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Comparative study of airborne pollen counts located in different areas of the city of Córdoba (south-western Spain)

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Abstract Airborne pollen counts are mainly determined using a volumetric suction sampler based on the impact principle, that is, a Hirst-type spore trap. As a consequence of their volumetric nature, samplers detect pollen from a wide area, and therefore, a single sampler is frequently used to acquire information on airborne pollen counts for the whole city. The main goal of the present study was to compare airborne pollen counts at two sites located at opposite ends (south-west vs. north-east) of the southern Spanish city of Córdoba, to assess the advantages and disadvantages of using more than one sampler in the city. Also, a comparative study was carried out using two samplers at the same site, in order to confirm the efficiency of the samplers. Results revealed that data from one volumetric sampler—located within a city of medium size with uniform topography and vegetation conditions—are sufficient to establish monitoring of the main airborne pollen types, the pollen seasons involved and the timing of peak counts. For clinical studies, however, data on pollen counts in specific areas of the city may be of value, since pollen intensity may vary from one district to another, mainly in the case of ornamental plants with a local distribution inside the city. Comparison of data obtained by the two samplers running at the same site indicated that potential inter-site differences could not be attributed to differences in sampler efficiency.

Keywords Aerobiology · Sampler location · Airborne pollen count

1 Introduction

Airborne pollen counts are commonly determined with the aid of a volumetric suction sampler based on the impact principle, that is, a Hirst-type spore trap (Hirst 1952). Since the presence of biological particles in the atmosphere is closely related to the incidence of adverse reactions affecting human health, it is essential to establish actual airborne pollen counts in areas where people spend a great deal of time. For that reason, samplers tend to be located in urban areas. It has recently been reported that people living in urban areas are more prone to suffer from pollen-induced respiratory allergies than those living in rural areas (D'Amato and Cecchi 2008).

The installation of samplers must comply with certain minimum requirements for aerobiological studies. These requirements have recently been published in a number of network manuals, for example, the Spanish Aerobiology Network (REA) Management and Quality Manual (Galán et al. 2007). The sampler should be placed on the roof of a building, taking care that adjacent buildings or obstacles do not

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impede the flow of air. Due to their volumetric nature, samplers can detect pollen from a wide area; a single sampler is therefore commonly used to provide information on airborne pollen counts for the whole city.

Several papers have compared airborne pollen counts between different cities (Trigo et al. 2000; Sánchez-Mesa et al. 2005; Alcázar et al. 2009; Recio et al. 2009), reporting that the major differences detected are attributable to the layout of local green spaces and to different local bioclimatic and biogeographical conditions.

Other authors have examined differences in airborne pollen counts between two or more areas of the same city, due to differences in microclimate or in the content and layout of urban green spaces. Galán et al. (1995), Alcázar et al. (1999) and Chakraborty et al. (2001) report differences attributable to sampler height at the same site, as a function of the height of the pollen source (e.g. trees vs. grass). Differences could be also due to the distance of the sampler from the pollen source (e.g. local flora vs. surrounding vegetation) (Raynor et al. 1975). The differences in vertical movement of air and the absence of long-range or regional-scale transport—range transport at lower heights—also justify these variations. Studies focussing specifically on different areas of a given city (Gonzalo-Garijo et al. 2006; Cariñanos et al. 2002a, Arobba et al. 2000) note that vegetation surrounding the city can have a decisive influence on the data collected.

The main goal of the present study was to compare airborne pollen counts at two sites located at opposite locations at the borders of the city (south-west vs. north-east) of the southern Spanish city of Córdoba, with the objective to assess the advantages and disadvantages of using more than one sampler in the city. The SW sampler has been operating since 1982 and the NE sampler is working from 2002 to compare the pollen load in two opposite areas. A comparative study was carried out using two samplers at the same site, in order to confirm that inter-site variability was due to differences in floral composition and rather than to sampler operation issues.

2 Materials and methods

Córdoba (37°50′ N, 4°45′W) is located at 123 m above sea level; it is a medium-sized city with a population of around 330,033 inhabitants and a surface of 290.23 km^2. It is characterized by a mediterranean climate with some continental features, cold, rainy winters and hot, dry summers. The annual average temperature is 17.6 °C, mean annual rainfall is 536 mm (1971–2000) and the prevailing wind direction is south-westerly (65.68 %) (National Meteorology Institute 2001).

The study was carried out from 2006 to 2010, using two Hirst-type volumetric spore traps (Hirst 1952), separated 9 km apart. One sampler was placed on the roof of the University Education Faculty in south-western Córdoba (37°52′8″N, 4°48′7″W), at 15 m above ground level (SW sampler). This building is surrounded by urban flora. The other sampler was placed on the roof of the Department of Botany, Ecology and Plant Physiology at the University of Córdoba campus in north-eastern Córdoba (37°54′50″N, 4°43′6″W), 22 m above ground level (NE sampler). The campus is located on the outskirts of the city near the "Sierra Morena" hills, and therefore, more influenced by natural than by urban vegetation.

To rule out the possibility that differences between sites were caused by differences in sampler functioning, a comparison of data obtained using two samplers located on the same building was conducted from May 2010 to July 2011 at the south-western site. Samplers were placed 8 m apart. Sampler A had been running for some time prior to the study, while sampler B was installed specifically for the study.

The methodology developed by the Spanish Aerobiology Network (Galán et al. 2007) was used to obtain the average daily airborne pollen variations (pollen grains/m^3).

The study focused on the seven most common airborne pollen types in Córdoba, those exceeding 1 % in all samplers: Cupressaceae, *Olea europaea*, *Platanus hispanica*, Poaceae, *Populus*, *Quercus* and Urticaceae (including *Urtica membranácea* Poir.).

The start and end of the pollen season was taken as the day on which a specific daily pollen count (pollen grains/m^3) was reached, as a function of flowering intensity and flowering behaviour:

- *Cupressus*, *Olea* and *Quercus*: Start > 50; End < 50.
- Poaceae: Start > 25; End < 25.
- Urticaceae: Start > 15; End < 15.

- *Platanus* and *Populus*: Start = 1 pollen grain/m^3 + 5 days with 1 or more pollen grains/m^3; End = 1 pollen grain/m^3 + 5 days with counts below this level.

Cupressus, *Olea*, Poaceae, *Quercus* and Urticaceae pollen types remain in the air over a long period of the year, even out of season. For this reason, to avoid very low concentrations at out of season, sometimes due to re-suspension, we have chosen a minimum concentration to determinate the pollen season: 50 pollen grain/m^3 for *Cupressus*, *Olea* and *Quercus*, 25 pollen grains/m^3 for Poaceae and 15 pollen grains/m^3 for Urticaceae. Since the other two pollen types (*Platanus* and *Populus*) have a short pollen season, very well delimited, the start date was defined as the first day on which a daily count of at least 1 pollen grain/m^3 was followed by 5 days with 1 or more pollen grains/m^3, and the end of the pollen season was defined as the last day on which a daily count of at least 1 pollen grain/m^3 was recorded followed by 5 days with counts below this level.

To look for statistical differences between pollen counts at the two sites, the Kolmogorov–Smirnov test was first applied to test data for normality. Since results were negative, data were transformed using the Ln (pollen grains/m^3 + 1) formula in order to obtain a normal distribution enabling parametric analysis. Pearson correlation analysis and *t* test were applied to pollen data recorded at the two sites (south-west and north-east) as well as to data obtained from samplers A and B at the south-west site, to test for possible differences between variations and means of the data recorder at each site. Finally, an ANCOVA analysis was performed in order to analyse the effects between location and pollen count, indicating the p value and R^2.

To analyse the clinical implication of the pollen concentration results in each area, pollen counts have been classified using a threshold system (Galán et al. 2007). These thresholds are useful to determine the biological quality of the air. To establish thresholds, certain characteristics have been taken into account: the anemophilous/entomophilous nature of the species, the annual pollen index, the daily pollen content in the air along the year and the potential allergenic capacity of the species. The three pollen count classes (low, moderate and high) refer to pollen count thresholds required for a small, medium or large percentage of the susceptible population to develop symptoms associated with the presence of this type of pollen.

Concentrations of pollen grains/m^3, considered low, moderate or high, for each pollen type:

- *Cupressus*, *Olea*, *Platanus* and *Quercus*: low = 1–50; moderate = 51–200; high > 200.
- *Populus*: low = 1–30; moderate = 31–50; high > 50.
- Poaceae: low = 1–25; moderate = 25–50; high > 50.
- *Urticaceae*: low = 1–15; moderate = 16–30; high > 30.

The total percentage of days with similar concentrations in both samplers has been estimated.

3 Results

Over the 5 years of study, *Cupressus*, *Olea*, *Platanus*, Poaceae, *Populus*, *Quercus* and Urticaceae pollen types accounted for around 90 % of the total pollen counts recorded. Each one of these pollen types represented at least 1 % of the total in all years (Fig. 1). The two samplers (SW and NE) yielded similar results in this respect.

Pearson correlation analysis and *t* test were performed on data from samplers A and B (Table 1). As the table shows, correlations between data from the two samplers were highly significant in all cases, and the *t* test showed that means were very similar with no statistically significative differences in most of the cases.

Some differences were found between samplers located at different sites in each year; the pollen index of *Olea*, *Platanus* and Urticaceae pollen was higher in the south-west, except in 2006 for all types and in 2009 for *Olea*, while the pollen index of *Cupressus*, *Quercus* and *Populus* was higher in the north-east, except *Cupressus* in 2008 and *Populus* in 2007 and 2008. Similar pollen index was recorded for Poaceae at the two sites (Fig. 2).

Averages of pollen season characteristics—start date, end date, duration and peak data (peak pollen count and date recorded)—are shown in Table 2. Usually, the pollen season started earlier in the NE for *Cupressus*, *Olea* and *Populus,* while for Poaceae, *Platanus* and Urticaceae, pollen grains were recorded first in the SW. Nevertheless, differences were in more cases of few days, not statistically significative. Most of the years, the pollen season was longer at the NE

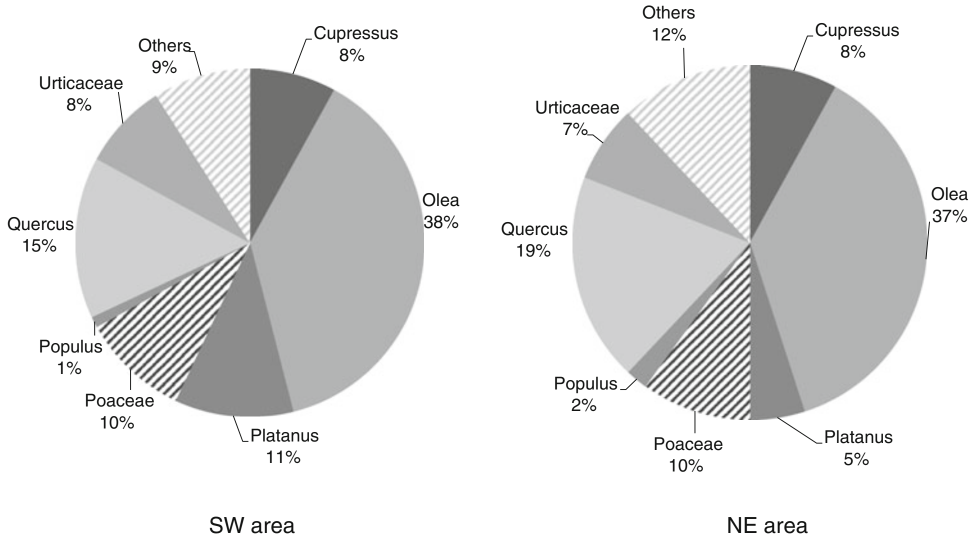

Fig. 1 Average percentages over the whole study period for the seven studied taxa

Table 1 Pearson's correlation coefficients and *t* test analysis between samplers in the same area (A–B)

Pollen types	Pearson correlation		*t* test		*N*
	R	*p*	Mean difference (A − B)	*p*	
Cupressus	0.983	0.000	−0.028	0.412	112
Olea	0.884	0.000	0.011	0.892	119
Platanus	0.962	0.000	−15.619	0.394	55
Poaceae	0.866	0.000	0.114	0.049	112
Populus	0.941	0.000	−0.197	0.948	85
Quercus	0.822	0.000	0.175	0.056	89
Urticaceae	0.893	0.000	0.041	0.473	131

site for *Cupressus*, Poaceae, *Populus*, *Quercus* and Urticaceae, and longer at the SW site for *Platanus*. Peak pollen counts for *Olea*, *Platanus* and Poaceae were recorded earlier at the SW site, where *Platanus* counts were generally much higher. *Cupressus*, *Quercus* and Urticaceae pollen counts tended to peak earlier in the NE, although displaying higher absolute values in the SW; the exception was *Quercus*, which exhibited higher counts in the NE.

In Table 3, statistical analysis revealed strong correlations between the two sampling sites (SW–NE), with significant values ($p < 0.01$) for the Pearson correlation coefficient in all cases. This indicates that pollen counts in the two areas displayed similar trends. The *t* test showed significant differences ($p < 0.05$) between means at the two sites except for *Olea* and Poaceae. Means were higher at the NE site, except for *Olea*, *Platanus* and Urticaceae, which were higher at the SW site. The ANCOVA analysis confirms some previous results, so that the location influences in the pollen data in *Cupressus*, *Platanus*, *Populus* and Urticaceae pollen types, with significant differences ($p < 0.05$). For the others, pollen types (*Olea*, Poaceae and *Quercus*) have not been obtained significant results.

The similarity percentages for the pollen levels presented in both areas (SW–NE) appear in Table 4. The similarity is always, for each pollen type, higher than 70 %. Although there are differences in the mean for some pollen types in the two opposite areas, the pollen levels of clinical importance are lower. For instance, *Platanus* show significant differences in the *t* test and ANCOVA analysis. However, taking into account pollen levels, these differences are much lower, and the percentage of similarity between samples is 88.52 %.

4 Discussion

Comparison of data obtained by the two samplers running at the SW site (A and B) indicated that potential inter-site differences could not be attributed

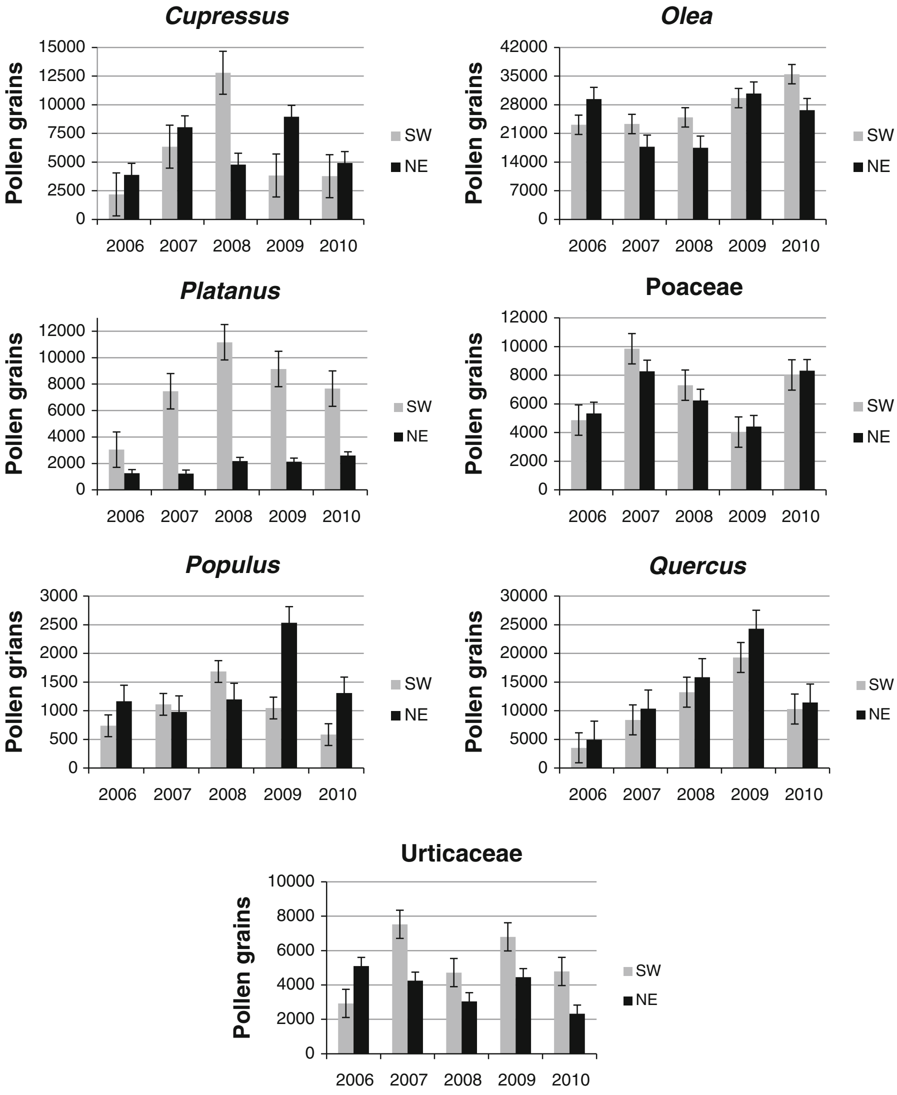

Fig. 2 Pollen index during the study period in both sampling areas

to differences in sampler efficiency: the data obtained were very similar, correlations between the two were significant and the means were very similar too.

The most common airborne pollen types were the same for both samplers (NE and SW), representing anemophilous species abundant in and around Córdoba city. The main difference in the contributions of different pollen types to the total count was found for *Platanus,* which is more numerous as an ornamental and shade tree in the proximity of the SW sampler (Alcázar et al. 2004).

Analysis of the pollen index for each pollen type and each study year revealed differences in the distribution of pollen-producing species in the neighbourhood of the traps. For ornamental species such as *Platanus* and *Populus*, differences reflected variations in the design of urban green spaces. For other species, differences were attributable to the varying proximity either of cropland (e.g. olive groves to the south of the city) or of woodland (cypress forests to the north due to reforestation on the slopes of the Sierra Morena, together with natural flora of *Quercus ilex*, subspecies *ballota*, *Q. coccifera, Q. faginea* and *Q. suber)*. These results, confirmed by statistical analysis, highlighted the link between airborne pollen counts and predominant local vegetation (Alcázar et al. 2009; Trigo et al. 2000).

In a broad sense, inter-site differences in the timing of pollen seasons were relatively slight. In most

Table 2 Average pollen season characteristics during the study period in both areas (SW–NE). (Standard deviations in brackets)

	Pollen station			Top values	
	Date	Duration (no days)	Pollen grains/m^3	Peak date	Pollen grains/m^3
Cupressus					
SW	16 January–15 March	59 (±12)	5,012 (±4,334)	24 February	622 (±373)
NE	10 January–13 March	63 (±19)	5,323 (±2,311)	16 February	539 (±268)
Olea					
SW	25 April–20 June	57 (±11)	26,582 (±5,141)	8 May	3,084 (±961)
NE	24 April–19 June	57 (±15)	23,510 (±6,270)	13 May	2,388 (±296)
Platanus					
SW	8 March–17 April	41 (±10)	7,659 (±2,975)	19 March	1,704 (±821)
NE	11 March–19 April	40 (±8)	1,861 (±595)	23-March	261 (±116)
Poaceae					
SW	20 April–20 June	62 (±10)	6,110 (±2,345)	18 May	546 (±260)
NE	24 April–25 June	63 (±16)	5,727 (±1,730)	23 May	360 (±91)
Populus					
SW	10 February–2 April	52 (±9)	1,019 (±415)	28 February	199 (±189)
NE	9 February–2 April	53 (±9)	1430 (±625)	28 February	227 (±74)
Quercus					
SW	20 March–29 May	71 (±18)	9,978 (±5,754)	3 May	905 (±829)
NE	20 March–30 May	72 (±26)	12,516 (±7,072)	28 April	1,086 (±894)
Urticaceae					
SW	27 January–24 May	118 (±17)	4,978 (±1,762)	27 March	486 (±331)
NE	29 January–28 May	120 (±21)	3,406 (±1,315)	26 March	219 (±141)

Table 3 Pearson's correlation coefficients

Pollen types	Pearson correlation		*t* test		ANCOVA analysis			*N*
	R	*p*	Mean difference (SW − NE)	*p*	Years	Location	R^2	
Cupressus	0.614	0.000	−0.2352	0.002	ns	*	0.070	312
Olea	0.845	0.000	0.0099	0.863	*	ns	0.014	288
Platanus	0.604	0.000	0.7683	0.000	ns	***	0.060	170
Poaceae	0.748	0.000	−0.0171	0.734	ns	ns	0.010	326
Populus	0.709	0.000	−0.1835	0.006	***	**	0.051	207
Quercus	0.704	0.000	−0.1446	0.008	***	ns	0.037	406
Urticaceae	0.652	0.000	0.2338	0.000	***	*	0.030	573

t Test and ANCOVA analyses between SW and NE samplers. In the ANOVA analyses, pollen types (dependent variables) were checked against effects of location (categorical predictor) with years being the covariate. The significance level *p* is given in all cases (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, *ns* non-significant)

cases—e.g. *Cupressus* and *Platanus*—differences were attributable to the different distances from the source to the trap.

Olea pollen was recorded by the SW sampler before the NE sampler, even though the earlier-flowering olive groves in Córdoba Province are located closer to the NE trap. This may be due to the detection of pollen grains transported by the prevailing south-westerly winds from elsewhere in Andalusia—conceivably Seville or Málaga, where the olive flowers earlier (Hernández-Ceballos et al. 2011; Fornaciari et al. 2000).

Table 4 Similarity percentage between pollen thresholds from SW and NE samplers

Pollen type	% Similitude
Cupressus	82.24
Olea	72.68
Platanus	88.52
Poaceae	84.70
Populus	94.53
Quercus	79.23
Urticaceae	73.22

Daily counts for each pollen type over the season were similar to those reported for Córdoba by Domínguez-Vilches et al. (1995), Guerra et al. (1996) and Cariñanos et al. (2007), among others. However, pollen counts were slightly higher, and in some cases, the pollen season started slightly earlier, than in previous years (García-Mozo et al. 2010).

A number of authors have highlighted the major contribution of ornamental flora to airborne pollen counts (Cariñanos et al. 2002a; Gonzalo-Garijo et al. 2006) and have stressed the influence of cropland and forest distribution (Cariñanos et al. 2002a). These factors may have prompted the slight inter-site differences noted here. Grain dispersal capacity may also have exerted some influence: for example, in a study of *Ligustrum* airborne pollen counts, Cariñanos et al. (2002b) noted that, because of their size and weight, *Ligustrum* pollen grains are unlikely to be transported over any great distance.

Differences between the SW and NE sites would therefore appear to be due largely to differences in the distribution of ornamental flora, but also due to cropland and forest distribution. However, these differences are minor from an allergological point of view; when the threshold values for the allergic reaction are reached, even large quantitative differences have little consequence (Arobba et al. 2000; Frenz et al. 1997).

5 Conclusion

Pollen count concentrations recorded with the NE and SW pollen traps show that the main pollen types are the same in both cases. Similarly, no major inter-site differences were found for pollen season start and end dates.

However, inter-site differences were observed in mean counts. Differences recorded for certain pollen types—including *Platanus*, *Populus* and Urticaceae—confirmed the influence of surrounding vegetation on airborne pollen counts at each trap.

In summary, one volumetric sampler—located within a city as the characteristic of Córdoba—is sufficient to establish the main airborne pollen types, the pollen seasons involved and the timing of peak counts.

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