

Dynamics and behaviour of airborne *Quercus* pollen in central Iberian Peninsula

Rosa Pérez-Badía · Verónica Bouso ·
Jesús Rojo · Consolación Vaquero ·
Silvia Sabariego

Received: 2 July 2012 / Accepted: 4 February 2013 / Published online: 19 February 2013
© Springer Science+Business Media Dordrecht 2013

Abstract *Quercus* pollen is one of the most abundant pollen types in the atmosphere of central Iberian Peninsula (Spain), as a consequence of the extensive representation of well-preserved forests and shrub communities dominated by species of the genus *Quercus* in this area. This paper analysed key features of the *Quercus* pollination season in the central Iberian Peninsula and the influence of weather-related variables on airborne *Quercus* pollen concentration through statistical techniques of correlation analysis and the use of a decision tree model for predicting pollen concentrations. *Quercus* species are very common in Spain and Portugal, dominating a number of ecosystems including Mediterranean forests. This gives rise to very high airborne *Quercus* pollen concentrations, particularly in spring. Sampling was carried out over a 6-year period using a Hirst volumetric sampler, and the sampling procedure established by the Spanish Aerobiology Network. Results show that between 92 and 98.5 % of total annual airborne *Quercus* pollen was recorded in the

April–June period. Annual pollen index were high in all study years, averaging 12,344 grains, but it should be highlighted that pollen production was highly variable between years. Correlations between mean daily *Quercus* pollen concentration and weather-related variables showed that in the pre-peak period, a significant positive correlation was observed with the mean daily temperature and the hours of sunshine and a negative correlation was observed with the humidity and the rainfall. In the post-peak period, a significant negative correlation was found with the mean daily temperature and the hours of sunshine. The predictions obtained in the decision tree model showed a moderate significant correlation ($r = 0.42$) with the daily *Quercus* pollen concentration predicted and the one observed. Temperature is the most influential variable in the release of *Quercus* pollen.

Keywords Aerobiology · Atmospheric pollen · Meteorological variables · Decision tree model

R. Pérez-Badía (✉) · V. Bouso · J. Rojo ·
C. Vaquero · S. Sabariego
Área de Botany, Institute of Environmental Sciences,
University of Castilla-La Mancha, Avda. Carlos III s/n.,
45071 Toledo, Spain
e-mail: rosa.perez@uclm.es

S. Sabariego
Department of Plant Biology II, Faculty of Biology,
Complutense University, 28040 Madrid, Spain

1 Introduction

The *Quercus* genus includes over 600 species of wind-pollinated trees and shrubs growing mainly in the northern hemisphere. In Europe, this genus is widely represented by native species, typically in temperate and Mediterranean forests and scrublands. In Spain, there are 13 native oak taxa (species and subspecies) which are of major ecological importance, dominating

a number of Iberian ecosystems. Predominant species in evergreen forests include cork oak (*Quercus suber* L.) and holm oak (*Q. ilex* subsp. *ilex* L. and *Q. ilex* subsp. *ballota* (Desf.) Samp.), while deciduous forests include oak (*Q. robur* L.), *Q. pyrenaica* Willd., *Q. faginea*, *Q. humilis* Miller and *Q. canariensis* Willd. Most of these woodlands are anthropogenic ecosystems of high socio-economic and conservation value and display high biodiversity (Pinto et al. 2011). In the “dehesa”, a semi-natural landscape for animal breeding which covers large areas of the south and west of the Iberian Peninsula, *Q. ilex* subsp. *ballota* is the most abundant tree species. All *Quercus* species are wind pollinated and stenopalynus (pollen grains are not distinguishable under light microscopy) and produce large amounts of pollen, that is, between 2.2 and 4.7×10^4 grains per flower (Gómez-Casero et al. 2004).

Quercus pollen monitoring can be used to evaluate the ecological conservation of Spain’s woodlands. *Quercus* fruit is eaten by certain native species of animals during the seasonal breeding (Cecich and Sullivan 1999; García-Mozo et al. 2002), and furthermore, possible changes in the distribution of oak can mean economically important consequences in the timber and livestock industries (Rodríguez-Rajo et al. 2005; Hidalgo et al. 2008).

Quercus pollen has been cited as a moderate cause of pollen allergy in many parts of Europe (Lewis et al. 1983), and cross-reactions have been reported with allergens of some Fagales, Betulaceae and Poaceae species (Ickovic and Thibaudon 1991). Some research suggests that abundant *Quercus* vegetation can trigger allergies (Negrini and Arobba 1992; Ross et al. 1996; Butland et al. 1997); negative results using skin prick test were reported by Prados et al. (1995), suggesting the low allergenic capacity of the *Quercus* species growing in central Spain.

A number of authors have analysed airborne *Quercus* pollen behaviour in climatically different areas and the influence of weather-related variables on pollen concentrations (Corden and Millington 1999; Recio et al. 1999; Rodríguez de la Cruz et al. 2008). Several papers have reported on methods for forecasting *Quercus* pollen season start dates, daily pollen concentrations and annual pollen emission (García-Mozo et al. 2002; Rodríguez-Rajo et al. 2005; García-Mozo et al. 2006a; Kasprzyk 2009). Predictions of this kind are of great value to ecological and agricultural

research (García-Mozo 2011), and research into airborne *Quercus* pollen behaviour and its relationship with climate factors is of particular interest for aerobiology and forestry sciences (Rizzi-Longo et al. 2005).

The charting of airborne *Quercus* pollen dynamics is especially useful in the Iberian Peninsula, where oaks cover a surface area of thousands of hectares. (Fernández-González 2011; Pinto et al. 2011). Airborne *Quercus* pollen concentrations are very high in central Spain, being surpassed only by Cupressaceae (Pérez-Badia et al. 2010). In this context, the aims of this study were to report on a study of the seasonal dynamics of *Quercus* pollen and analyse the influence of weather-related variables on *Quercus* pollen concentration through statistical correlation analysis and the use of a decision tree model for predicting pollen concentrations.

2 Materials and methods

Airborne *Quercus* pollen was collected in Toledo (39°51'N, 4°01'W) over a 6-year period (2005–2010). Toledo is located at the centre of the Iberian Peninsula in central Spain, 529 metres above sea level (Fig. 1). Bioclimatically, it is situated in the Mesomediterranean belt, with a dry ombrotype (Fernández-González 2011). Marked temperature oscillations are reported throughout the year: Temperatures are low in winter (January: mean 6.4 °C) and high in summer (July: mean 26 °C). Annual mean temperature is 15.4 °C. Rainfall is scarce (mean 382 mm) and mainly concentrated in spring and late autumn, with a remarkable summer drought (Medio Ambiente 2001).

Biogeographically (Table 1), Toledo belongs to the Mediterranean Region (W Mediterranean Sub-region) and, according to Fernández-González (2011), lies on the boundary between two biogeographical provinces: the Mediterranean Central Iberian Province (Castilian Subprovince, Manchegan Sector) and the Mediterranean West Iberian Province (Lusitan-Extremadurean Subprovince, Toledan-Taganean Sector).

Natural vegetation in the Toledo area comprises holm oak forests (*Q. ilex* subsp. *ballota* (Desf.) Samp.), shrubs, bushes and pasturelands alternating with meadows. Holm oak forests are well represented in the hills around Toledo, together with Portuguese oaks

(*Quercus faginea* Lam. subsp. *broteroi* (Cout.) A.Camus), gall oaks (*Quercus pyrenaica* Willd.) and cork oaks (*Q. suber* L.), among other species. Common shrub and bush species include kermes oaks (*Quercus coccifera* L.), terebinth (*Pistacia terebinthus* L.), wild olive trees (*Olea europaea* L., var. *sylvestris* Brot.), strawberry trees (*Arbutus unedo* L.), *Phyllirea angustifolia* L. and buckthorns (*Rhamnus alaternus* L.). Grasses, crucifers, nettles and goosefoot are the most characteristic herbaceous species in forest, ruderal and weed communities.

Airborne *Quercus* pollen was collected by a Hirst volumetric sampler (Hirst 1952), located on the roof of a building on the University of Castilla-La Mancha campus in Toledo, approximately 17 m above ground level. This 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).



Fig. 1 Geographical situation of Toledo in central Spain

The main pollen season (MPS), that is, that portion of the pollen season during which most pollen is recorded, was calculated according to Corden and Millington (1999) and Rodríguez-Rajo et al. (2005) for *Quercus* pollen, following the methodology proposed by Andersen (1991). This method includes 95 % of the seasonal total pollen concentration, 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.

Spearman's correlation analysis was used to determine the relationship between daily pollen concentrations (expressed as grains/m³) and the main weather-related variables. A nonparametric statistic was chosen since the data were not normally distributed. Correlation analysis was performed for all years from 2005 to 2010. The weather-related variables selected were maximum, minimum and mean temperatures ($T_{\max}$, $T_{\min}$, T_{mean} , °C), hours of sunshine (HS, h), rainfall (R , mm), relative humidity (%) and wind speed (m/s).

We considered the daily value for each variable mentioned, the value of each day added to the value of the previous day ($T_{\max-1}$, $T_{\min-1}$, $T_{\text{mean-1}}$, HS-1 and $R-1$) and the value of each day added to the value of 2 preceding days ($T_{\max-2}$, $T_{\min-2}$, $T_{\text{mean-2}}$, HS-2 and $R-2$). Weather data were supplied by the Spanish Meteorological Agency (AEMET).

For the purposes of analysis, following García-Mozo et al. (2006a), the pollen season was divided into two periods: pre-peak period (from the start date up to the pollen peak date) and post-peak period (from the peak date to the end of the pollen season), since previous analyses of the pollen season as a whole did not yield significant results.

Due to the nonlinearity and nonnormality of the data set, a model was constructed for the prediction of

Table 1 Geographical, climatic and biogeographical characteristics of study area

Station	Geographical characteristics		Climatic and biogeographical characteristics			
	Altitude (m above sea level)	Geographical location	Annual rainfall (mm)	Mean annual temperature (°C)	Climate	Mediterranean region-biogeographical provinces
Toledo	529	39°51'N, 04°02'O	382	15.4	Mediterranean continental	Mediterranean Central Iberian Province (Manchean Sector) and Mediterranean West Iberian Province (Toledan-Taganean Sector)

daily *Quercus* pollen concentration based on decision trees, using the CHAID (CHi squared Automatic Interaction Detector) exhaustive growing method (Kass 1980; Biggs et al. 1991). This method examines all possible combinations between the dependent variable with respect to independent variables at the end to provide the best predictive model.

This simple model allows successively occurring conditions to be represented and categorised. Decision trees are constructed top down, the root node being placed at the top. The construction of a decision tree involves two main steps:

1. Selection of a splitting rule for each internal node. In a node with over 45 cases, the algorithm selects the most significant predictive variable. The optimum partition generated by this variable should generate classes with more than 20 cases.
2. Stopping criterion. The process is stopped at the so-called terminal node, when the node has more than 45 cases or when there is no significant variable.

We used the daily data of *Quercus* pollen of the main pollen season from 2005 to 2010 and of the weather-related variables mentioned above. The model was validated using the tenfold cross-validation. It is a way to validate the model with the data themselves, and tenfold cross-validation is commonly used as a compromise between computation time and model accuracy. Model performance is expressed as a coefficient of correlation (Pearson correlation test). A graph of the measured and modelled concentrations has been included.

A linear regression analysis was too performed in order to compare the results with those obtained by the decision tree. We used the stepwise method and a logarithmic transformation ($\log [x + 1]$, where x = daily mean *Quercus* pollen counts expressed as grains/m³) was carried out, since the data were not normally distributed.

The SPSS 15.0[®] software package was used for all statistical analyses.

3 Results

Over the six-year studied period (2005–2010), a total of 74,066 *Quercus* pollen grains were collected, giving an annual mean of 12,344 pollen grains. This is a very

high figure, accounting for an average of 22.6 % of the total pollen in Toledo, and an average of 29.3 % of the total pollen for woody species, mainly trees. The highest annual pollen concentrations (17,305) were recorded in 2005 and the lowest (7,551 and 7,594, respectively) in 2006 and 2007 (Table 2). An average 96.5 % of total airborne *Quercus* pollen was recorded in the April–June period (Fig. 2). The first grains were detected in the months of March or April depending on the year (Fig. 3).

In 2008 and 2009, the highest of daily mean *Quercus* pollen concentration was recorded in the first fortnight of April; in other years, concentrations at this stage were insignificant (Fig. 3). The month with the highest monthly *Quercus* pollen concentration (Table 2) varied: April in 2006, 2009 and 2010 versus May in 2005 and 2007; in 2008, monthly *Quercus* pollen concentrations were similar in both months (5,435 grains in April and 5,663 in May). From June onwards, concentrations started to decline, although in June 2007 and 2008 relatively high monthly *Quercus* pollen concentrations were recorded (1,374 and 2,002 grains, respectively).

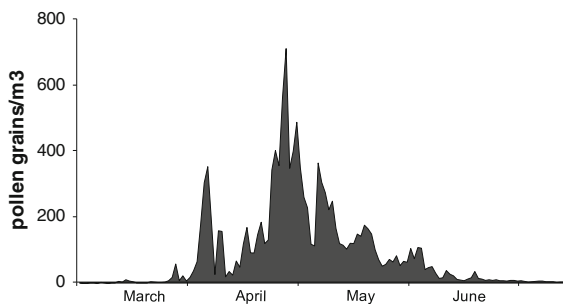
Regarding rainfall data, irregular patterns were observed along this period (2005–2010); 2005 was the driest year, showing very low rainfall values (160 mm), and 2010 was the wettest (543 mm). The highest monthly values were reached in October (years 2005, 2006 and 2008), April and May (2007), December (2009) and February and March (2010). Temperature data registered in these six years showed that the highest monthly mean temperatures were recorded in June, July and August, while the minimum values were recorded in December and January (Table 3).

Main pollen season (MPS) start and end dates displayed considerable year-on-year variations: Start dates ranged from 9 March (2007) to 22 April (2010) and end dates from 1 June (2009) to 10 July (2007) (Table 4). The mean duration of the pollen season was 79 days. The peak daily concentration was recorded in late April or early May, except in 2008 and 2009, when it occurred in early April. The peak daily concentration was very high in all years, but particularly in 2005 and 2010, when it exceeded 2,000 grains/m³.

Correlations between mean daily *Quercus* pollen concentration and weather-related variables during the pre-peak and post-peak periods are shown in Table 5. Differences between the two periods were

Table 2 Monthly and annual total *Quercus* pollen concentrations, mean, percentages and standard error (SE) over the study period (2005–2010)

	2005	2006	2007	2008	2009	2010	Mean	%	SE
January	2	7	62	9	5	4	14.8	0.1	11.6
February	2	0	106	7	2	3	20.0	0.2	21.1
March	13	16	184	325	443	34	169.2	1.4	91.0
April	5,890	3,791	1,611	5,435	11,708	6,783	5,869.7	47.5	1,696.6
May	10,267	3,246	3,992	5,663	3,959	3,597	5,120.7	41.5	1,327.4
June	758	273	1,374	2,002	523	573	917.2	7.4	324.0
July	84	97	147	179	71	64	107.0	0.9	23.00
August	58	33	41	47	28	32	39.8	0.3	5.6
September	141	29	34	28	17	9	43.0	0.3	24.4
October	42	17	16	13	14	6	18.0	0.1	6.2
November	30	18	23	8	11	4	15.7	0.1	4.9
December	18	24	4	2	6	2	9.3	0.1	4.7
<i>Quercus</i> pollen total	17,305	7,551	7,594	13,718	16,787	11,111	12,344	100.0	
Pollen total	53,874	40,706	56,000	59,465	62,422	55,263	54,622		
Arboreal pollen total	49,439	28,709	38,256	45,407	50,211	40,954	42,163		
% <i>Quercus</i> /arboreal pollen	35.0	26.3	19.9	30.2	33.4	27.1	29.3		
% <i>Quercus</i> /total pollen	32.1	18.6	13.6	23.1	26.9	20.1	22.6		

**Fig. 2** Seasonal fluctuations in the average of the daily mean *Quercus* pollen concentration

considerable: in the pre-peak period, a significant positive correlation was observed with mean daily temperature and hours of sunshine, both on the day of the pollen concentration and on the one and two days prior to it. A negative correlation was observed with daily rainfall, attaining statistical significance in the case of rainfall on the one or two days prior to the pollen-concentration day. A significant negative correlation was also observed between daily pollen concentration and relative humidity. In the post-peak period, a significant negative correlation was found with mean daily temperature and hours of sunshine in all cases.

The interpretation of the results displayed in the decision tree diagram (Fig. 4) showed that temperature is the most influential variable in the release of *Quercus* pollen. The ranges of values of the variables and the mean of quantities of pollen associated have been represented graphically. A mean daily temperature of between 19.7 °C and 20 °C during the *Quercus* pollen season was the most conducive to elevated mean daily airborne pollen concentration ($x = 261.1$ grains/m³; Fig. 4). By contrast, mean daily temperatures below 13.6 °C and above 20 °C had a negative impact on pollen concentration ($x = 77.9$ and 37.8 grains/m³, respectively). At mean daily temperatures of 13.6 °C or less, pollen concentration rose if the $T_{\text{mean}-1}$ exceeded 22.9 °C ($x = 117.7$ grains/m³). Where mean daily temperatures ranged between 13.6 °C and 19.7 °C and the $T_{\text{min}-2}$ was 22.7 °C or less, *Quercus* pollen concentration was found to be considerably higher ($x = 419.5$ grains/m³) than when this variable exceeded 38 °C ($x = 94.1$ grains/m³). Finally, at mean daily temperatures of over 20 °C, pollen concentration declined moderately if wind speed was greater than 3.6 m/s ($x = 20.1$ grains/m³) (Fig. 4).

The daily *Quercus* pollen concentration predicted using decision trees (CHAID exhaustive growing method) showed a moderate significant correlation

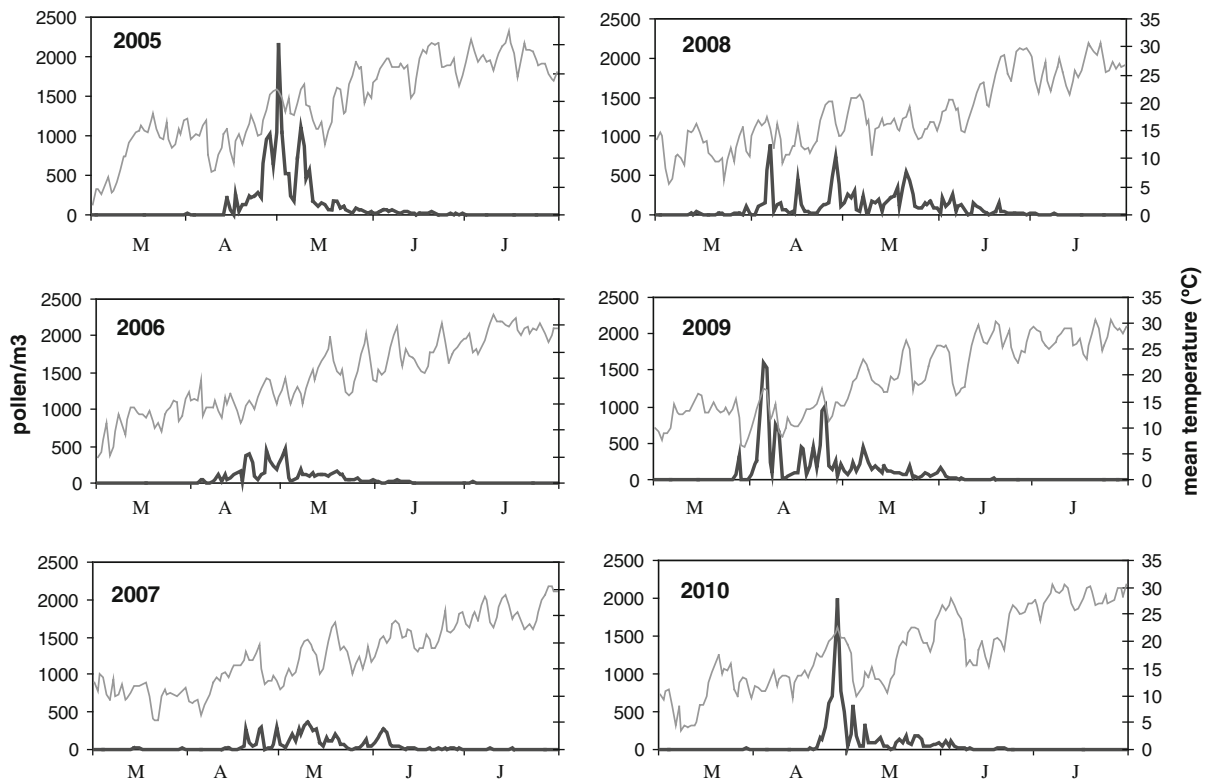


Fig. 3 Annual daily variation in daily airborne *Quercus* pollen and mean temperature (grey line) in Toledo each year from 2005 to 2010

Table 3 Monthly mean temperatures, T (°C) and rainfall, R (mm) over the study period (2005–2010)

	2005		2006		2007		2008		2009		2010	
	T	R	T	R	T	R	T	R	T	R	T	R
January	4.8	0	5.6	18	6.2	8	8.3	14	5.9	17	6.3	58
February	5.5	29	7.1	16	10.2	28	9.9	17	8.5	30	7.6	87
March	11.2	14	11.8	26	10.6	31	11.5	5	12.2	20	10.1	75
April	14.6	7	15.6	39	13.3	92	14.6	66	13	23	15.1	58
May	20	9	20.6	23	17.2	86	16.7	53	20.1	11	16.9	34
June	26.4	1	24.5	32	21.4	36	22.7	25	24.9	8	22.2	64
July	27.8	0	28.9	1	26	1	26.2	1	27.5	0	28.2	6
August	26.7	4	26	3	25.3	22	26.7	0	28	23	27.2	3
September	21.3	1	23.2	12	22.6	3	21.3	8	22.2	16	22	19
October	16.7	59	18.3	109	15.9	56	15.8	151	18.3	35	15.3	49
November	9.2	21	12.8	81	9.1	17	8.6	5	12.6	9	9.7	28
December	6.2	15	6.5	15	6.5	3	6.7	52	6.9	143	7	61
Annual mean T	15.9		16.7		15.4		15.8		16.7		15.6	
Annual Rainfall		160		374		383		396		334		543

($r = 0.42$, $p < 0.01$, $n = 476$) with the daily *Quercus* pollen concentration observed. When we contrasted graphically the daily values observed with those

predicted (Fig. 5), we note a similar trend between them, but the model is not able to predict the maximum values observed mainly in the years 2005, 2009 and

Table 4 Characteristics of the main *Quercus* pollen season

	2005	2006	2007	2008	2009	2010	Mean (2005–2010)
Start pollen season	17-Apr	09-Apr	09-Mar	30-Mar	28-Mar	22-Apr	3-Apr
End pollen season	24-Jun	03-Jul	10-Jul	25-Jun	01-Jun	07-Jun	22-Jun
Length (days)	69	86	124	80	66	47	79
<i>Quercus</i> pollen total season	17,045	7,205	7,211	13,131	16,173	10,686	11,909
Peak day (date)	01-May	02-May	10-May	07-Apr	05-Apr	28-Apr	24-Apr
Peak day (concentration)	2,179	466	366	898	1,613	2,006	1,255
<i>Quercus</i> pollen total annual	17305	7,551	7,594	13,718	16,787	11,111	12,344
% total pollen count	33.1	18.5	13.5	23.3	26.9	20.1	22.6

Table 5 Spearman's correlation coefficients obtained between daily values of *Quercus* airborne pollen and meteorological variables during periods pre-peak and after-peak

	Pre-peak	Post-peak
Maximum temperature ($T_{\max}$)	0.745**	−0.341**
$T_{\max}$ -1	0.801**	−0.336**
$T_{\max}$ -2	0.785**	−0.360**
Mean temperature (T_{mean})	0.774**	−0.396**
T_{mean} -1	0.798**	−0.406**
T_{mean} -2	0.774**	−0.430**
Minimum temperatura ($T_{\min}$)	0.654**	−0.449**
$T_{\min}$ -1	0.646**	−0.479**
$T_{\min}$ -2	0.625**	−0.507**
Hours of sunshine (HS)	0.490**	−0.192**
HS-1	0.654**	−0.149**
HS-2	0.687**	−0.130*
Rainfall (R)	−0.167	0.010
R -1	−0.340**	−0.028
R -2	−0.360**	−0.084
Relative humidity	−0.448**	0.128*
Wind speed	0.077	−0.022

Accumulated values of 1 day preceding (variable-1) and 2 days preceding (variable-2)

**99 %, *95 %

2010. The linear regression analysis, performed in parallel, showed worse results; the coefficient of determination between observed and predicted data was $R^2 = 0.19$.

4 Discussion

Airborne *Quercus* pollen concentrations can be classified as very high. In nearby cities such as Madrid

(Gutiérrez et al. 2002) and Cuenca (Pérez-Badia et al. 2011), lower *Quercus* concentrations are recorded, although in some years concentrations in Madrid have proved similar to those observed in Toledo (Gutiérrez et al. 2002). Lower annual *Quercus* pollen concentrations have also been reported in towns in northwestern Spain, including Orense, Santiago de Compostela (Rodríguez-Rajo et al. 2005) and León (Vega et al. 2002), and also in southern Spanish cities such as Granada and Jaén (García-Mozo et al. 2006a). These differences observed in the airborne *Quercus* pollen concentrations among Spanish monitoring stations can be explained on the one hand by the different extension of the *Quercus* forest in the study areas and on the other hand because there are several *Quercus* species with different pollen production (Tormo et al. 1996; Gómez-Casero et al. 2004; Jato et al. 2007).

The high concentrations in Toledo are attributable to the good conservation and to the extensive representation of forests and woods comprising mainly holm oaks (*Q. ilex* subsp. *ballota* (Desf.) Samp.), cork oaks (*Q. suber* L.) and kermes oaks (*Quercus coccifera* L.) in the surrounding area and in the mountains of the province. As a result, airborne *Quercus* pollen concentrations in Toledo are—like those recorded in Córdoba and Gerona (García-Mozo et al. 2006a)—among the highest in Spain and are surpassed only by those reported in the Extremadura region of southwestern Spain, where annual *Quercus* pollen routinely exceed 23,000 grains (Paulino et al. 2002).

Year-on-year variations in pollen levels (Table 2) have been observed, but in this case, we cannot attribute this variations to the masting or alternate bearing, that is, the alternation of high-count and low-count years reported for *Quercus* by other authors (Rodríguez-Rajo et al. 2000).

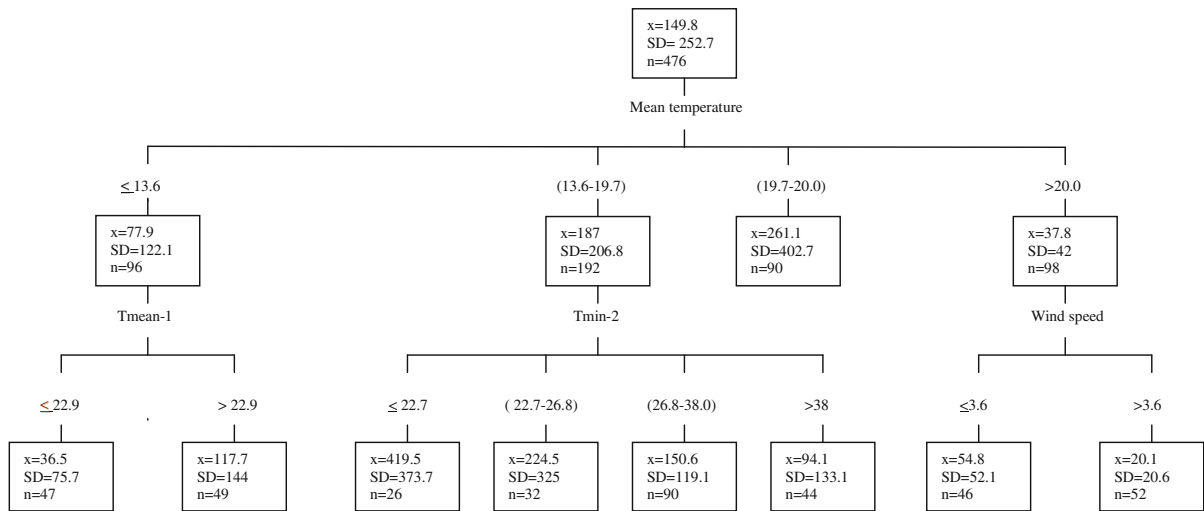


Fig. 4 Decision tree showing the relationship between daily *Quercus* pollen concentration and weather-related variables. x mean pollen concentration; SD standard deviation; n number of cases

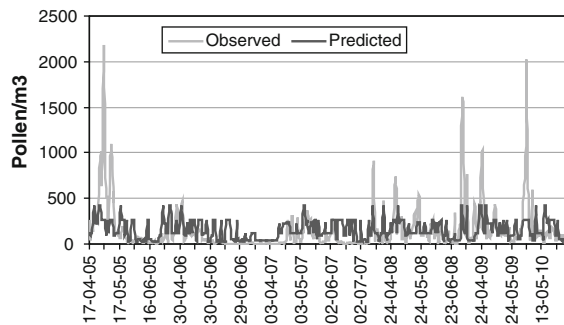


Fig. 5 Seasonal distribution of the *Quercus* pollen concentration observed (grey line) and predicted (black line) during the MPS from 2005 to 2010

Most airborne *Quercus* pollen was collected between April and June, a finding also reported in other Spanish and Portuguese cities (García-Mozo et al. 2006a) as well as elsewhere in southern Europe, including the Italian city of Trieste (Rizzi-Longo et al. 2005). However, in more northerly European cities such as Derby (UK), airborne *Quercus* pollen is recorded almost solely in the month of May (Corden and Millington 1999). The highest monthly pollen concentrations in Toledo are recorded in either April or May, coinciding with the flowering of *Q. ilex* subsp. *ballota* (Desf.) Samp., the most abundant species locally.

Year-on-year variations in the duration of the main pollen season (MPS), and in the start and end dates, may be attributed to differences in weather patterns. As other authors have reported (Rodríguez de la Cruz

et al. 2008), the pollen season may have started earlier in 2007, 2008 and 2009 due to an increase in mean daily temperatures over the first two months of the year, which may have prompted early flowering of some holm oaks and cork oaks. In Toledo, mean January and February temperatures in those three years were higher than those recorded in 2005, 2006 and 2010 (Table 2). Studies carried out elsewhere in Spain (García-Mozo et al. 2002; Rodríguez-Rajo et al. 2005) and northern Europe (Corden and Millington 1999) note that the *Quercus* pollen season tends to start earlier every year, a finding which they attribute to a possible climate change that of late has become increasingly evident. These results were not borne out in the present study (Table 3), although a six-year study period is clearly not long enough to confirm this potential trend.

The positive influence of temperature and hours of sunshine on airborne *Quercus* pollen concentrations has been noted by a number of authors (Recio et al. 1999; Rizzi-Longo et al. 2005; Rodríguez-Rajo et al. 2005; García-Mozo et al. 2006b). Here, both variables had a significant positive effect on pollen release in the pre-peak period and a negative impact in the post-peak period. This was because the increase in temperatures in late spring and early summer coincided with the end of the pollen season; by the post-peak period, therefore, trees had released most of their pollen, and the small remaining amounts were released gradually thereafter (García-Mozo et al. 2006a).

Several studies in the Mediterranean area note the major influence of rainfall prior to flowering on pollen counts (García-Mozo et al. 2006a). Although we are aware that it is not possible to obtain conclusions with only monthly rainfall data, in Toledo, it seems that rainfall over the months prior to the pollen season does not influence on the total annual pollen concentrations. Thus, rainfall prior to flowering was considerably higher in 2010 than in other years, and the total annual pollen was lower than the registered in other years such as 2008 and 2009.

The results obtained using decision trees (CHAID exhaustive growing method) as a model to classify and predict *Quercus* pollen concentration are moderately satisfactory, but they are better than those obtained by linear regression analysis. CHAID model cannot predict the highest amounts of pollen, that is, pollen peaks. However, the percentage of days with samples of pollen above 500 grains, only represents 6 % of the total. Another thing to consider is that our model is built only with data from six years, and there is a great variation in the amounts of pollen from every year. Perhaps the results could be improved considering a number of data from more years and introducing other variables that can be influencing the pollen concentration.

The decision tree models constitute a nonparametric classification technique that can be used to carry out predictions (Kass, 1980) when other models as regression do not offer goods results. It presents some advantages as the nonexistence of multicollinearity when the independent variables are highly correlated. The decision tree provides both linear and nonlinear relationships and greater ability to detect interactions between variables (Thuraisingham, 1999; Vayssières et al. 2000). Other advantages of using this test in comparison with other statistical tests are that this is a simple model that allows successively occurring conditions to be represented and categorised, making easy to-interpret results; the decision rules generated can be readily applied without the need for mathematical procedures, making it a viable alternative to many traditional statistical techniques (Death and Fabricius 2000).

Decision tree models are not widely used in aerobiology at present, although it has been employed to predict *Platanus* pollen concentrations in Madrid (Sabariego et al. 2008). Similar modelling techniques (multivariate regression trees) have been used in Poland in airborne *Ganoderma* spore concentrations

(Grinn-Gofrón and Strzelczak 2011; Kasprzyk et al. 2011) or more recently by Oteros et al. (2012) for modelling olive flowering phenology.

Acknowledgments The authors are grateful to the Consejería de Educación y Ciencia de la Junta de Comunidades de Castilla-La Mancha for financial support provided through project POIC10-0302-2695.

References

- Andersen, T. (1991). A model to predict the beginning of the pollen Season. *Grana*, 30, 269–275.
- Biggs, D., De Ville, B., & Suen, E. (1991). A method of choosing multiway partitions for classification and decision trees. *Journal of Applied Statistics*, 18, 49–62.
- Butland, B. K., Strachan, D. P., Lewis, S., Bynner, J., Butler, N., & Britton, J. (1997). Investigation into the increase of hay fever and eczema at age 16 observed between the 1958 and 1970 British birth cohorts. *British Medical Journal*, 315, 717–721.
- Cecich, R. A., & Sullivan, N. H. (1999). Influence of weather at time of pollination on acorn production of *Quercus alba* and *Quercus velutina*. *Canadian Journal of Forest Research*, 29, 1817–1823.
- Corden, J., & Millington, W. (1999). A study of *Quercus* pollen in the Derby area, UK. *Aerobiologia*, 15, 29–37.
- Death, G., & Fabricius, K. E. (2000). Classification and regression trees: A powerful yet simple technique for ecological data analysis. *Ecology*, 81(11), 3178–3192.
- Fernández-González, F. (2011). La vegetación en la provincia de Toledo. In C. López-Carrasco, M. P. Rodríguez, A. San Miguel, F. Fernández-González, & S. Roig (Eds.), *Pastos, paisajes culturales entre tradición y nuevos paradigmas del siglo XXI* (pp. 17–36). Madrid: SEEP.
- Galán, C., Cariñanos, P., Alcázar, P., & Domínguez, E. (2007). *Spanish Aerobiology Network (REA): Management and quality manual*. Córdoba: Servicio de publicaciones de la Universidad de Córdoba.
- García-Mozo, H. (2011). The use of aerobiological data on agronomical studies. *Annals of Agricultural Environmental Medicine*, 18, 1–6.
- García-Mozo, H., Galán, C., Aira, M. J., Belmonte, J., Díaz de la Guardia, C., Fernández, D., et al. (2002). Modelling start of oak pollen season in different climatic zones in Spain. *Agricultural and Forest Meteorology*, 110, 247–257.
- García-Mozo, H., Galán, C., Jato, V., Belmonte, J., Díaz de la Guardia, C., Fernández, D., et al. (2006a). *Quercus* pollen season dynamics in the Iberian Peninsula: Response to meteorological parameters and possible consequences of climate change. *Annals of Agricultural Environmental Medicine*, 13, 209–224.
- García-Mozo, H., Pérez, R., Fernández González, F., & Galán, C. (2006b). Airborne pollen sampling in Toledo, Central Spain. *Aerobiologia*, 22, 55–66.
- Gómez-Casero, M. T., Hidalgo, P., García-Mozo, H., Domínguez, E., & Galán, C. (2004). Pollen biology in four Mediterranean *Quercus* species. *Grana*, 43, 22–30.

- Grinn-Gofrón, A., & Strzelczak, A. (2011). The effects of meteorological factor son the occurrence of *Ganoderma* sp. spores in the air. *International Journal Biometeorology*, 55, 235–241.
- Gutiérrez, M., Cervigón, P., & Pertinez, C. (2002). Aerobiología en Madrid: Estación de Ciudad Universitaria. *Rea*, 7, 225–230.
- Hidalgo, P. J., Martín, J. M., Quijada, J., & Moreira, J. M. (2008). A spatial distribution model of cork oak (*Quercus suber*) in southwestern Spain: A suitable tool for reforestation. *Forest Ecology and Management*, 225, 25–34.
- Hirst, J. M. (1952). An automatic volumetric spore trap. *Annals of Applied Biology*, 39, 257–265.
- Ickovic, M. R., & Thibaudon, M. (1991). Allergenic significance of Fagaceae pollen. In G. D'Amato, F. Th. M. Spiekma, & S. Bonini (Eds.), *Allergenic pollen and pollinosis in Europe* (pp. 98–108). Oxford: Blackwell Scientific Publications.
- Jato, V., Rodríguez-Rajo, F. J., & Aira, M. J. (2007). Use of *Quercus ilex* subsp. *ballota* phenological and pollen-production data for interpreting *Quercus* pollen curves. *Aerobiologia*, 23, 91–105.
- Kasprzyk, I. (2009). Forecasting the start of *Quercus* pollen season using several methods—the evaluation of their efficiency. *International Journal Biometeorology*, 53, 345–353.
- Kasprzyk, I., Grinn-Gofron, A., Strzelczak, A., & Wolski, T. (2011). Hourly predictive artificial neural network and multivariate regression trees models of *Ganoderma* spore concentrations in Rzeszów and Szczecin (Poland). *Science of the Total Environment*, 409, 949–956.
- Kass, G. (1980). An exploratory technique for investigating large quantities of categorical data. *Applied Statistics*, 29, 119–127.
- Lewis, W. H., Vinay, P., & Zenger, V. E. (1983). *Airborne and allergenic pollen of North America*. London: Hopkins.
- Medio Ambiente. (2001). *Guía resumida del clima en España (1971–2000)*. Madrid: Secretaría General Técnica Ministerio de Medio Ambiente.
- Negrini, A. C., & Arobba, D. (1992). *An illustrated guide to pollen analysis*. London: Hodder and Stoughton.
- Oteros, J., García-Mozo, H., Hervás-Martínez, C., & Galán, C. (2012). Clustering analysis for modelling olive flowering phenology. *International Journal Biometeorology*. doi: 10.1007/s00484-012-0581-3.
- Paulino, R., Tormo, R., Silva, I., & Muñoz, A. F. (2002). Aerobiología en Extremadura: Estación de Cáceres (2000–2001). *Rea*, 7, 177–182.
- Pérez-Badía, R., Rapp, A., Morales, C., Sardinero, S., Galán, C., & García-Mozo, H. (2010). Pollen spectrum and risk of pollen allergy in central Spain. *Annals of Agricultural Environmental Medicine*, 18(1), 99–112.
- Pérez-Badía, R., Rapp, A., Vaquero, C., & Fernández-González, F. (2011). Aerobiological study in east-central Iberian Peninsula: Pollen diversity and dynamics for major taxa. *Annals of Agricultural Environmental Medicine*, 17, 139–151.
- Pinto, C. A., Henriques, M. O., Figueiredo, J. P., David, J. S., Abreu, F. G., Pereira, J. S., et al. (2011). Phenology and growth dynamics in Mediterranean evergreen oaks: Effects of environmental conditions and water relations. *Forest Ecology and Management*, 262, 500–508.
- Prados, M., Aragon, R., Carranco, M. I., Martínez, A., & Martínez, J. (1995). Assessment of sensitization to holm oak (*Quercus ilex*) pollen in the Merida area (Spain). *Allergy*, 50, 456–459.
- Recio, M., Trigo, M. M., Toro, J., & Cabezudo, B. (1999). Incidencia del polen de *Quercus* en la atmósfera de Málaga y su relación con los parámetros meteorológicos. *Acta Botanica Malacitana*, 24, 77–88.
- Rizzi-Longo, L., Pizzulin-Sauli, M., & Ganis, P. (2005). Aerobiology of Fagaceae pollen in Trieste (NE Italy). *Aerobiologia*, 21, 217–231.
- Rodríguez de la Cruz, D., Sánchez, E., & Sánchez, J. (2008). Aerobiological study of Fagaceae pollen in the middle-west of Spain. *Aerobiologia*, 24, 67–76.
- Rodríguez-Rajo, F. J., Méndez, J., & Jato, V. (2000). Influencia de la temperatura en la floración de *Quercus* en el sur de Galicia (Orense y Vigo, 1994–1998). *Acta Botánica Malacitana*, 25, 153–163.
- Rodríguez-Rajo, F. J., Méndez, J., & Jato, V. (2005). Factors affecting pollination ecology of *Quercus* anemophilous species in north-west Spain. *Botanical Journal of the Linnean Society*, 149, 283–297.
- Ross, A. M., Corden, J. M., & Fleming, D. M. (1996). The role of oak pollen in hay fever consultations in general practice and the factors influencing patients' decisions to consult. *British Journal of General Practice*, 46, 451–455.
- Sabariago, S., Gutiérrez, M., Cervigón, P., & Cuesta, P. (2008). Forecasting airborne *Platanus* pollen in the Madrid region. *Grana*, 47, 234–240.
- Thuraisingham, B. (1999). *Data Mining: Technologies, Techniques, Tools, and Trends*. New York: CRC press.
- Tormo, R., Muñoz, A., Silva, I., & Gallardo, F. (1996). Pollen production in anemophilous trees. *Grana*, 35, 38–46.
- Vayssières, M. P., Plant, R. E., & Allen-Diaz, B. H. (2000). Classification trees: An alternative non-parametric approach for predicting species distribution. *Journal of Vegetation Science*, 11, 679–694.
- Vega, A. M., Fernández-González, D., Valencia-Barrera, R. M., Fernández Salegui, A. B., Santos, F., & Latasa, M. (2002). Aerobiología en Castilla y León: Estación de León. *Rea*, 7, 119–124.