

Aerobiological study of Fagaceae pollen in the middle-west of Spain

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Abstract The concentration of airborne Fagaceae pollen in Salamanca and the correlations with some meteorological parameters have been examined. *Castanea* and *Quercus* pollen grains were collected from 1998 to 2004 using a Burkard spore trap. No pollen grains of *Fagus* were found. The main pollen season took place in April and May for *Quercus* and in June and July for *Castanea*. Yearly variations on these dates could be related to the influence of meteorological factors such as rainfall, temperature, or dominant winds. The highest values appeared in the year 2004 for both taxa. The Fagaceae airborne content was mainly due to *Quercus* pollen, *Castanea* having a scarce pollen content in the city of Salamanca. The highest counts of Fagaceae pollen grains were found from mid May to early June due to the pollen behavior of oaks. The cumulative counts varied over the years, with a mean value of 2,384 pollen grains, a highest total of 6,036 in 2004 and a lowest total of 954 in 2001. No cyclic variations were observed. Daily pollen concentrations presented positive correlation with temperature, negative with relative humidity and slightly negative with rainfall using Spearman's correlation coefficients, only in the

case of *Castanea*, because the particular hourly distribution of rainfall during the spring might affect *Quercus* airborne pollen.

Keywords *Castanea* · Fagaceae · Meteorology · Pollen · *Quercus* · Salamanca · Spain

1 Introduction

The Fagaceae family is widespread in the temperate zone of the northern hemisphere. The different genera of this botanical family produce pollen grains during the spring and early summer months in some European sites (Spieksma 1991). These pollen grains are the main source of allergens from trees in springtime (D'Amato 2001). Different processes of cross-sensitivity are frequent among three families of the Fagals: Betulaceae, Corylaceae, and Fagaceae (Dalen and Voorhost 1981), because subjects who are positive to antigens of *Betula* have positive reactions to other antigens of other genera belonging to the related families. However, the Fagaceae family, in spite of the great pollen production of some of its genera (Tormo Molina et al. 1996), could only be responsible for allergenic symptoms when airborne pollen grains are abundant (Ickovic and Thibaudon 1991; Holmquist et al. 2005), playing only, therefore, a supporting role in inducing pollinosis in Europe.

The Fagaceae family is very important from different points of view, such as the ecological,

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forestry, or economical, due to the great amount of Fagaceae forests in different parts of the world. In fact, the relationship between airborne Fagaceae pollen behavior and climate also is of great interest for aerobiology and forestry sciences. During the last years, the behavior of the pollen seasons and their fluctuation in the annual totals over several years, with a special regard to meteorological parameters, has been studied for some sites and genera (González-Parrado et al. 2006; Peternel et al. 2006) and, specifically, for Fagaceae (Corden and Millington 1999; Iglesias et al. 1999; Rodríguez Rajo et al. 2000; Jato et al. 2001; García-Mozo et al. 2002; Rizzi-Longo et al. 2005).

Due to the great interest in Fagaceae pollen in some related fields and the small number of airborne pollen content studies in the city of Salamanca (Hernández Prieto et al. 1998; Sánchez Reyes et al. 2004), a detailed study of Fagaceae pollen behavior regarding the main meteorological parameters has been carried out.

2 Materials and methods

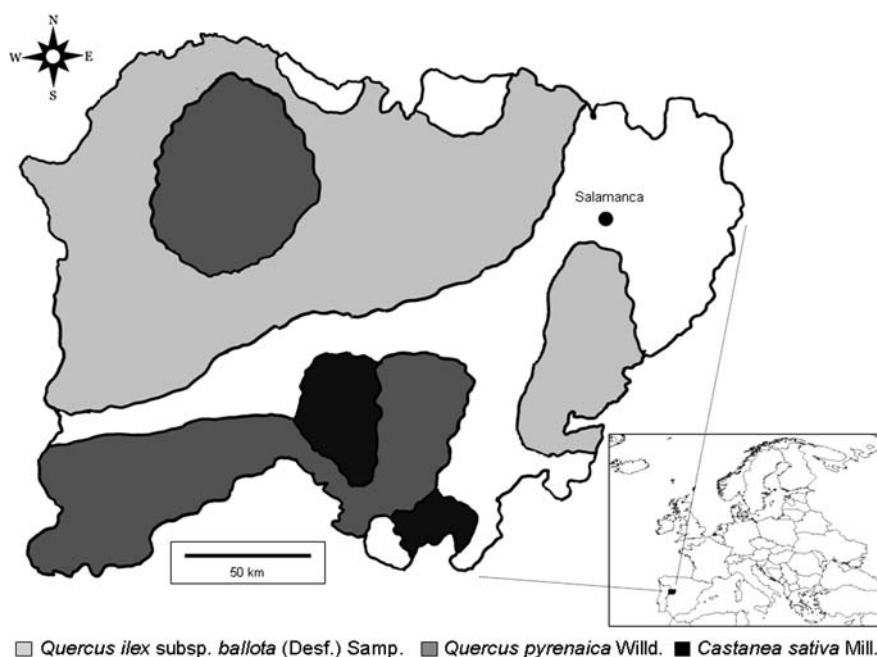
Aerobiological samples were collected from 1 January 1998 to 31 December 2004 using a Burkard 7-day

volumetric spore trap located in a historic center building placed 20 m above ground level. Sampling method, slide preparation, and data interpretation were performed according to the Spanish Aerobiology Network (Domínguez et al. 1991).

Salamanca stands in the mid-west of the Iberian peninsula (40°58'N; 5°40'W; U.T.M. 30TTL74) at 800 m above sea level, and it has around 180,000 inhabitants. The climate is Mediterranean continental, characterized by a low annual rainfall level (382 mm) that determines a dry season in the summer period. On average 66 days per year have precipitation, mainly during the spring and autumn. The annual mean temperature is 11.7°C, the mean maximum temperature is 17.9°C, and the mean minimum temperature is 5.5°C, with rigorous winters and hot summers.

In terms of biogeography, the city belongs to the Mediterranean region (Rivas-Martínez et al. 2002), to the Mediterranean West Iberian Province and, to a lesser extent, the Mediterranean Central Iberian Province. This region is characterized by wide expanses of pastures with, essentially, holm oaks (*Quercus ilex* L. subsp. *ballota* (Desf.) Samp.), which are characteristic of the *Genisto hystricis-Quercetum rotundifoliae* sigmetum (Rivas-Martínez 1987). Forests with oak trees (*Quercus pyrenaica* Willd.) are mainly located in

Fig. 1 Geographical location and distribution of main Fagaceae forests in Salamanca



mountainous areas in the west and south-west (Fig. 1), belonging to the *Luzulo forsteri-Quercetum pyrenicae* sigmetum and the *Genisto falcatae-Quercetum pyrenaicae* sigmetum, while other small and humid forests are represented by the *Holco mollis-Quercetum pyrenaicae* sigmetum. Other species of this genus are present in nearby areas not too far from the city of Salamanca. Gall-oak (*Quercus faginea* Lam.), a Mediterranean vegetation element, grows in mixed pastures located in the north and the west areas of the town. English oak (*Quercus robur* L.), a European element that needs deep and humid soils, forms small forests in the south. Cork oak (*Quercus suber* L.), a West Mediterranean element, is common in forests and pastures located in several areas of the north, south, and west. Red oak (*Quercus rubra* L.), an introduced species, is rarely cultivated. The other widespread genus of the Fagaceae family, *Castanea*, is represented by one species near the city, *Castanea sativa* Mill, a European element, which requires deep and acid soils. In all the areas in which chestnut trees grow, principally in the south, it seems not to be spontaneous. In case of beech (*Fagus sylvatica* L.), a typical European element, there is one tree of uncertain origin in a chestnut forest.

Pollen grains of *Castanea* and *Quercus* were separately counted and their known morphological differences given (Van Benthem et al. 1984; Díez and Suárez 1987) using a Nikon Optiphot microscope (40×/0.70 objective). The pollen data are expressed as pollen grains per cubic meter of air (pollen/m³), and the two genera were individually and then cumulatively (as Fagaceae) evaluated. For graphic presentation, the daily variations are presented from May to August for *Castanea* and from March to June for *Quercus*. For each year, the main pollen season (MPS) was determined by taking 90% of the annual

total recorded pollen concentration using cumulative values (Nilsson and Persson 1981). Starting and ending dates were established to correspond to the days when the sum of the daily concentrations reaches 5% of the total sum and when the sum reaches 95%, respectively.

The Spearman's correlation coefficients between daily pollen concentration (expressed as pollen/m³) and some daily meteorological parameters (mean, minimum and maximum temperature expressed in °C; relative humidity in %; rainfall expressed in mm; mean wind speed expressed in m/s) were analyzed. The non-parametric Spearman's coefficient was chosen because daily pollen counts are not normally distributed. These correlations have been calculated for each year and taxon. Meteorological data were supplied by the Spanish National Institute of Meteorology, whose meteorological station (Matacán) is located 10 km east of the pollen sampling site. Statistical analysis was carried out by SPSS (v.13) software package.

3 Results

In the atmosphere of the city of Salamanca, pollen grains of *Fagus* were not found from 1998 to 2004. The annual sums of Fagaceae, including the share of *Castanea* and *Quercus* indicated by different shades in Fig. 2, were rather variable in the studied period. The mean value was 2,384, with the highest total of 6,036 in 2004 and the lowest total of 954 in 2001. Years 1999 and 2002 also displayed rather high and lower annual sums, with 2,221 and 2,342, respectively. The percentage of the Fagaceae annual sum in respect to total pollen count ranged from 9.8% in 2001 to 33% in 2002, with 18.5% as mean value. The high percentage

Fig. 2 Fagaceae pollen totals in the city of Salamanca from 1998 to 2004

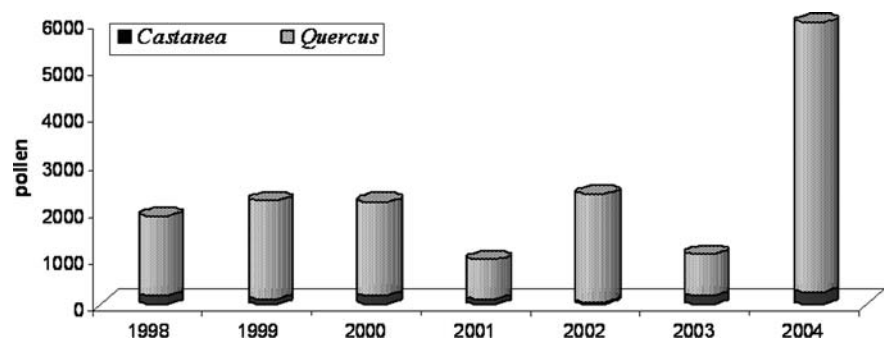
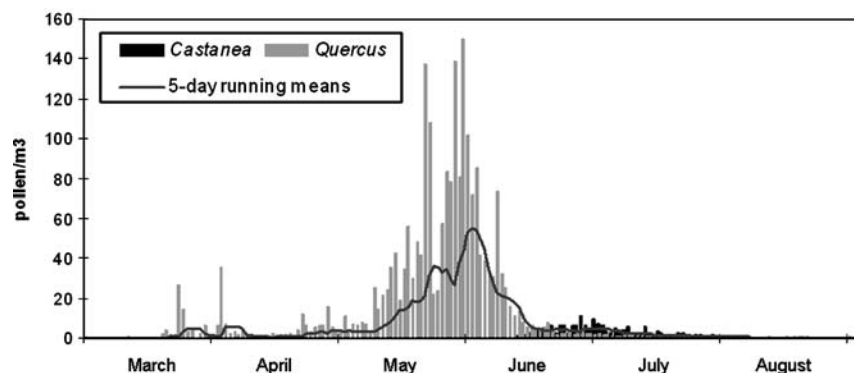


Fig. 3 Daily variation of the average of the daily pollen counts of Fagaceae in Salamanca for the studied period. Different shades show the share of the two genera. The line shows the 5-day running means



of 2004 was due to *Quercus*, which reached almost a third of the total airborne pollen content.

The highest values for *Quercus* occurred in 1999, 2002, and 2004 and for *Castanea* in 1998, 2000, and 2004. The percentage of *Quercus* in the annual sum of Fagaceae is very high, ranging from 97.5% in 2002 to 82.7% in 2003, with a mean value of 91%. Consequently, *Castanea* shows a mean value of 9%, ranging from 17.4% in 2003 and 2.5% in 2002.

The seasonal variations in the average of the daily pollen concentrations of Fagaceae for the studied period from 1 March to 31 August are analyzed in Fig. 3. The share of *Castanea* and *Quercus* in the daily amount of Fagaceae is indicated by three different shades. The gray line shows the seasonal course of the average of the 5-day running means.

The presence of Fagaceae pollen grains already started from mid-late March. From late April, the levels of daily pollen increased gradually until the last week of May (29 May), when they reached the highest mean daily value (150 pollen/m³). Subsequently, the mean counts decreased until mid June, then increased slightly again the last week of June and reached 11 pollen/m³ (26 June). During March and mid April, the daily percentage of Fagaceae in respect to the daily total pollen catch was low (14% in the highest peaking day), while during late April and May it became higher and reached, on the peak day, about a quarter of the total airborne pollen content.

The seasonal course of the average of the 5-day running means for these 6 years showed a principal pollen period from late April to early June due to the pollen behavior of *Quercus*. From late June, *Castanea* began its flowering period, and the values of Fagaceae increased slightly again until early July, when these values decreased. In this case, the levels

of Fagaceae pollen were lower than those detected during spring.

The main dispersal time of *Castanea* usually took place from June to the beginning of August. Successive peaks occurred from late June to mid July, but *Castanea* pollen grains may frequently be found in air samples, even when the flowering season is over. As expected, there were several peaks alternating with days of low pollen concentrations (Fig. 4).

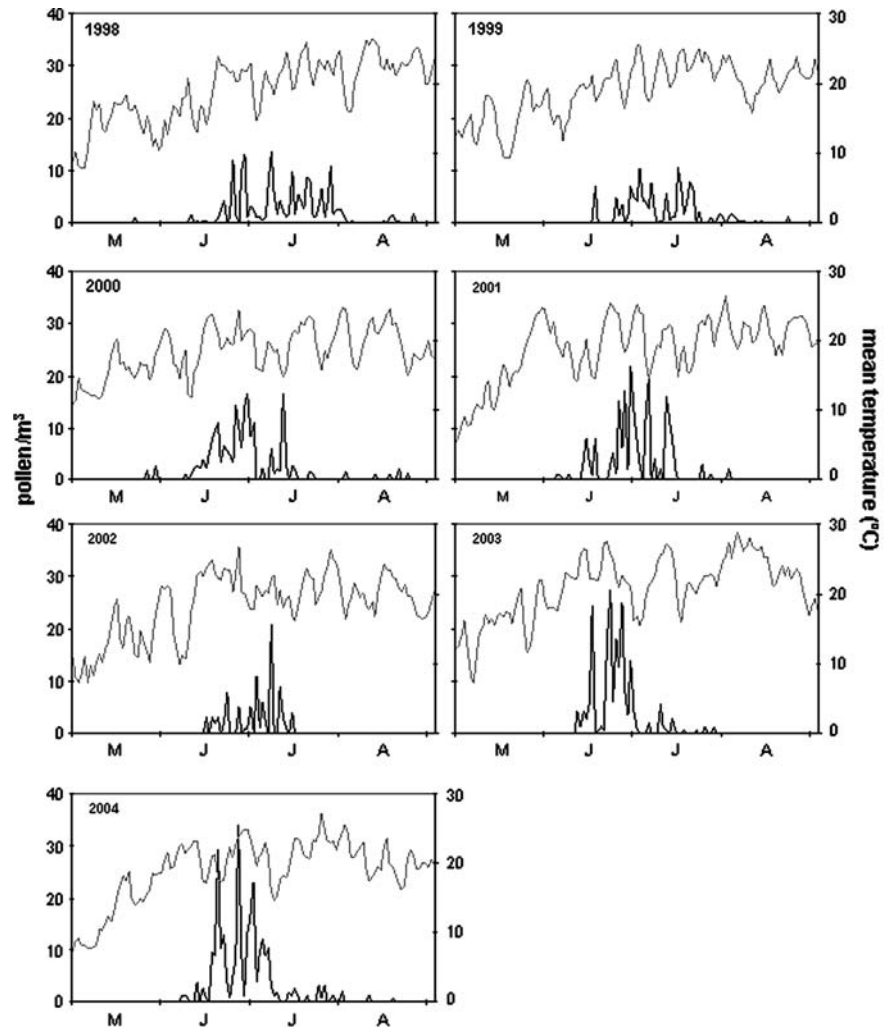
The mean values of the annual sums are shown in Table 1 and were 166, with the highest total of 268, 204, and 191 in 2004, 2000, and 1998, respectively. The lowest annual total of 58 was reached in 2002. The percentage of the chestnut annual sum with respect to the total annual sum was very low, with 1.4% as a mean value, ranging from 0.7% in 2002 to 2.2% in 2003.

The highest daily pollen values usually occurred in late June or mid July, with the earliest peak on 22 June 2003 (25 pollen/m³) and the latest on 14 July 1998 (14 pollen/m³). The average of the maximal daily counts was 26 June. The average peak value was 11 pollen/m³, with the highest value on 26 June 2004 (34 pollen/m³), and the lowest on 2 July 1999 (11 pollen/m³). The daily percentage of *Castanea* grains with respect to the daily total pollen concentrations was rather low, reaching on average about a tenth of the total airborne pollen content (9.7%) in the peaking day.

On average, the MPS started on 17 June and ended on 23 July. The duration of the MPS ranged between 29 and 47 days, and its mean length was 37 days.

The share of the *Quercus* annual sum in respect to the total pollen counts was rather high, ranging from 8.5% in 2001 to 31% in 2004, with 18.5% as mean value. The mean value of the annual sums was 2,218,

Fig. 4 Annual daily variation in daily airborne *Castanea* pollen and mean temperature (gray line) in Salamanca each year from 1998 to 2004



with the highest total of 5,768 in 2004 and the lowest of 825 in 2001 (Table 1).

The highest daily pollen values usually appeared in mid-late May, with the earliest peak on 8 May 1998 (148 pollen/m³) and the latest on 27 May 1999 (250 pollen/m³) and 2004 (513 pollen/m³). On average, the maximal daily counts of 150 pollen/m³ occurred on 29 May. The highest value appeared on 27 May 2004 (513 pollen/m³), and the lowest on 21 May 2001 (47 pollen/m³). The daily percentage of oak pollen grains in respect to the daily total airborne pollen was very high, almost a half (49%) on the average peak day and reaching, on average, 26% of daily pollen concentrations from late April to the end of May.

The average of MPS starting date is 16 April. The MPS ends on average on 9 June. The duration of the MPS ranged between 37 and 83 days, the mean length of the MPS being 55 days.

The correlations between daily pollen concentration and temperature (mean, minimum, and maximum) resulted mildly positive and significant (Table 2). The values of correlation between the daily pollen concentration and the relative humidity were negative for these two taxa. In respect to the other meteorological parameters analyzed, there were slightly negative correlations between *Castanea* daily pollen concentrations and rainfall, while the correlations between *Quercus* daily concentrations and mean wind speed were slightly positive.

Table 1 Aerobiological parameters for the two genera of Fagaceae present in the atmosphere during the studied period

	1998	1999	2000	2001	2002	2003	2004	Mean
<i>Castanea</i>								
Annual total	191	120	204	129	58	187	268	166
Date of peak day (peak value)	14 July (14)	2 July (11)	29 June, 11 July (11)	29 June (16)	7 July (13)	22 June (25)	26 June (34)	26 June (11)
Starting/ending date of MPS	19 June/1 August	16 June/2 August	10 June/15 July	13 June/14 July	15 June/14 July	12 June/20 July	17 June/15 July	17 June/23 July
Length of MPS (days)	43	47	35	31	29	38	29	37
<i>Quercus</i>								
Annual total	1,691	2,093	1,982	825	2,284	883	5,768	2,218
Date of peak day (peak value)	8 May (148)	27 May (250)	24 May (279)	21 May (47)	21 May (394)	16 May (97)	27 May (513)	29 May (150)
Starting/ending date of MPS	20 March/11 June	27 April/4 June	1 April/3 June	21 March/2 June	27 April/3 June	20 April/3 June	27 April/11 June	16 April/9 June
Length of MPS (days)	83	39	64	73	37	44	46	55

4 Discussion

The pollen behavior of Fagaceae in Salamanca corresponds to that already described during the pollen season in Europe (Ickovic and Thibaudon 1991): *Quercus* in April and May; *Castanea* in June and July. Yearly variations of these dates could be related to the influence of some meteorological factors. In this way, delays in the dates of the pollen season could be related to local precipitations inducing atmospheric wash in the moment when flowering starts and these pollen types begin to appear in the atmosphere. However, as previously stated, there was a small peak of *Quercus* pollen grains in late March and early April. In the case of the years 1998 and 2001, the small peaks of *Quercus* pollen grains detected in late March and early April could be related to the high mean daily temperatures of the first 3 months of the year. In fact, the mean temperature of January, February, and March in these years was almost 2°C higher than in the reference mean period (1971–2000) and may induce early spring flowering of some holm oaks and cork oaks trees located in some southern and western termophilous areas. Finally, in some cases the pollen shedding course of *Quercus* usually occurred from late March to early June (Fig. 5), and this course may start previously due to the influence of wind coming from areas where early flowering of some holm oaks and cork oaks (García-Mozo et al. 2006) located about 70 km away from the city was detected.

The highest values that appeared from mid May to early June could be explained by the main pollen shedding of *Quercus*, whose various species are widespread in many areas located near the city. These species have a successive pattern of pollen shedding course, owing to the shift of flowering times in trees growing in different local climatic sites, mainly in southern and western zones of the administrative province of Salamanca, which may explain the successive oak peak periods observed every year, especially in May. At this point, it must not be omitted that pollen is also carried by dominant winds, bringing a mildly lengthened pollen season, as also occurs in the case of *Castanea*, with a well-studied long-range transport (Peeters and Zooler 1988). Moreover, chestnut pollen grains may come, as in Galicia (Jato et al. 2001), a northwestern region of Spain with a pronounced Atlantic influence, not only

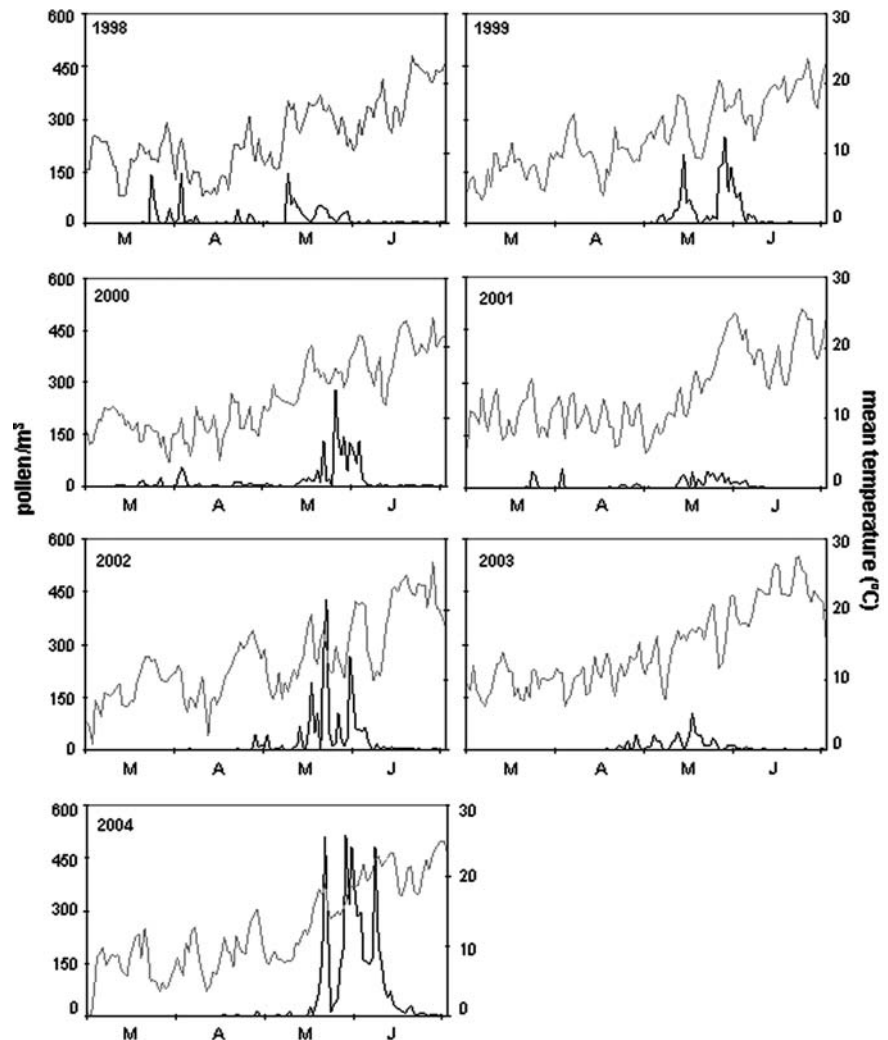
Table 2 Spearman's correlation coefficients for daily pollen counts of *Castanea* and *Quercus* in relation to the meteorological parameters during the studied period

	T_{mean}	T_{max}	T_{min}	R	R_{Hum}	W
<i>Castanea</i>	0.419**	0.405**	0.408**	-0.125**	-0.375**	0.025
<i>Quercus</i>	0.378**	0.361**	0.354**	-0.02	-0.412**	0.126**

T_{mean} : mean daily temperature; T_{max} : maximum daily temperature; T_{min} : minimum daily temperature; R : daily rainfall; R_{Hum} : relative humidity; W : mean wind speed; ** = 99%

from local trees, but also from trees growing at different distances and altitudes. Nevertheless, the low number of *Castanea* pollen grains detected in the city of Salamanca during the studied period may indicate that the mountains located between the chestnut forests and the town could play a role as topographic barrier for these small pollen grains.

The Fagaceae airborne pollen content was mainly due to *Quercus*, but years with a high annual sum of this genus do not coincide with those with a high annual sum of *Castanea*, as already observed in Brussels (Detand and Nolard 2000) and Trieste (Rizzi-Longo et al. 2005), except in the case of 2004, which presented the highest airborne pollen

Fig. 5 Annual daily variation in daily airborne *Quercus* pollen and mean temperature (gray line) in Salamanca in each year from 1998 to 2004

concentrations, especially for *Quercus*. This fact might be explained by the recovery of floral structures that, after an intense drought period during the first years of the study, benefited from the rainy autumns of 2002 and 2003, as occurred in other sites in Spain (García-Mozo et al. 2006).

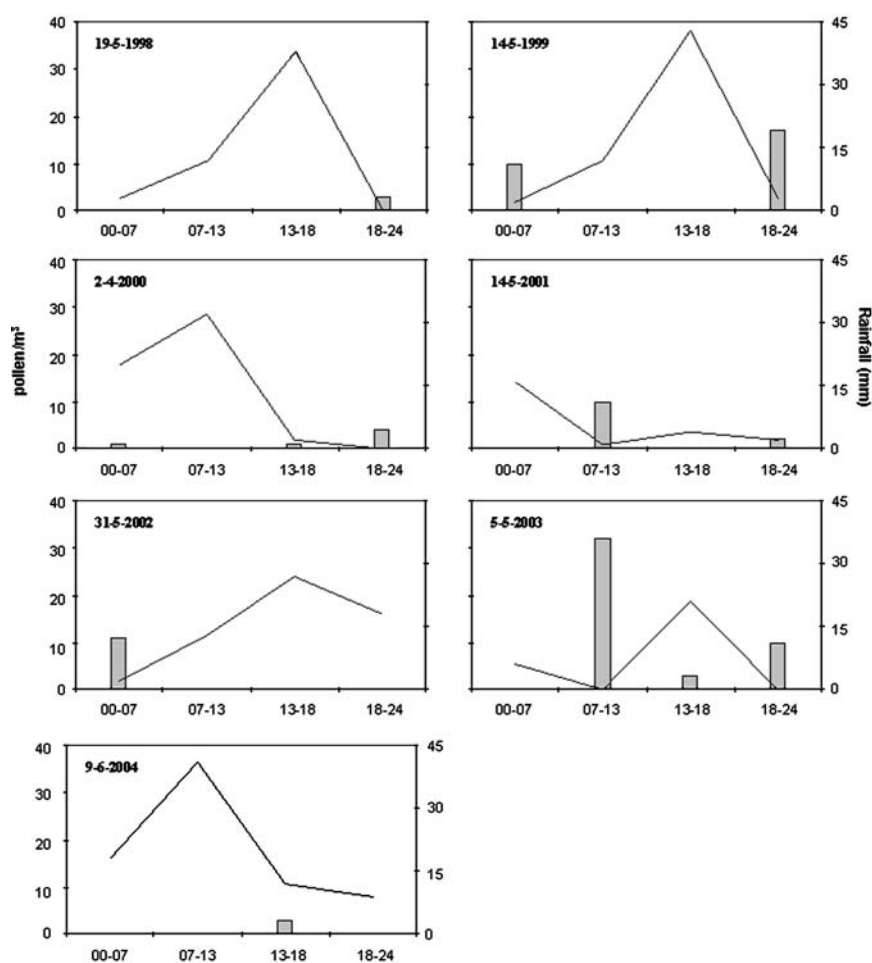
The maximum annual total of Fagaceae was registered in 2004, when high pollen shedding of *Quercus* appeared, as also occurred in 1999, 2000, and 2004, with high pollen totals. The years 2001 and 2003 showed rather low levels of Fagaceae pollen grains, but with a higher contribution of *Castanea*.

During the studied period, a short shift in MPS from year to year appeared, with small differences of 10–20 days in the MPS starting and ending date, except for the *Quercus* MPS starting date, whose differences reached almost 40 days due to the early

flowering of some oak species in the third week of March 1998 and 2001.

The absence of negative significant correlations between *Quercus* pollen concentrations and rainfall might be due to the particular hourly distribution of rainfall throughout the spring and early summer days in Salamanca, as shown in Fig. 6, where 7-h variations of accumulated pollen concentrations and rainfall are represented during some days of the 1998–2004 period. Rainfall takes place only for a few hours on rainy days, while important pollen concentrations can be observed in the remaining hours once the rainfall has finished. In fact, relative humidity, a more invariant daily parameter and related to rainfall, showed negative significant correlations with *Castanea* and *Quercus* airborne pollen. The correlations between Fagaceae pollen

Fig. 6 Seven-hour accumulated concentrations of airborne *Quercus* pollen and rainfall (gray column) in Salamanca during some days of the studied period



concentrations and temperature (mean, maximum, and minimum) were positive and, as Rodríguez-Rajo et al. (2005) stated for *Quercus*, the high level of significance showed that temperature might influence the levels of pollen in this botanical family.

5 Conclusions

The pollen content of Fagaceae in Salamanca corresponds to that already described in Europe: *Quercus* in April and May; *Castanea* in June and July. Yearly variations of these dates could be related to the influence of some meteorological factors such as rainfall, temperature, or dominant winds. The highest values occurred from mid May to early June and are due to the main pollen behavior of the different oak species.

The percentage of the annual sum of these two taxa in respect to total pollen count may be considered as relevant, although *Castanea* pollen concentrations did not reach important values.

Variations in the annual sum of Fagaceae pollen, probably depending on meteorological features and/or physiological cycles, were observed. In this way, neither positive nor negative long-term trends in Fagaceae pollen behavior were noticed in Salamanca during the analyzed period and, in addition, no cyclic variations were observed.

The correlations between daily pollen concentration and some meteorological parameters are slightly positively significant for temperatures (mean, maximum, minimum) and negative for relative humidity for the two genera. In the case of *Quercus*, the absence of negative significant correlations between pollen concentrations and rainfall might be due to the particular hourly distribution of rainfall throughout the spring in the middle-west of Spain.

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