

A comparative study on the effects of altitude on daily and hourly airborne pollen counts

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Abstract The concentration of pollen grains in the air was studied using two aerobiological volumetric Hirst-type spore traps, one at ground level and the other at a height of 16 m on a terrace. The study was carried out between 2009 and 2011, from March to June in Badajoz (SW Spain). Intradiurnal and daily pollen counts were compared with both, different meteorological parameters and the distribution of local pollen sources. Forty-six pollen types were identified and 89 % of the total grains corresponded to *Quercus*, Poaceae, *Olea*, Pinaceae and *Plantago* pollen types, in descending order. The mean height ratio of the daily pollen count was 1.02. Significant correlations were observed when comparing daily pollen counts for predominant pollen types at both levels. The comparisons have shown significant differences in the daily pollen count between the two samplers in the case of *Olea* and Pinaceae, but not for

Quercus, Poaceae and *Plantago*. Similar results were obtained using the intradiurnal airborne pollen database. No significant correlation has been found between pollen count and the different meteorological parameters, showing no dependence on height. These differences of *Olea* and Pinaceae may be explained in part by the uneven distribution of the pollen sources and the disturbance by nearby buildings. The temporal variation patterns between the two sites were similar; however, taking into account the average of the data, the higher values were obtained first at the ground level and later at 16 m.

Keywords Sampler height · Intradiurnal pollen count · Pollen sources distribution

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1 Introduction

Airborne particles close to the ground directly depend on fluctuations in the local sources. The effects of these fluctuations diminish with altitude, although deposition process also depends on the particle size and density. The smaller spores predominate at higher altitudes and the bigger ones predominate near the ground (Chakraborty et al. 2001). The force of convection tends to exert its effect on the opposite direction, reducing the sedimentation rate and lift pollen and other particles to higher altitudes (Gregory

1973; Bryant et al. 1989). Two processes are involved on particle transport: the constant turbulent airstreams that vertically and horizontally mix particles throughout the lower atmosphere and the intense convection with vertically transport, and also sporadic turbulence that may carry particles to higher altitudes (Mandrioli et al. 1984).

Some aerobiological studies have been focused on airborne pollen vertical distribution in the atmosphere, by comparing pollen at different heights. Most studies have compared pollen concentrations at two different heights: at ground level (0.5–1.5 m) and at 12–15 m (Rantio-Lehtimäki et al. 1991a, b; Galán et al. 1995; Fiorina et al. 1999; Alcázar et al. 1999; Alcázar and Comtois 2000; Thibaudon et Sulmont 2002; Bergamini et al. 2004; Khattab and Levetin 2008). Other studies compared pollen count at more different heights, from ground level to 55 m, i.e., at three heights (Lyon et al. 1984; Bryant et al. 1989), at four heights (Alcázar and Comtois 2000) or at six heights (Chakraborty et al. 2001), in this last case, a Rotorod sampler was used. Notwithstanding, there is a lack of studies taking into account both, hourly data and the locations of pollen sources, in order to allow more accurate interpretation of the data. Most comparative studies of pollen at different heights have been developed in the USA (Lyon et al. 1984; Khattab and Levetin 2008), Canada (Alcázar and Comtois 2000), Finland (Rantio-Lehtimäki et al. 1991a, b), Spain (Galán et al. 1995; Alcázar et al. 1999), France (Thibaudon et Sulmont 2002), Italy (Fiorina et al. 1999; Bergamini et al. 2004), UK (Bryant et al. 1989) and India (Chakraborty et al. 2001). Hirst-type spore trap was the most widely used by fixed samplers (Rantio-Lehtimäki et al. 1991a, b; Galán et al. 1995; Thibaudon et Sulmont 2002; Khattab and Levetin 2008), or portable samplers (Alcázar et al. 1999; Alcázar and Comtois 2000) or both, fixed and portable samplers (Bergamini et al. 2004). In others studies, different samplers such as Kramer Collins spore trap (Lyon et al. 1984), Partrap FA 52 (Fiorina et al. 1999) and Rotorod (Chakraborty et al. 2001) were used.

Generally, airborne particles decrease with height from the ground level (Rantio-Lehtimäki et al. 1991a; Galán et al. 1995; Bergamini et al. 2004). Differences have been observed in this pattern depending on the time of day. The fact that the pollen concentration decreases with increasing height has been shown through two types of studies: observations at specific

heights in stations that differ widely in altitude above sea level and observations at different heights above ground level at the same station, this is only a consequence of farawayness from sources. The origins of variation in these studies were the irregular distribution of the pollen sources (Alcázar and Comtois 2000), the effects of the nearby buildings (Bryant et al. 1989) and the particle sizes (Chakraborty et al. 2001). This paper offer additional information regarding both, intradiurnal pollen count and the locations of the pollen sources. The main advantage of this study is that these new variables may allow more accurate interpretations of the data.

The main goal of this study focused on daily and intradiurnal airborne pollen at two commonly employed heights. It has also been studied a comparison with different environmental parameters related to meteorological parameters and the surrounding vegetation on pollen concentrations, trying to determine their relative impacts.

2 Materials and methods

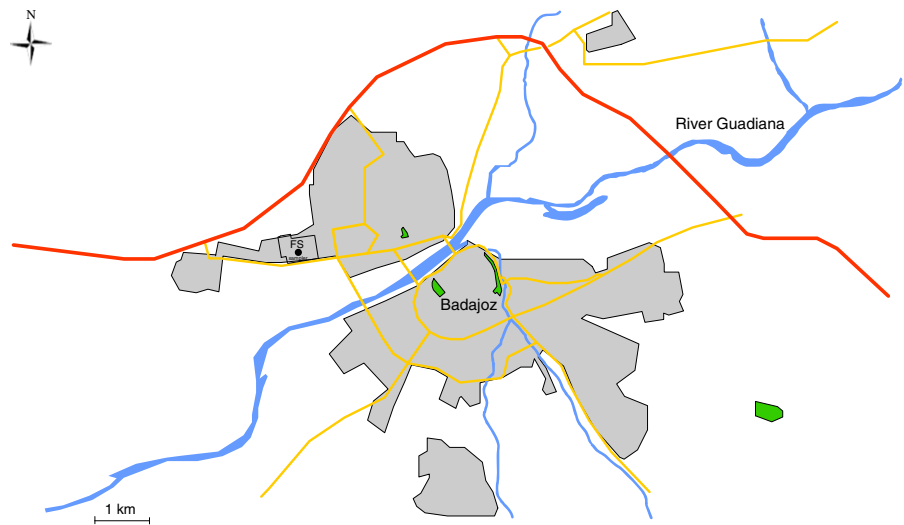
2.1 The study area and the potential pollen sources

Pollen monitoring has been carried out in two different sites of the Faculty of Science, University of Extremadura, Badajoz (38°52'42"N, 7°00'73"W): (a) at ground level in the experimental garden (*g*) and (b) at 16 m above ground level in the terrace (*t*); being separated 16 m apart (Fig. 1). Badajoz is located at 184 m above sea level. It is a medium-sized city, with 151,565 inhabitants, but the largest city in Extremadura (1,470 km²) (NSI 2012), located in a rural agricultural province. Around the city, there are irrigated crops (e.g., fruit, corn and tomatoes), olive trees, distant holm-oak trees and many grazing animals. The trees and shrubs that probably contribute to airborne pollen, within an area of approximately 500 m of diameter around the sampling zone, were recorded on a map.

2.2 Meteorological data

Different meteorological parameters were provided by the AT Delta-T DL2 fixed weather station situated at the experimental garden of the Botany building in the Faculty of Sciences campus. It is located 3 and 16 m

Fig. 1 Locations of the sampling sites in the Faculty of Sciences (FS) in the University of Extremadura campus



apart the two pollen monitoring samplers, the garden and the terrace, respectively. The meteorological parameters considered in this study were wind direction (Wd), wind speed (Ws), sun hours (Sh), relative humidity (Rh), rainfall (R), solar radiation (Sr), maximum air temperature ($T_{\max}$), mean air temperature (T_{mean}) and minimum air temperature ($T_{\min}$).

2.3 Pollen data

The average daily and intradiurnal pollen counts during spring (21 March–21 June), from 2009 to 2011, were obtained using two Hirst (Hirst 1952)-type volumetric spore traps. Standardized data management procedures were used as described by the Spanish Aerobiology Network (REA) (Galán et al. 2007). The slides were examined along two or four longitudinal transects, depending on the number of pollen grains per slide (Tormo et al. 1996). The daily average (0000–2400 hours) pollen counts and the intradiurnal variations [coordinated universal time (UTC) hourly counts] were expressed as pollen grains/ m^3 of air. The intradiurnal distribution model of the predominant pollen types (*Quercus*, Poaceae, *Olea*, Pinaceae and *Plantago*) was derived from the main pollen season, taking into account 5–95 % of annual pollen record (Nilsson and Persson 1981). Predominant pollen types represent 89 % of total airborne pollen (see Result chapter). The ratios between the average daily pollen count in both samplers were calculated taking into account the total pollen during the period studied and also for each predominant

pollen type. Daily and intradiurnal pollen counts were compared between the two samplers, taking into account the total pollen count for the five predominant pollen types. For the analysis of the intradiurnal pollen peak five continuous days (120 hours) were selected which included the day with the pollen peak in each year. These five selected days represent 13.2–52.1 % of total pollen, depending on pollen type at g and t (*Quercus* 22.7, 22.5 %; Poaceae 22.2, 19.6 %; *Olea* 35.9, 41.0 %; Pinaceae 50.6, 52.1 %; *Plantago* 13.2, 20.4 %). This method was selected to avoid erratic data and to provide the most valuable information.

The normality of the data was evaluated by the Shapiro–Wilk test (W). Because the data did not adjust to a normal distribution in any case, even after applying a logarithmic transformation, the Wilcoxon's test (Z) was applied to compare the daily and hourly data between the two sites. For the correlations between the pollen counts between both levels, and between the pollen counts with the meteorological parameters, the Spearman's correlation coefficient (r) was used. The confidence level was 95 %. The standard errors have been also calculated and represented in some figures for supporting the results.

3 Results

3.1 Nearby pollen sources

A total of 4,904 trees and ornamental shrubs are presented in the studied area. Table 1 shows all of the

Table 1 Inventory of the trees and shrubs grouped by the major anemophilous pollen types, including the number of specimens (*N*) and the species included in each group

Pollen type	<i>N</i>	Species	Pollen type	<i>N</i>	Species
<i>Acacia</i>	4	<i>Acacia dealbata</i>	<i>Fraxinus</i>	110	<i>Fraxinus angustifolia</i> , <i>F. ornus</i>
<i>Acer</i>	60	<i>Acer negundo</i> , <i>A. monspessulanum</i> , <i>A. platanoides</i>	<i>Juglans</i>	15	<i>Juglans regia</i>
<i>Alnus glutinosa</i>	21	<i>Alnus glutinosa</i>	<i>Morus</i>	102	<i>Morus alba</i> , <i>M. nigra</i>
<i>Arecaceae</i>	16	<i>Phoenix canariensis</i> , <i>P. dactylifera</i> , <i>Washingtonia filifera</i> , <i>W. robusta</i>	<i>Olea</i>	60	<i>Olea europaea</i>
<i>Erica</i>	11	<i>Erica arborea</i>	<i>Platanus</i>	208	<i>Platanus hispanica</i>
<i>Castanea</i>	106	<i>Castanea sativa</i>	<i>Pinaceae</i>	538	<i>Cedrus deodara</i> , <i>C. atlantica</i> <i>Pinus halepensis</i> , <i>P. pinea</i> , <i>P. radiata</i>
<i>Casuarina</i>	1	<i>Casuarina cunninghamiana</i>	<i>Populus</i>	79	<i>Populus alba</i> , <i>P. nigra</i>
<i>Corylus</i>	10	<i>Corylus avellana</i>	<i>Quercus</i>	338	<i>Quercus faginea</i> , <i>Q. ilex</i> , <i>Q. robur</i> , <i>Q. rotundifolia</i> , <i>Q. pyrenaica</i>
<i>Cupressaceae</i>	170	<i>Cupressus arizonica</i> , <i>C. macrocarpa</i> , <i>C. sempervirens</i> , <i>Platycladus orientalis</i>	<i>Salix</i>	58	<i>Salix atrocinerea</i> , <i>S. babilonica</i>
<i>Eucalyptus</i>	157	<i>Eucalyptus camaldulensis</i> , <i>Myrtus communis</i>	<i>Ulmus</i>	208	<i>Ulmus minor</i>

**Fig. 2** Distribution of *Quercus* in the campus of the University of Extremadura. The circled red crosses represent the spore traps

specimens grouped under the pollen type. In the list, there are represented different specimens for *Pinaceae*, *Quercus*, *Platanus* and *Ulmus*. The remainder of the specimens (54 %) corresponded to species whose pollen was not detected in the aerobiological samples,

likely due to their entomogamous nature. These species included *Brachychiton populneus*, *Catalpa bignonioides*, *Citrus aurantium*, *Cistus ladanifer*, *Crataegus monogyna*, *Melia azedarah*, *Nerium oleander*, *Prunus avium*, *Prunus cerasifera*, *Prunus*

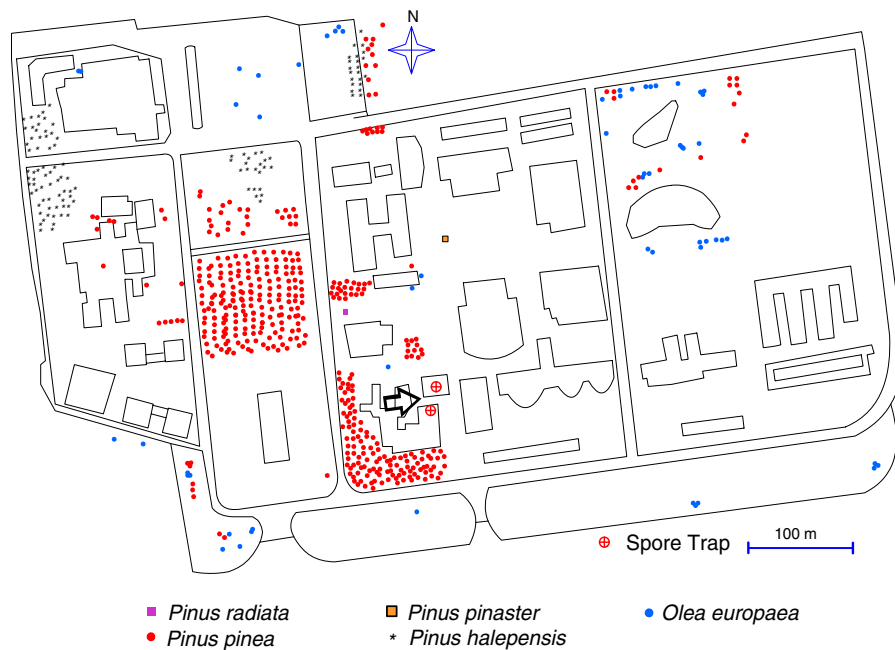


Fig. 3 Distribution of Pinaceae and *Olea* in the University of Extremadura campus. The circled red crosses represent the spore traps

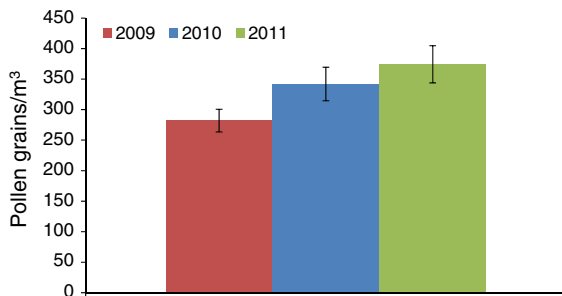


Fig. 4 Average annual pollen count during the spring (21 March–21 June), from 2009 to 2011, in Badajoz. The error bars represent the standard error

dulcis and *Viburnus tinus*. The distribution of the specimens of *Quercus* species (Fig. 2) and *Pinus* species and *Olea europaea* (Fig. 3) was selected and represented due to their relevance in this study.

3.2 Airborne Pollen

A total of 162,969 pollen grains for terrace sampler (*t*) and 159,773 for garden sampler (*g*) were detected during the study period and grouped into 46 pollen types with an average annual pollen count of 333 pollen grains/m³ (Fig. 4).

Eighty-nine percentage of airborne pollen grains corresponded to five pollen types in descending order: *Quercus*, Poaceae, *Olea*, Pinaceae and *Plantago*. The highest daily average pollen count (2,300 grains/m³) was recorded on April 8, 2011 at the *t* sampler. The *t/g* ratio of daily average pollen count was 1.02, whereas the values obtained considering only predominant pollen types were 1.05 (*Quercus*), 0.99 (Poaceae), 1.17 (*Olea*), 0.85 (Pinaceae) and 1.25 (*Plantago*).

Daily pollen counts for the *t* and *g* samplers did not show a normal distribution, even after applying a logarithmic transformation ($W = 0.982$, $p < 0.001$; $W = 0.946$, $p < 0.001$, respectively). For this reason, it has been used nonparametric statistic analyses.

In this study, no significant differences have been found between the daily average pollen count for the two samplers during the three studied years ($Z = -0.919$, $p = 0.358$). However, it has been observed significant correlations for each year: 2009 ($r = 0.963^{**}$), 2010 ($r = 0.949^{**}$) and 2011 ($r = 0.894^{**}$). A statistically significant correlation was also obtained for the entire study period ($r = 0.942^{**}$, $p < 0.001$).

Wilcoxon's test has shown significant differences in the daily pollen count between the two samplers in the case of *Olea* and Pinaceae, but not for *Quercus*,

Table 2 Wilcoxon's test comparing the daily pollen count for predominant pollen types, at 16 m and at ground level in the spring (21 March–21 June), from 2009 to 2011

Statist	Pollen type				
	<i>Quercus</i>	Poaceae	<i>Olea</i>	Pinaceae	<i>Plantago</i>
Z	−1.510	−1.322	−2.500	−3.537	−0.653
p	0.131	0.186	0.012	<0.001	0.514

Poaceae and *Plantago* (Table 2; Fig. 5). However, significant Spearman's correlations were found for all predominant pollen types, *Quercus*, Poaceae, *Olea*, *Plantago* and Pinaceae (Table 3).

The daily pollen count at the *t* and *g* sites showed significant correlations with relative humidity ($r = -0.141^{**}$, $p = 0.013$; $r = -0.165^{**}$, $p = 0.004$), rainfall ($r = -0.260^{**}$, $p < 0.001$; $r = -0.294^{**}$, $p < 0.001$) and minimum temperature ($r = -0.178^{**}$, $p = 0.002$; $r = -0.156^{**}$, $p = 0.006$). All of the predominant pollen types showed significant correlations at the *t* and *g* sites with Sr and $T_{\max}$, T_{mean} and $T_{\min}$. Poaceae pollen also correlated with Rh and R, and these data indicated that this was the pollen with the best correlation with the meteorological parameters. Pinaceae was the only pollen type whose levels showed significant correlations at both sites with the wind direction ($r = 0.132^{*}$, $p = 0.021$; $r = 0.141^{*}$, $p = 0.014$) and the wind speed ($r = 0.188^{**}$, $p < 0.001$; $r = 0.211^{**}$, $p < 0.001$).

Figure 6 shows the hourly average concentrations for the five predominant pollen types at each sampling point. Table 4 shows statically significant correlations between the peak hour in the curve during the five selected days for *Quercus*, Poaceae, *Olea* and *Plantago* and the meteorological parameters; nonstatistical correlation has been observed in the case of Pinaceae. Figure 7 represents only the most statistically significant

Table 3 Spearman's correlation test comparing the daily pollen count for predominant pollen types, at 16 m and at ground level in the spring (21 March–21 June), from 2009 to 2011

Statist	Pollen type				
	<i>Quercus</i>	Poaceae	<i>Olea</i>	Pinaceae	<i>Plantago</i>
r	0.953	0.932	0.951	0.866	0.825
p	<0.001	<0.001	<0.001	<0.001	<0.001

results. The Rh and the mean temperature showed significant negative and positive correlations, respectively, with *Quercus* and Poaceae pollen. The Sr showed a significant positive correlation with Poaceae, *Olea* and *Plantago* pollen, and the Ws showed a significant positive correlation with Poaceae pollen. The Wd only showed a significant correlation with Poaceae pollen at the *g* site ($r = -0.204^{*}$, $p = 0.025$).

Intradiurnal pollen peak were recorded from 1000 to 1400 hours for *Plantago* pollen, from 1200 to 1600 hours for *Quercus*, from 10:00 to 15:00 for *Olea*, from 1200 to 1600 hours for Pinaceae pollen and from 1500 to 2000 hours for Poaceae pollen. The highest intradiurnal pollen peak of the predominant pollen types was recorded on different days. The highest intradiurnal pollen peaks were reached for two sites in nearly 3 h (statistical average 2 h 48 min), although in the case of *Plantago* were found more differences, near 13 h at May 12, 2011 (Fig. 7d). On the average, the pollen peaks of all species were generally recorded between 1100 and 1800 hours; although in some occasion, they appeared out of this period of time even during the night (Fig. 7a–c). Average intradiurnal pollen peak appeared first at the *g* site (1236 hours) and later at the *t* site (1354 hours) and also occurred at the same time in the two sites in the 30 % of the cases (Fig. 7). The comparisons of the intradiurnal pollen

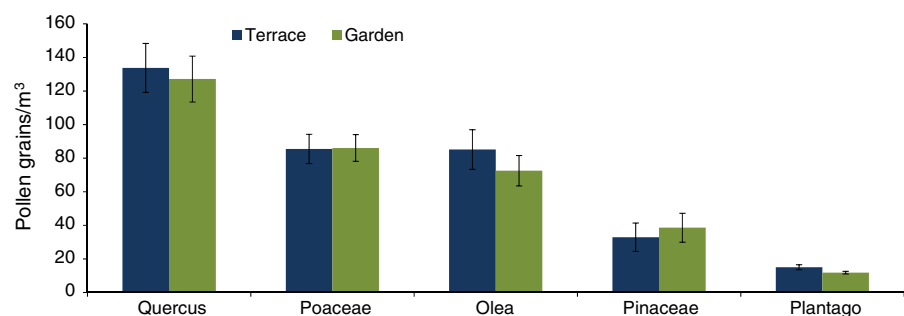
Fig. 5 Average daily pollen concentrations (pollen grains/m³) of the predominant pollen types (*Quercus*, Poaceae, *Olea*, Pinaceae and *Plantago*) at 16 m (*t*) and at the ground level (*g*). The error bars represent the standard error

Fig. 6 Intradiurnal pollen count for **a** *Quercus*, **b** *Poaceae*, **c** *Olea*, **d** *Pinaceae* and **e** *Plantago* at the Faculty of Sciences at 16 m (*t*) and at the ground level (*g*) in the main pollen season during the spring (21 March–21 June), from 2009 to 2011. The *error bars* represent the standard error

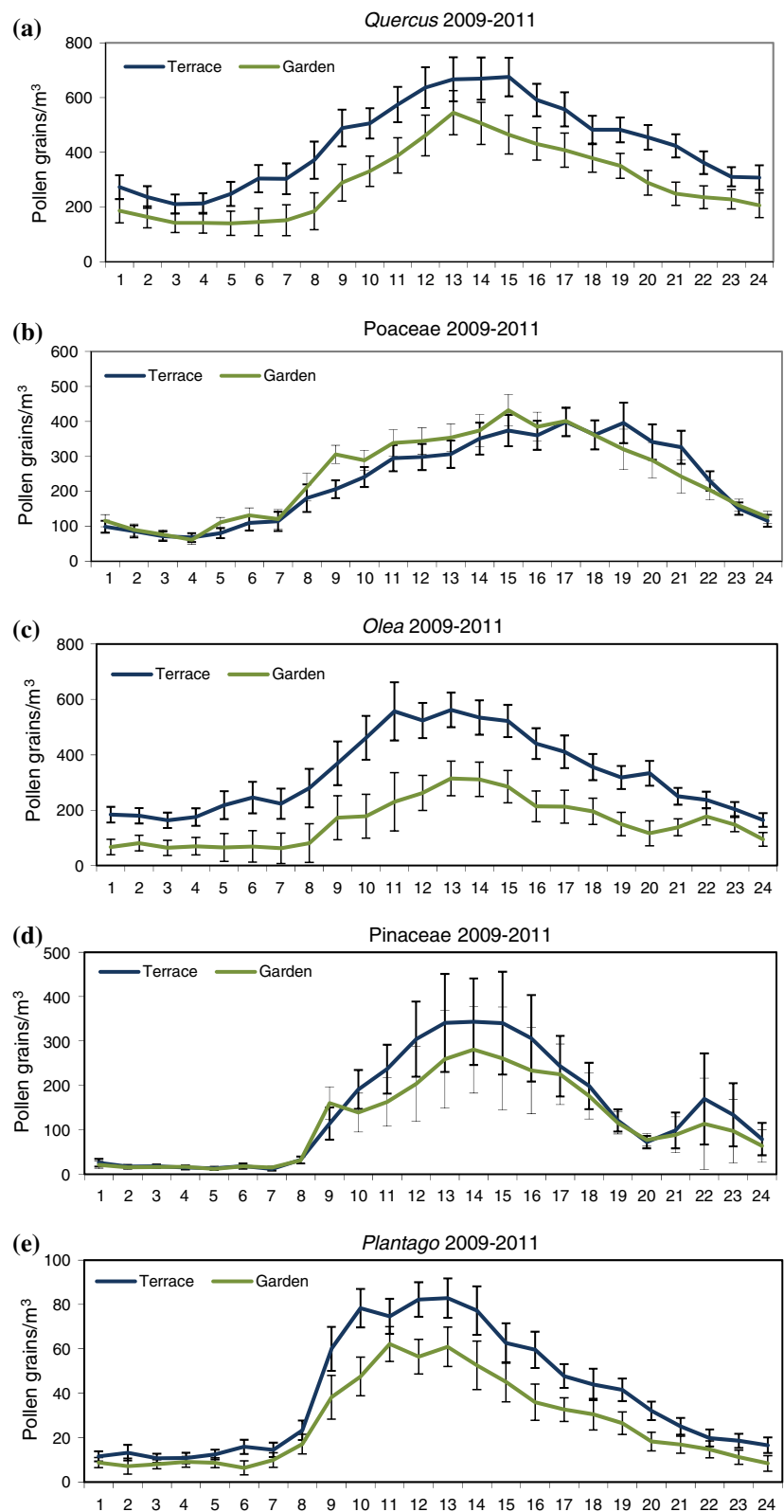


Table 4 Spearman's test in those cases with significant correlations between the 5 days that include each pollen peak in each year of *Quercus*, Poaceae, *Olea* and *Plantago* and themeteorological parameters, Ws, Rh, Sr and T_{mean} , at the Faculty of Sciences at 16 m (*t*) and at the ground level (*g*)

Pollen type	Meteorological parameters	Statist	Site studied					
			<i>t</i> Spring 2009	<i>g</i>	<i>t</i> Spring 2010	<i>g</i>	<i>t</i> Spring 2011	<i>g</i>
<i>Quercus</i>	Rh.	<i>r</i>	−0.432**	−0.402**	−0.430**	−0.414**	−0.310**	−0.349**
		<i>p</i>	<0.001	<0.001	<0.001	<0.001	0.001	<0.001
	T_{mean}	<i>r</i>	0.693**	0.612**	0.210*	0.247**	0.327**	0.369**
		<i>p</i>	<0.001	<0.001	0.021	0.007	<0.001	<0.001
Poaceae	Rh.	<i>r</i>	−0.644**	−0.548**	−0.612**	−0.433**	−0.542**	−0.565**
		<i>p</i>	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Sr	<i>r</i>	0.726**	0.622**	0.461**	0.467**	0.532**	0.381**
		<i>p</i>	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	T_{mean}	<i>r</i>	0.663**	0.706**	0.614**	0.422**	0.490**	0.386**
		<i>p</i>	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Ws	<i>r</i>	0.459**	0.606**	0.495**	0.412**	0.237**	0.239**
		<i>p</i>	<0.001	<0.001	<0.001	<0.001	0.009	0.008
<i>Olea</i>	Sr.	<i>r</i>	0.376**	0.370**	0.483**	0.456**	0.217*	0.416**
		<i>p</i>	<0.001	<0.001	<0.001	<0.001	0.017	<0.001
<i>Plantago</i>	Sr.	<i>r</i>	0.657**	0.553**	0.404**	0.387**	0.222*	0.202*
		<i>p</i>	<0.001	<0.001	<0.001	<0.001	0.015	0.027

count at the two sites showed significant differences for *Olea*, Pinaceae and *Plantago*, but not for *Quercus* and Poaceae (Table 5). Statistically significant correlations were found between the two sites for the levels of *Quercus* ($r = 0.863^{**}$), Poaceae ($r = 0.683^{**}$), *Olea* ($r = 0.650^{**}$), Pinaceae ($r = 0.717^{**}$) and *Plantago* ($r = 0.339^{**}$). The significance levels were $p < 0.001$ in all of the cases.

4 Discussion

Most of the previous studies were conducted in Europe and North America, and the length of the sampling ranged from 1 to 2 years (Lyon et al. 1984, Bryant et al. 1989, Galán et al. 1995). These papers have not studied the airborne pollen, neither the meteorological parameters under intradiurnal variations. Only Tormo et al. (2013) studied the hourly variations of four samplers analyzed together. Furthermore, the precise distribution of the pollen sources was not considered when explaining the data. These previous studies were conducted within a range between ground level and 15–20 m in height and showed differences of the

height in pollen concentration. In this study, the absence of significant differences in the daily pollen count between the ground level and the terrace level and the significant correlations found between the sites concur with Rantio-Lentimäki et al. (1991b), Galán et al. (1995), Alcázar et al. (1999) and Thibaudon and Sulmont (2002), but not with Raynor et al. (1973), Bryant et al. (1989), Chakraborty et al. (2001) and Asensio et al. (2003). These latter studies included higher sampling heights or more sampling points, which could partly explain the differences found. Raynor et al. (1973) studied five different heights ranging from 1.5 to 108 m, whereas Bryant et al. (1989) situated the samplers at 45 m. Asensio et al. (2003) studied airborne pollen on 8 different flat floors. The studies with results similar to those in the present study applied a similar sampling design as this study.

Among the five defined major pollen types, only *Olea* and Pinaceae daily pollen count showed significant differences between the two heights. However, significant correlations were found for all of the major pollen types studied between the two heights. In the case of Pinaceae pollen type, significant differences at

Fig. 7 Intradiurnal pollen curve of selected pollen types at 16 m (*t*) and at the ground level (*g*) with some meteorological parameters. **a** *Quercus* with wind speed, **b** Pinaceae with wind direction, **c** Poaceae with mean temperature, **d** *Plantago* with relative humidity, **e** *Olea* with wind speed

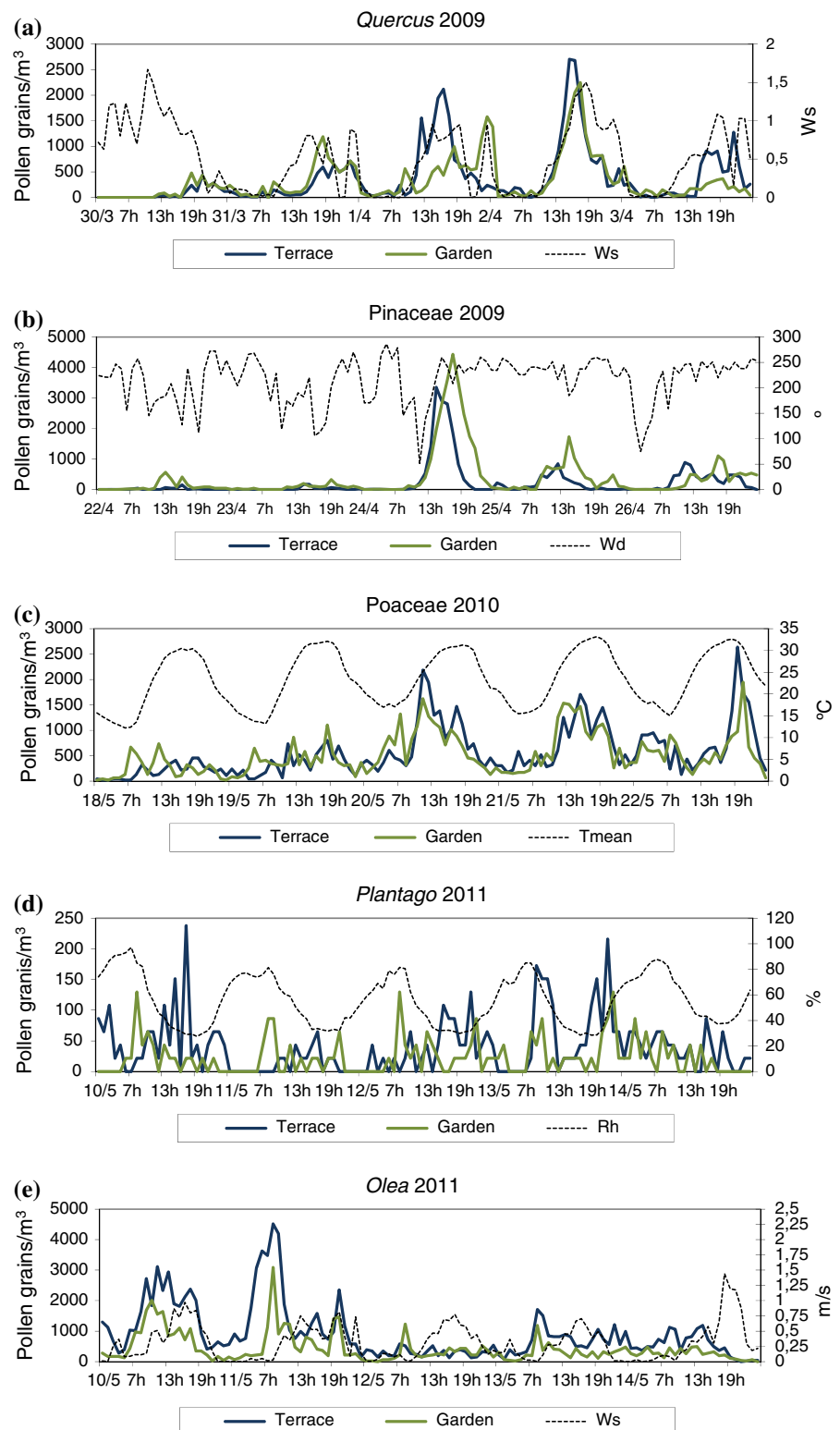


Table 5 Wilcoxon's test results comparing the 5 days that include each pollen peak in each year of the predominant pollen types, at 16 m and at the ground level in the spring (21 March–21 June), from 2009 to 2011

Statist	Pollen type				
	<i>Quercus</i>	Poaceae	<i>Olea</i>	Pinaceae	<i>Plantago</i>
Z	−0.109	−0.078	−6.621	−4.841	−7.058
p	0.913	0.938	<0.001	<0.001	<0.001

Numbers in bold show statistically significant differences

two heights may be due to the possible barrier effect of the building with the terrace and the proximity of the pine trees. The large size of the pollen grains of Pinaceae and the proximity of its pollen source could have caused a greater concentration at the ground level, as indicated by the t/g ratio (0.85). Moreover, the local meteorological conditions (namely Ws and direction) could affect this pollen distribution that seems to be released in a large amount within a few days. In fact, Pinaceae was the only pollen type that showed a significant correlation between the daily concentration at both heights with Wd and speed.

On the other hand, different papers have hypothesized that the relative abundance of the pollen species located at different heights could be based on the proximity of their origins (Bryant et al. 1989). In this paper, it has been observed that differences in *Olea* pollen between the two sites may be due to the closeness of the sources. The t/g ratio of *Olea* (1.17) could confirm this claim, as could be the absence of abundant sources of *Olea* pollen in the vicinity of the site. On the contrary, the absence of significant differences between the sites of *Quercus* and Poaceae pollen could be due to the wide distribution of pollen sources. The t/g ratios of these pollen types were 1.05 and 0.99, respectively. *Plantago*, with a t/g ratio of 1.25, showed significant differences in the intradiurnal, but not the daily, pollen count between the sites. The relevance of this result is small because the average daily pollen count in the terrace and the garden were 15 and 12 pollen grains/m³, respectively.

Bryant et al. (1989) found significant differences in the concentrations of *Quercus* and Poaceae at various heights. On the other hand, they found no such differences for *Pinus* in all cases oppositely to our results. They hypothesized that the relative abundance of the pollen species located at different heights could be based on the proximity of their origins. Galán et al.

(1995) observed that for the major pollen types (*Olea*, *Plantago* and Poaceae) there were no significant differences in concentration at different heights, whereas we have found them in *Olea*, Pinaceae and *Plantago*. Thibaudon and Sulmont (2002) did not find these differences for *Quercus* and Poaceae. The significant correlations found in this study for all major pollen types agree with the study of Rantio-Lehtimäki et al. (1991b), which showed significant correlations between the pollen concentrations at the two sampling heights for Poaceae, *Pinus* and *Quercus* and more pollen types.

Some studies have also considered the vegetation distribution in the vicinity of the site, although these studies have not considered monitoring at different heights. The present study included the major ornamental species Cupressaceae, Ulmaceae, Oleaceae, Pinaceae, Meliaceae and Platanaceae. Fernandes and Mendonça (2004) indicated that the major trees in Beja (Portugal) were in the families Ulmaceae, Cupressaceae and Meliaceae. Staffolani et al. (2011) showed a great number of potentially allergenic species, mainly Cupressaceae, Oleaceae and Pinaceae, in Córdoba (Spain) and in Ascoli Piceno (Italy).

In general, particle concentrations usually decrease with height (Rantio-Lehtimäki et al. 1991b; Galán et al. 1991; Bergamini et al. 2004). However, the pattern depended on the time of day. Average intradiurnal pollen peak of the 5 days that include each pollen peak in each year have shown pollen peaks first at the garden level than at the terrace. These facts could be explained by the transport time (a product of the distance and the Ws) from the source to the sampler (Stach et al. 2007). The significant correlations in the intradiurnal pollen counts between the two sites suggest that height has little effect on pollen count, although it is important to consider variation due to the proximity of the sources (Alcázar and Comtois 2000) and of buildings (Bryant et al. 1989), as well as the tendency of large particles to reside at lower heights than small particles (Chakraborty et al. 2001). As a consequence of this variability, this study found nearly 3 h (2 h and 48 min) on average between the hourly maximum concentrations of the two sites, with a maximum difference of 13 h. In this paper, the maximum concentrations between the two sites occurred at the same time in 30 % of the cases. These differences in the timing of pollen peak be explained by turbulence that results in nonhomogenous pollen

distribution; other authors suggested that these differences could be due to variations in the environmental conditions and in the spatial distribution of the pollen sources (Piotrowska 2004; Alcázar et al. 2009). Significant differences were also found in both, daily and intradiurnal pollen count between the two sites for *Olea*, *Plantago* and Pinaceae, but not for *Quercus* or Poaceae. Few significant correlations were found at either site between the hourly concentrations of *Quercus*, *Olea* and *Plantago* and the meteorological parameters. However, at the garden level, the proximity of some of the species as *Dactylis glomerata* and *Piptatherum miliaceum* to the sampling sites probably resulted in a significant positive correlation between the intradiurnal concentration of Poaceae and the Rh, the Sr, the mean temperature and the Ws.

5 Conclusions

Daily pollen count at 1.5 and 16 m has shown similar results. However, differences have been observed when different pollen types were separately analyzed, and also at intradiurnal scale. These differences may be partly explained by the unequal distribution of the sources and the disturbance from nearby buildings, as no differences have been observed on the different meteorological parameters. The temporal variation patterns were the same for all of the species, although the maximum concentration was obtained first at the ground level and later at 16 m.

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