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INTRADIURNAL VARIATIONS OF ALLERGENIC TREE POLLEN IN THE ATMOSPHERE OF TOLEDO (CENTRAL SPAIN)

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Abstract: To study the impact of inhaling airborne pollen on health, it is important to know not only their average daily concentrations but also the intradiurnal behaviour of these biological particles. This study reports the bi-hourly distribution of the arboreal airborne pollen types more abundant in the atmosphere of Toledo (central Spain), many of them triggering important allergic processes in Toledo citizens and tourist visitors. Knowledge of bi-hourly pattern atmospheric variation pollen may help pollinosis patients to adopt preventive measures and plan their outdoor activities accordingly. Intradiurnal variation has been studied for the arboreal pollen types: Cupressaceae, *Fraxinus*, *Olea*, *Platanus*, *Populus*, *Quercus* and *Ulmus*, during the period 2005–2008. The main hourly pollen concentrations were observed during sunlight hours and the maximum pollen values obtained at midday and in the afternoon, except for pollen types *Quercus* and *Platanus*, whose maximum pollen concentrations were obtained during the night. The statistical analyses performed to compare pollen concentration and main hourly meteorological variables proved to be significant for most of the taxa. The results show a significant and positive effect of temperature, solar radiation and wind speed on the daily variability undergone by atmospheric pollen. Relative humidity influenced in a negative way on the intradiurnal variation of pollen in the atmosphere of Toledo.

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INTRODUCTION

Pollen grains are one of the most important groups of atmospheric biological particles that originate allergic processes. Pollinosis has increased in developed countries in the last decades, both in the number of affected patients and in the severity of allergic reactions [8, 29]. Rhinitis affects up to 25% of the world population and asthma up to 18%, with a clear tendency to increase their prevalence [4]. Knowledge of intradiurnal variation of the atmospheric pollen may be useful to research and treat pollen allergies. Knowledge of intradiurnal variation patterns and meteorological influence is important for allergy patients and is essential to reduce the exposure of allergic patients so that preventive measures can be taken when planning outdoors activities [9, 20, 35]. Pollen content in the air is characterized by their annual, daily and intradiurnal periodicity depending on biologic patterns of pollen emission [13, 24, 25, 43]. But also depends on meteorological factors such as temperature, rainfall and relative humidity that, among others, also influence intradiurnal patterns [1, 43]. Atmospheric stability affects the intradiurnal pollen concentration because it restricts the vertical movements of the air [6]. The direction and the speed of the wind influence on the horizontal dispersion of the particles and affect hourly distribution of pollen concentration. In calm conditions,

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the intradiurnal curve responds to a given pattern due to the registered pollen mostly originating from the nearest areas. Moreover, wind is a long-distance transporter that contributes to the detection of non-native pollen, influencing the intradiurnal distribution model of a particular type of pollen [22, 41].

This study analyzes the intradiurnal airborne behaviour of 7 arboreal pollen types in the atmosphere of Toledo (central Spain): Cupressaceae, *Fraxinus*, *Olea*, *Platanus*, *Populus*, *Quercus* and *Ulmus*, and their relationship to meteorological variables. Cupressaceae, *Fraxinus*, *Olea* and *Platanus* are important from the point of view of allergic diseases, and among them, Cupressaceae and *Olea* are more notable [31]. *Cupressus* is the most abundant ornamental tree in Toledo, emitting 24% of the total pollen. This type is the main cause of winter hay fever [12, 27], its sources being mainly from the parks and gardens of the city and surroundings. Pollen from the olive tree, *Olea europaea*, is very important in the hay fever of central and southern Spain during the months of May and June [31, 42].

The main goal of this paper is to analyse the bi-hourly dynamics of these pollen types and compare the variation patterns with those detected in other places. This work will help to improve the quality of life of Toledo citizens and visitors who suffer from allergy.

MATERIAL AND METHODS

Study area. Toledo, the capital of the Autonomous Community of Castilla-La Mancha, is a city of around 83,000 inhabitants, but as a World Heritage Site it is visited by over 2 million tourists every year. Toledo is located at the centre of the Iberian Peninsula, 529 m a.s.l. The landscape of its surroundings is constituted by cultured fields where cereals and olive groves predominate, and natural vegetation is composed of Mediterranean forest dominated by holm oak (*Quercus ilex* L. subsp. *ballota* (Desf.) Samp.) and Mediterranean shrub land dominated by *Cistus* spp., *Erica* spp., *Rosmarinus officinalis* L., *Thymus* spp., *Lavandula stoechas* L. subsp. *pedunculata* (Miller) Samp. ex Rozeira, among others. In the scenario of this work, *Quercus* pollen type is of main interest from the ecological point of view since Toledo is located at the centre of the Iberian Peninsula where Mediterranean vegetation with holm and cork forests being predominant [17, 18, 31]. From a bioclimatic viewpoint, it belongs to the Mediterranean macrobioclimate and to the Mesomediterranean belt with a dry ombroclimate [36]. The mean annual temperature is 15.4ºC and the mean annual rainfall is 382 mm [26].

Airborne pollen data. Airborne pollen was monitored from 2005–2008. We used a Hirst 7-day volumetric spore trap, based on Hirst design [23], and located on the roof of a building of the University of Castilla-La Mancha, around 17 m above the ground. Daily pollen concentrations were collected and analysed following the rules recommended by the Spanish Aerobiology Network (REA) to obtain daily and hourly average concentrations [11].

Meteorological data. Meteorological data were provided by the meteorological station located on the campus of the University of Castilla-La Mancha (UCLM), near the pollen trap. This station belongs to the Instituto Meteorológico Regional de Castilla-La Mancha (iMETCam) and provides hourly meteorological data. The environmental variables subjected to statistical analysis include hourly measurements of mean temperature (ºC), relative humidity (RH%), solar radiation (W/m^2) and wind speed (m/s).

Data analysis. Principal Pollination Period (PPP) has been calculated following the methodology designed by Andersen [3]. This method includes 95% of the seasonal total pollen, and comprises from the day in which 2.5% of total pollen is registered to the day in which 97.5% of total pollen is registered. Pollen grains intradiurnal variation in Toledo atmosphere has been studied following the method described by Galán *et al.* [14]. These results have been represented graphically showing bi-hourly percentage values, with the time corresponding to official Spanish time (UTC + 1 hour during autumn and winter and UTC + 2 hours during spring and summer).

The SPSS 15.0® Software Package was used in all statistical analyses. The correlation between hourly meteorological variables and hourly pollen concentration values during the pre-peak period (PP), the period comprising from the start of the season up to the peak day recording the maximum daily pollen concentration, was analysed with the non-parametric Spearman's correlation test.

RESULTS

Meteorological data for this period show that 2005 was the driest year, with very low rainfall values (Tab. 1). On the contrary, autumn in 2006 and 2008 was very rainy, with values around 200 mm. In 2006, autumn practically doubled the spring rainfall values for the same year (97 mm). This, together with the abundant spring rainfalls in 2007 (243 mm), led us to detect a remarkable increase in total-pollen levels and in these pollen types in 2007 and 2008 in comparison to 2006 (Tab. 2).

Regarding temperature, values were similar during the summer and autumn (except in 2006, when a warmer autumn was observed), and lower values obtained for spring 2007 and 2008 (15.8–16ºC in 2007–2008 against 18.9–18.8ºC in 2005–2006). Besides, a gradual increase in average winter temperature was observed throughout the 4 years of study (from 6ºC in 2005 to 9ºC in 2008) (Tab. 1).

During the studied period, a total of 209,859 pollen grains, corresponding to 37 different pollen types, were detected. Among these, 148,790 (70.9%) grains corresponded to the 7 pollen types studied in this work: Cupressaceae, *Fraxinus*, *Olea*, *Quercus*, *Platanus*, *Populus* and *Ulmus*.

Table 1. Mean temperatures (ºC) and rainfall (mm) per season per year 2005–2008.

Year	Season, year	T (ºC)	Rainfall (mm)
2005	Winter	6.0	30
	Spring	18.9	30
	Summer	25.9	5
	Autumn	12.3	91
	Year	**15.8**	**156**
2006	Winter	7.2	58
	Spring	18.8	97
	Summer	26.8	17
	Autumn	14.2	205
	Year	**16.7**	**377**
2007	Winter	8.9	37
	Spring	15.8	243
	Summer	24.9	25
	Autumn	11.9	76
	Year	**15.3**	**381**
2008	Winter	9	32
	Spring	16	137
	Summer	26	18
	Autumn	11.5	209
	Year	**15.6**	**396**

Cupressaceae was the predominant pollen type, representing 24.1% of the total number of pollen grains, followed by *Quercus* (22%) and *Olea* (11%). Regarding the annual Pollen Index (PI) during the 4 years, the pollen types with the lowest PI were: *Populus*, *Platanus*, *Fraxinus* and *Ulmus* (Tab. 2). Annual variations differences in Cupressaceae, *Olea*, *Quercus* and *Ulmus* pollen types were observed. *Platanus* maintained more or less the same figure, and in *Populus*, a very small amount was detected in 2005 (Tab. 2).

The PPP for each analysed pollen type (Tab. 2) shows that *Fraxinus*, together with Cupressaceae and *Quercus*, present the longest pollination periods (around 90 days) due to the consecutive flowering of different species coming from inside and outside the city. On the other hand, *Platanus*, *Populus* and *Ulmus* represent the shortest ones: 37, 42 and 46 days, respectively. Cupressaceae and *Fraxinus* pollen types are the first to flower (January), while *Olea* flowers the latest (May).

Regarding intradiurnal variation, the highest hourly concentration detected in these 4 years was found in the Cupressaceae pollen type: a total number of 925 grains/m^3/h were detected on 4 March 2007 (16:00). This was followed by *Populus* pollen type with 606 grains/m^3/h, reached on 7 March 2007 (12:00), and *Quercus*, with 380 grains/m^3/h, reached on 27 April 2005 (00:00). The lowest values in peaks of pollen grains correspond to *Ulmus*, 62 grains/m^3/h, reached in 20 February 2008 (15:00).

Averages in intradiurnal variation models, represented as percentage of the 4 years, indicate that Cupressaceae shows the highest amounts of pollen around midday, with 45% of pollen distributed between 10:00–18:00 (Fig. 1). This is from 08:00 onwards when the amount of atmospheric pollen increases progressively, when the temperature begins to increase and relative humidity tends to decrease.

Fraxinus only represents 0.5% of total pollen amounts in Toledo (Tab. 2). For this pollen type, intradiurnal variation shows little oscillations and only a slight decrease is clear at 12:00 (Fig. 1).

Olea, *Populus* and *Ulmus* pollen types reach their maximum in the afternoon (14:00–18:00), when maximum temperature, wind speed and minimum relative humidity are reached (Fig. 1). *Olea* shows the highest pollen count (around 42%) during the afternoon (14:00–18:00) (Fig. 1), with the maximum at 18:00. During the remaining hours of the day the percentages pollen values are similar. Intradiurnal variation of *Populus* and *Ulmus* pollen types shows the highest concentration at midday and in the afternoon (12:00–18:00): during this period the amount of pollen registered is 62% for *Populus* and 50% for *Ulmus*, with a peak at 16:00 (Fig. 1).

Platanus and *Quercus* show their maximum pollen concentrations at night, when minimum temperature is

Table 2. Annual Pollen Index per each pollen type, percentages (%), mean, standard deviation (SD), minimum value (Min.) and maximum value (Max.). Principal Pollination Period (mean 2005–2008): start date, end date and length (number of days).

	2005	2006	2007	2008	Total	%	Mean	SD	Min.	Max.	Start date	End date	Lengh (days)
Cupressaceae	17,236	4,838	11,666	16,922	50,662	24.1	12,666	5,810	4,838	17,236	4 Jan	28 Mar	84
Fraxinus	225	317	232	354	1,128	0.5	282	64	225	354	1 Jan	5 Apr	95
Olea	6,525	5,417	7,427	3,767	23,136	11.0	5,784	1,576	3,767	7,427	4 May	23 Jun	51
Platanus	2,190	1,916	2,203	1,934	8,243	3.9	2,061	157	1,916	2,203	21 Mar	26 Apr	37
Populus	982	3,974	4,754	5,761	15,471	7.4	3,868	2,058	982	5,761	9 Feb	22 Mar	42
Quercus	17,305	7,551	7,594	13,718	46,168	22.0	11,542	4,812	7,551	17,305	6 Apr	25 Jun	81
Ulmus	1,418	951	554	1,059	3,982	1.9	996	356	554	1,418	5 Feb	22 Mar	46
Total arboreal pollen	45,881	24,964	34,430	43,515	148,790	70.9	37,198	9,533	24,964	45,881			
Total pollen	53,874	40,706	56,000	59,279	209,859	–	52,465	8,148	40,706	56,000			

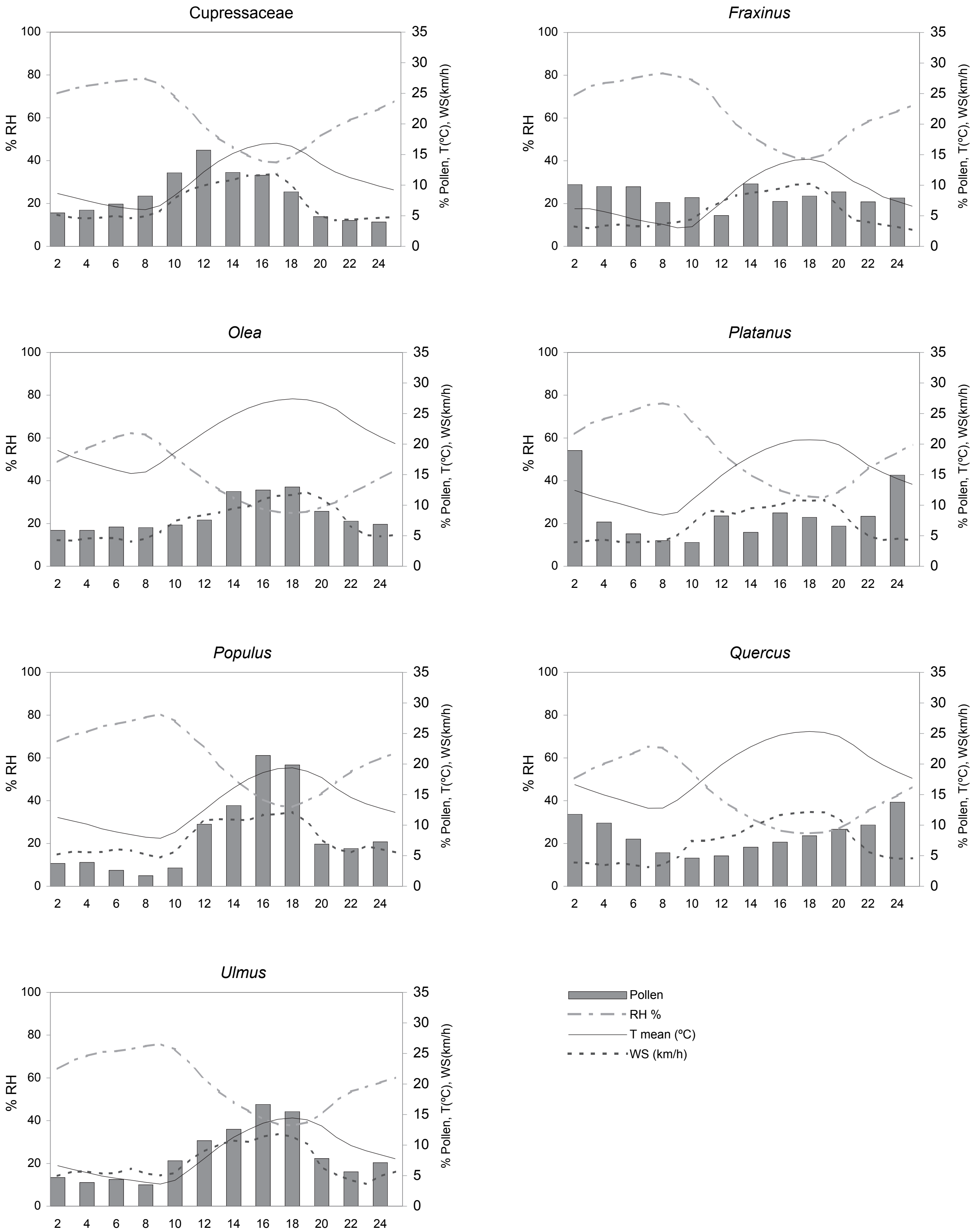

Figure 1. Mean bi-hourly distribution, expressed in percentage, of each arboreal pollen type (Cupressaceae, *Fraxinus*, *Olea*, *Platanus*, *Populus*, *Quercus* and *Ulmus*). Mean of hourly temperature (T mean, ºC), relative humidity (RH%), and wind speed (WS km/h) during the respective Principal Pollination Period (2005–2008).

Table 3. Correlation coefficient between hourly pollen count during the pre-peak period and main meteorological parameters based on the Spearman correlation test (significance levels *99%).

	Cupressaceae	*Fraxinus*	*Olea*	*Platanus*	*Populus*	*Quercus*	*Ulmus*
T mean (ºC)	0.284*	0.126*	0.437*	0.292*	0.407*	0.088*	0.291*
Relative humidity (%)	-0.298*	-0.134*	-0.346*	-0.285*	-0.410*	-0.133*	-0.349*
Solar incidental radiation (W/m^2)	0.311*	0.046*	0.191*	0.042*	0.275*	-0.233*	0.335*
Wind velocity (m/s)	0.300*	0.073*	0.358*	0.269*	0.365*	0.026*	0.312*

reached. *Platanus* concentrates 43% of pollen between 24:00–02:00, showing a peak at night (02:00). During daylight hours, maximum values for *Platanus* pollen are reached at midday and in the afternoon (Fig. 1). The results obtained for pollen type *Quercus* indicate that, in the atmosphere of Toledo, maximum concentrations (52% of the total amount of pollen) are observed between 22:00–06:00 (Fig. 1). On the contrary, the lowest concentrations are obtained from 08:00–12:00.

Correlation analyses between hourly pollen concentrations within the pre-peak period (PP) and the main hourly meteorological variables proved to be significant and positive for all pollen types and mean temperature, solar radiation and wind speed. However, correlations were negative for relative humidity. Correlation coefficients are very low for some meteorological variables and pollen types, like *Fraxinus* and *Quercus* (Tab. 3).

DISCUSSION

Cupressaceae, the predominant pollen type throughout this period in the atmosphere of Toledo, shows a intradiurnal variation similar to the that observed in the cities of Córdoba and Málaga [14, 44], with hourly peaks at midday hours: between 12:00–14:00, when temperature begins to increase and relative humidity tends to decrease.

Fraxinus pollen presents amounts more or less similar throughout along the day. These results differ from those obtained in Córdoba [14], where peaks are observed at midday. The small amounts of *Fraxinus* pollen in Toledo can explain the absence of a clear intradiurnal model.

Olea pollen counts were lower in 2006 and 2008. Drought in 2005 and lower temperatures in spring 2008 may have negatively influenced on pollen production in those years. The foregoing, together with the fact that the olive tree is a species with years of greater production followed by years of lower production [19, 21, 45], may explain such behaviour. The intradiurnal model obtained agrees with the one in Córdoba [10, 13, 14]. In all cases, the maximum values are obtained in the same time slot. The intradiurnal pattern obtained in Toledo is between the pattern C2 (maximum at 12.00 and 16.00 hours) and the pattern A2 (maximum at 17.00 and 22.00 hours) described by Alba *et al.* [1] for Granada.

Platanus showed a similar pollen count throughout the 4-year period of study. The intradiurnal pattern for *Platanus* could explain that part of the pollen comes from the parks and gardens of the city and other part from places further away. Although some authors [5] indicate that *Platanus* pollen does not disperse over long distances, the pollen concentrations during the night in Toledo, with maximum values at 24:00 and 2:00 hours, could come from cities near Toledo such as Aranjuez, Madrid or Ciudad Real, where the plane tree is very abundant and *Platanus* pollen represents, respectively, 21.7%, 19.6% [39] and 11.92% [32] of the total detected pollen in those cities. The wind coming from these areas could be responsible for the medium range transport up to Toledo, as has been described in other areas of Spain [22]. The pollen recorded during the day reaches the maximum values at midday and in the afternoon, as happens in other cities in the Iberian Peninsula, where the highest pollen concentrations are observed throughout the daylight hours [14, 35, 37, 40, 44].

Populus pollen grains increased progressively during the studied period, and the smallest pollen count was detected during 2005. Perhaps the low amount of pollen of *Populus* registered in 2005 was due to the pruning carry out that year. Bi-hourly maximum was reached between 14:00–18:00, and differed only by several hours in comparison to the peaks described for Córdoba (12:00 to 14:00) [14].

The different amounts of *Quercus* pollen collected every year do not seem to be related to mean temperature and rainfall values, but to the alternating of years of low and high pollen production [16]. Different studies in United Kingdom [7] and Córdoba [14, 15] have shown pollen peaks during the afternoon. In the case of Almería [37], Málaga [44] and Mar del Plata (Argentina) [30], *Quercus* pollen follows a very homogeneous behaviour throughout the day, as it is detected in Toledo, with no significant peaks. However, *Quercus* in Toledo shows a slight pollen increase throughout the night hours, probably coming from sources situated far from the spore trap. This pollen could originate mainly from the mountain range called “Montes de Toledo” located in the south of the city where a good representation of oak forests can be found.

Ulmus keeps similar annual pollen count in the air, somewhat higher in 2005 and lower in 2007. To a great extent, *Ulmus pumila* L., an ornamental species, represents most of the *Ulmus* pollen type. This species is very representative in parks and gardens in Toledo, therefore being subjected to different prunings throughout the year. Hence, no clear relation can be established between annual pollen production and annual variation of meteorological variables. However, the effects of the different meteorological variables on the hourly distribution of the amount of pollen remain clear (Fig. 1, Tab. 3), and the model obtained for *Ulmus* agrees with that obtained for Córdoba [14].

Flowering, pollination and dispersion of pollen grains are closely related to meteorological parameters, especially to temperature and rainfall [1, 19, 31, 34]. Although the intradiurnal emission is highly genetically determined, the statistical results indicate in general, a significant and positive effect of temperature and solar radiation, and a negative influence of relative humidity on the intradiurnal variation of pollen in the atmosphere of Toledo. The increase of temperature and solar radiation cause the dehiscence of the anthers and the resulting release of pollen into the atmosphere. All this has been reported in previous works [28, 33]. The negative effect of humidity on pollen levels occurs because the grains of pollen absorb this humidity, become heavier and do not reach the spore trap [2, 38]

Summarizing, the analysis reported here shows the bi-hourly dynamics of the main arboreal pollen types of the atmosphere of Toledo, indicating the time of day when the maximum pollen concentration is reached. Pollen types from Cupressaceae, *Olea*, *Populus*, and *Ulmus* show maximum concentrations between 12.00–18:00 hours, and *Quercus* and *Platanus* pollen types at 24:00–02:00 hours, respectively. In Toledo, as in many other regions, the highest pollen concentrations are found during daylight hours. In the morning and at night, with no convection of the air, great amounts of pollen grains fall to the ground. On the other hand, pollen production shows a positive correlation with temperature and it is at midday and in the afternoon when the values of pollen and temperature are the highest.

Pollen concentrations during the night are probably the result of transport from a distant place, so that the hourly variation pattern from *Quercus* and *Platanus* present the highest concentrations during the night and the lowest at midday could be explained by the same reason.

CONCLUSIONS

Intradiurnal variation models for the main allergenic arboreal pollen in the atmosphere of Toledo (cypress – Cupressaceae, ash tree – *Fraxinus*, olive tree – *Olea* and plane tree – *Platanus*) provide us with useful information on the hours gathering the highest pollen concentration. These hours should be avoided by allergic patients and should be borne in mind when planning outdoor activities and walks in parks, gardens, and countryside areas where these pollen types are found. This information has great relevance for the health of Toledo citizens and for the 2 million of tourists who visit the city every year.

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