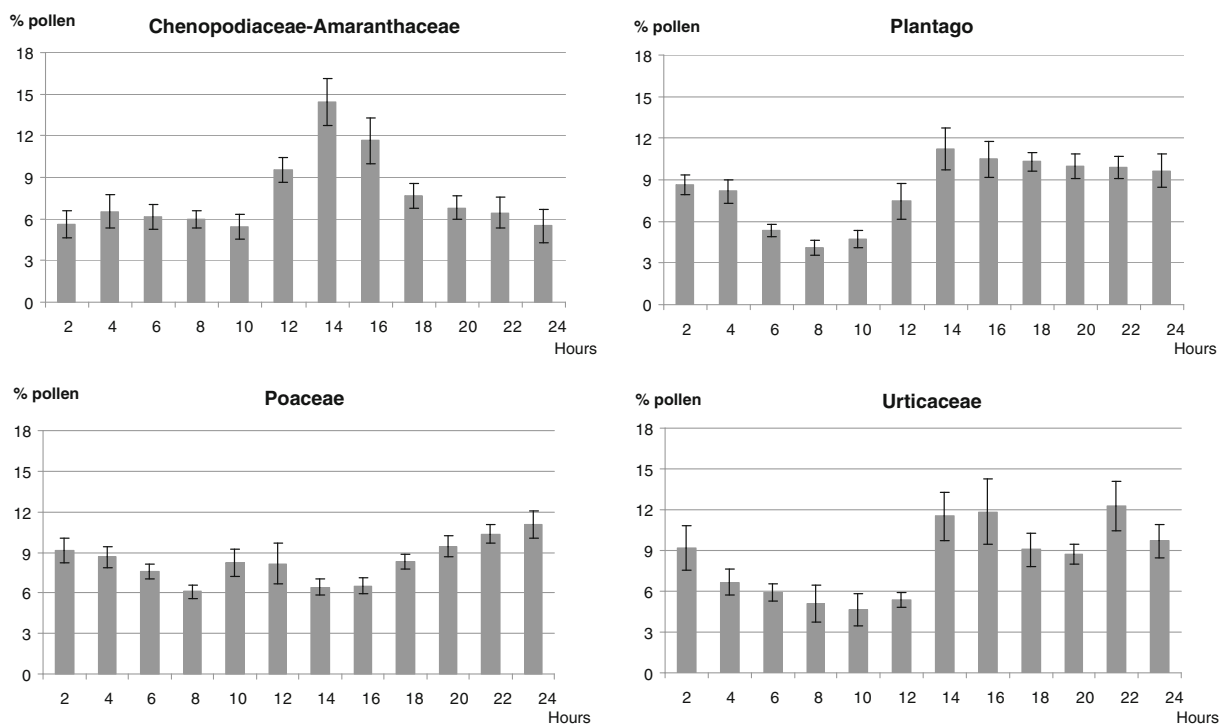


Fig. 4 Mean ($\pm$ standard error) bi-hourly distribution of pollen counts over 24 h, expressed as percentages, for the herbaceous pollen types: Chenopodiaceae–Amaranthaceae, *Plantago*, Poaceae and Urticaceae

Table 4 Coefficients of correlation between daily pollen pre-peak concentration and major meteorological variables, using the Spearman correlation test

	Chenopodiaceae– Amaranthaceae	<i>Plantago</i>	Poaceae	Urticaceae
T mean (°C)	0.647**	0.479**	0.610**	0.361**
T max (°C)	0.640**	0.446**	0.569**	0.394**
T min (°C)	0.611**	0.535**	0.563**	0.198**
Rainfall (mm)	−0.227**	−0.126	−0.67	−0.074
Sun hours	−0.006	0.305**	0.74	−0.054
Atmospheric Pressure (millibars)	0.210**	0.063	0.66	0.169*
Wind velocity (km/h)	−0.153**	0.013	0.065	−0.118**

**99%, *95%, significance levels

and were surpassed only by those recorded in Cuenca (Pérez-Badía et al. 2011); the abundance of Urticaceae pollen in Toledo is due to the presence of a hygro-nitrophilous environment along the banks of the River Tagus, which favours the spread of plant species and communities dominated by Urticaceae. Counts recorded for Chenopodiaceae–Amaranthaceae (6.5% of total herbaceous pollen) and *Plantago* (5.3%) were lower than those observed for Poaceae and Urticaceae; values were similar to those noted elsewhere in the Castilla-La Mancha region, including Cuenca (Pérez-Badía et al. 2011), and are attributable mainly to ruderal species.

Total herbaceous pollen counts varied from year to year, reflecting the effect of weather-related variables, and especially of temperature (which influences phenology) and rainfall (which influences pollen production and persistence in the air). Similar findings have been reported in numerous studies (Trigo et al. 1996; García-Mozo et al. 2006a; Green et al. 2004; Jato et al. 2009; Kasprzyk, 2006, Sabariego et al. 2010). The lowest herbaceous pollen count in Toledo was recorded in 2005 (6.4% of total count). That year, January and February temperatures were the lowest of the whole study period (4.8°C and 5.5°C, respectively), while spring rainfall in April and May was very scarce (Table 1).

A significant positive correlation was observed in all cases between pollen counts and daily maximum, mean and minimum temperatures. A number of authors have highlighted the positive effect of temperature on anther maturity and dehiscence, and thus on airborne pollen counts (Annie and Liem 1980; Spieksma and Nikkels 1998). A negative correlation was observed in all cases between pollen counts and rainfall, although it attained statistical significance only for Chenopodiaceae–Amaranthaceae and Urticaceae. Daily rainfall has a negative impact on pollen counts, due to the atmospheric

washout of pollen grains. This effect has been widely reported (González Minero and Candau 1996; Laaidi 2001; Rodríguez-Rajo et al. 2003).

Analysis of wind speed data revealed a significant negative correlation with pollen counts for Chenopodiaceae–Amaranthaceae and Urticaceae, possibly indicating that this pollen originated largely in the vicinity of the trap. Similar findings have been reported in Toledo for earlier years (Pérez-Badía et al. 2010a) and also—at least for Urticaceae—in other Spanish cities including Lugo and Cuenca (Rodríguez-Rajo et al. 2003; Pérez-Badía et al. 2011).

Examination of intradiurnal variation revealed three distinct distribution patterns reflecting the varying distance of pollen-emitting sources from the trap, and indicating a possible time-lag between pollen release and pollen capture (Rodríguez-Rajo et al. 2003; Galán et al. 1991, Perez-Badía et al. 2010b, Pérez-Badía et al. 2011).

The peak daily counts for Chenopodiaceae–Amaranthaceae and *Plantago* were recorded during the hottest part of the day, i.e. from 1400 to 1600 hours, the rising temperature prompting anther dehiscence and thus pollen release. The coincidence of maximum counts with maximum temperatures indicates that pollen sources were located close to the city. Similar behaviour has been reported for these pollen types in other Spanish cities, among them Córdoba and Almería (Galán et al. 1991; Sabariego 2003).

Urticaceae displayed two peaks, one at 1400–1600 hours prompted by pollen sources close to the trap, and the other at 2200 hours, caused by sources further away from the trap. This behaviour has been noted for other pollen types, such as *Quercus* in Cuenca (Pérez-Badía et al. 2011) and *Castanea* in Galicia (Rodríguez-Rajo et al. 2003), both of which peak at different times.

Poaceae counts remained fairly stable throughout the day, although with mild dips at 0800 hours and again at 1400–1600 hours. This undoubtedly reflects the fact that the family contains a large number of species flowering at different periods, with different anther-opening and pollen-release times, and located at different distances from the trap. Weather conditions also vary from one area to another, which would also help to account for varying Poaceae behaviour patterns depending on geographical location (Käpylä 1981; Kasprzyk et al. 2001; Kasprzyk 2006; Norris-Hill 1999; Latalowa et al. 2005; Muñoz et al. 2010).

Poaceae pollen is a leading cause of allergies, both in Europe and worldwide (Frenguelli et al. 2010; Jäger 2008), due not only to the considerable allergenicity of Poaceae pollen, but also to the large number of species of which the family consists, and the extensive areas occupied by plant communities in which Poaceae predominate (Sabariego et al. 2010). In Toledo, Poaceae was the most abundant herbaceous pollen, and pollen grains were present in the air for most of the year. It is a risk factor for patients with respiratory diseases and is the major cause of respiratory allergies in central Spain (Alergológica 2005). The prevalence of positive skin tests among pollinosis patients is 75% (Subiza et al. 2007). Over the 6 years of the study, pollen levels exceeded 25 grains/m³ on an average of 43 per year. These levels are widely considered sufficient to trigger respiratory symptoms (Solomon 1984; Rantio-Lehtimäki et al. 1991; Galán et al. 2007).

Airborne Urticaceae pollen is also present in Toledo over several months of the year, attaining peak concentrations in March and April. The family includes two key allergenic genera, *Urtica* and *Parietaria*. *Parietaria* pollinosis affects between 10% and 30% of allergy-sufferers in Spain (Luengo and Cadahía 2003); the pollen season may be sufficiently prolonged to trigger practically constant symptoms in patients (Subiza et al. 2007). *Urtica* gives rise to a notably high rate of positive skin-prick tests in central Spain (44% in Madrid and 49% in Toledo, Subiza et al. 2007).

The highest *Plantago* pollen counts were recorded in April, May and June. In Spain, this pollen can trigger symptoms in 25–75% of pollen-allergy sufferers (Subiza et al. 2007), although the allergenic importance of this pollen type remains unknown, since its flowering period overlaps with that of Poaceae.

June, July and August are the worst months for people suffering from Chenopodiaceae–Amaranthaceae pollen allergies. Póla (2003) and Subiza et al. (2007) note that this is the third most important cause of pollen allergies in Toledo, with risk thresholds estimated at between 10 and 15 grains/m³ of air. Fortunately, these values were reached in Toledo on an average of only 11 days per year.

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