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ORIGINAL PAPER

Altitudinal fluctuations in the olive pollen emission: an approximation from the olive groves of the south-east Iberian Peninsula

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Abstract The possible existence of altitudinal fluctuations in the seasonal behaviour of the olive pollen emission was studied. Three pollen volumetric samplers distributed in olive groves all over the altitudinal cliseries of the province of Jaén (south-east Spain) were used. Pollen emission data were recorded during a 3-year period (2007–2009). This research has revealed the effect of altitude on consecutive olive pollen season in the province of Jaén. The first pollen grains were detected in the olive growing areas located within the area of the Guadalquivir River, where are found the lowest levels of altitude into the province. A notable delay in the pollination season of the olive groves located at higher altitudes was observed. Geographical fluctuations on both daily pollen concentrations and number of critical days were also detected. Accumulated variables of temperature and precipitation since the start of the pre-flowering period have been shown to be two of the main factors affecting olive pollen levels. The fluctuations observed in the olive pollen season may similarly occur in the case of other allergenic plant species such as cypress (*Cupressaceae*), plane tree (*Platanaceae*) or grasses (*Poaceae*). Furthermore, and for the clinical consequences of the findings presented in this study, we believe that it would be advisable to install a micro-aerobiological network permanently in the province of Jaén.

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Keywords Airborne olive pollen · Altitudinal fluctuations · Correlation analysis · Meteorological effect · *Olea europaea* L.

1 Introduction

In the Mediterranean basin, olive trees (*Olea europaea* L.) are one of the most widespread arboreal cultivated species that are perfectly adapted to that mild climate. Spain has the largest surface area given over this crop. The region of Andalusia (south Spain) accounts for 60% of the total olive crop, concentrated mainly in the provinces of Córdoba and Jaén (Barranco et al. 2008). In this region, olive pollen is the most abundant type within the annual pollen spectrum, so that the levels registered at certain times of the year are extremely high, due mainly both to the geographical location of this crop as well as the intense flowering of the trees, which produce abundant pollen during springtime (Galán et al. 1998; Ruiz Valenzuela et al. 1998; Díaz de la Guardia et al. 2003; Aguilera and Ruiz Valenzuela 2008). Olive pollen is considered as one of the main causes of respiratory allergic disease in the Mediterranean region (D'Amato et al. 2007). In Spain (Florido et al. 1999), southern Italy (D'Amato and Lobefalo 1989), Greece (Gioulekas et al. 2004) and

Turkey (Kirmaz et al. 2005), olive pollen is an important cause of pollinosis, provoking seasonal allergic rhinitis and bronchial asthma among the population. In the province of Jaén, *Olea* is the most important cause of pollinosis, with 84% of patients sensitized to pollen (Florido et al. 1999). In the last years, the frequency of olive-induced pollinosis is increasing as a consequence of improved diagnostic procedures and as a result of changes in the farming practices (Liccardi et al. 1996). Moreover, it is of interest that ecoenvironment and crop management are factors that are able to induce allergological changes (Conde Hernández et al. 2002).

Although the olive tree is an amphiphilous species, its pollination strategy relies mainly on anemophily (Trigo et al. 2008). Anemophilous plants tend to produce a high amount of pollen because of the unpredictability of the wind, which is their pollination vector. There is agreement among many authors that the massive pollen production of these species is a strategy to ensure pollination (Faegri and van der Piel 1979; Tormo Molina et al. 1996). Hence, these plants release higher amounts of pollen grains into the atmosphere.

The relationship between geographical location and behaviour of the pollen season in species such as olive or grasses has been largely studied (Emberlin et al. 2000; Fornaciari et al. 2000, 2002; Galán et al. 2005, 2008; Bonofiglio et al. 2009). A time lag from west to east in the olive pollen season was observed by several authors (Fornaciari et al. 2000; Díaz de la Guardia et al. 2003; Galán et al. 2005). Also the existence of a chronology in the phenological onset of the flowering period with respect to the altitude has been previously demonstrated (Fornaciari et al. 2000; Galán et al. 2008; Aguilera and Ruiz Valenzuela 2009). This last fact leads us to believe that both the olive pollen emission and dispersion could have important altitudinal fluctuations conditioned by the location of the olive grove. This knowledge would be especially relevant for patients allergic to olive pollen, because the allergenic content of the atmosphere could be different in function to area.

Therefore, our study aimed to determine whether there are any altitudinal fluctuations in the seasonal behaviour of the olive pollen emission. For this purpose, we present a comparative aerobiological study of the olive pollen from different altitudinal areas located in the south-east Iberian Peninsula, analysing the intensity of the olive pollen season over the study period as well as potential temporal and spatial patterns in these data. Moreover, the evolution of the critical days for allergic population was also studied.

2 Materials and methods

The province of Jaén (13,498 km^2) is located in the south-east of the Iberian Peninsula. The climate profile is continental Mediterranean, with cold winters and hot, dry summers. Annual average temperature is 15.82°C, and annual average precipitation is 667.4 mm. However, these vary considerably according to the altitude and topography.

The more than 570,000 ha of olive groves throughout the province cover 41.5% of its total surface area, being the most important olive crop area in the world (Barranco et al. 2008). In this intensive monovarietal cultivation, 97% of olive trees correspond to the *Picual* variety. Since cultivated areas cover a wide altitudinal gradient, the olive groves of Jaén provide an adequate experimental scenario for testing the possible effects of altitude on the pollen emission and dispersion. The lowest altitudes are located within the area of the valley of the Guadalquivir River. By contrast, the crops located at higher altitudes tend to be concentrated in the south and south-east of the province, that is, in the Subbetic Cordillera. This altitudinal gradient imposes variable meteorological conditions on olive groves.

The study was performed using both aerobiological and meteorological databases. The pollen sampling activity was carried out with the use of the pollen volumetric samplers of the Hirst type (Burkard model; Hirst 1952). The traps were located in three different altitudinal olive growing areas throughout the province: Andújar (Ad; 232 m a.s.l), Jaén (Jn; 568 m a.s.l) and Alcalá la Real (Al; 900 m a.s.l) (Fig. 1). Pollen emission data were recorded during a 3-year period (2007–2009). The standard data management procedures were employed following the rules proposed by the Spanish Aerobiology Network (REA) (Galán et al. 2007). The main pollen season (MPS) was determined by using a modification of the criterion described by Galán et al. in 2001 for *Olea* pollen season: the pollen-season-start-date was defined as the first day on which at least five pollen grains/m^3 were reached, with subsequent days containing five or more pollen grains/

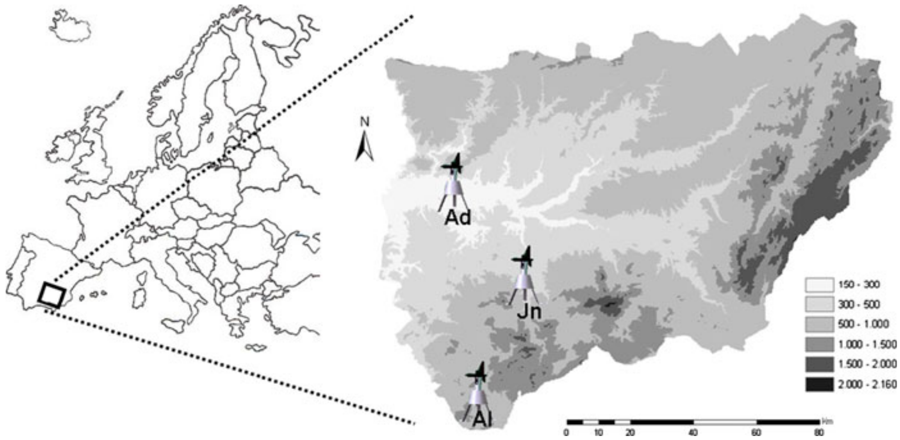

Fig. 1 Location of the sampling sites. *Ad* Andújar, *Jn* Jaén and *Al* Alcalá la Real (the numerical ranges refer to altitudinal ranges in metres)

m^3. On the other hand, the end of the season was considered to be the last day on which five pollen grains/m^3 are recorded and subsequent days (at least three consecutive days) present concentrations below this level. The most relevant data recorded during the MPS at different sampling stations—the starting and ending date, the duration (in days) of the pollen season, the pollen index (Ip), calculated as the sum of daily pollen concentrations captured during the whole flowering period, the maximum daily concentration reached and the date on which it was recorded (peak day)—were summarized in a table. Furthermore, average daily pollen concentrations in every study area were annually compared. Also, the number and geographical distribution of the critical days (critical day = day with a concentration >400 grains/m^3—threshold level of olive pollen required for eliciting symptoms of seasonal allergic in patients living in our area (Florido et al. 1999) was analysed.

To study the effect of the altitude, and consequently of the related meteorological conditions on olive pollen emission, Spearman's non-parametric correlation test was performed. In most cases, the meteorological parameters affecting the emission and dispersion of pollen at the beginning of the pollen season are often different from those that occurred at the end of it. For this reason, the same correlation analysis was applied on both the pre-peak period (it is considered as the period between the start of the main pollen season and the day on which maximum counts were recorded) and post-peak period (it is considered as the period between the peak day and the end of the main pollen season). As confidence levels were used 95%, the meteorological variables considered in this study were arranged into two groups: (a) daily values of maximum temperature (Tmax, °C), minimum temperature (Tmin, °C), relative humidity (H, %), solar radiation (Rad, MJ/m^2), precipitation (Pp, mm) and wind direction (Wd) and velocity (Wv) and (b) cumulative values of mean temperature (Tac_PRE) and precipitation (Pacp_PRE, mm) since the start of the pre-flowering period in the province of Jaén, estimated in 30 March (Aguilera and Ruiz Valenzuela 2009) until each day of the pollen season. Meteorological data were provided by the Agroclimatic Station Network of the Andalusian *Consejería de Agricultura y Pesca*. The information provided was recorded in the weather stations nearest to the study monitoring units (http://www.juntadeandalucia.es/agriculturaypesca).

The STATISTICA 7.0 software was used for the statistical analysis.

3 Results

The average of the daily olive pollen during the study period is shown in Fig. 2. The pollen season in the province of Jaén spans basically from the end of April to the middle of July, although exist a different temporal and spatial pattern between areas. The most relevant data during the MPS of the three sampling locations are shown in Table 1. The pollen season generally begin in Andújar, followed by Jaén and finally for Alcalá la Real. These temporal fluctuations were more evident in the peak day dates. The first peak days were generally registered in Andújar, between 7 and 8 of May, followed in a few days for the peak days

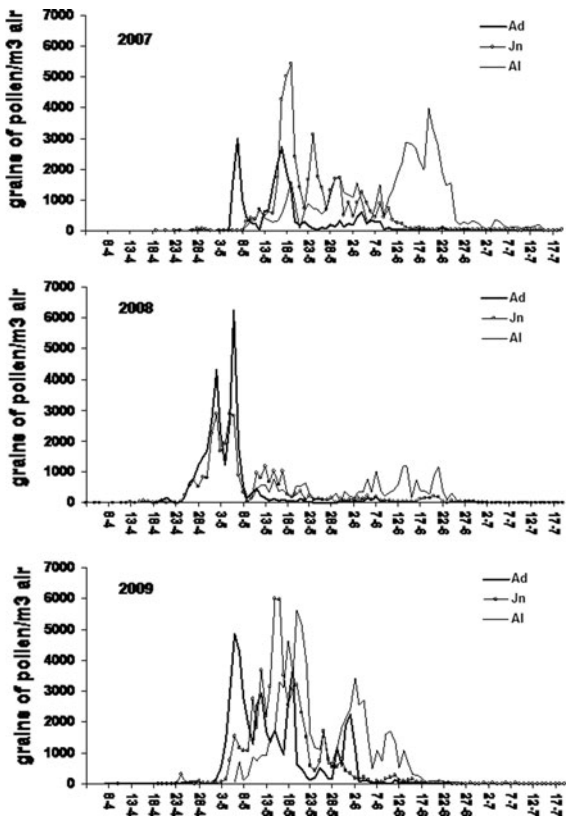

Fig. 2 Average daily concentration of olive pollen through the studied period at each of the sampling stations. *Ad* Andújar, *Jn* Jaén and *Al* Alcalá la Real

of Jaén, recorded over middle of May. The highest quantities of pollen in the atmosphere of Alcalá la Real were detected later and notably delayed in comparison with other sites, towards end of May or middle of June. Similarly were observed variability in the intensity of the peak days. The high peak counts were found in Jaén, with an average value of 4,777 ± 1,649 grains of pollen. Andújar and Alcalá la Real showed similar peak values, with average values of 3,659 ± 1,057 grains of pollen and 3,595 ± 2,240 grains of pollen, respectively.

Although very high quantities of pollen grains were collected in all three areas, strong fluctuations appeared between years and sampling sites. The year 2008 showed the lowest PI values in each study site with the exception of Andújar. 2007 and 2009 showed higher PI values in comparison with the other year of study, being 2009 the year with the highest olive pollen records. Comparing study areas the lowest quantity of olive pollen was registered in Andújar (average PI value of 33,298 ± 15,197), followed by Jaén (average PI value of 45,383 ± 13,564) and Alcalá la Real (average PI value of 52,150 ± 27,419), this last generally showing the highest PI values of the province (Fig. 3). The MPS lasted for a similar length of time in 3 years for each study site, but variations between areas were observed. The duration of the pollen season was higher in Jaén and lower in Andújar site, being this order the same over the study period.

An average season with more than 60 days exceeding 400 grains/m^3 was recorded. The severity of the olive pollen season in the province of Jaén ranged from 27 April to 26 June, although depending on the site (Fig. 4). Seasonal severity in Alcalá la Real (30 ± 11 critical days) was the highest of all study sites, while Andújar (18 ± 7 critical days) showed the lowest number of critical days.

The correlation results for meteorological parameters and pollen count values in both pre-peak period and post-peak period are shown in Tables 2 and 3, respectively. Only significant coefficients are shown.

Table 1 Principal characteristics of the MPS of *Olea europaea* L. pollen in the air for each year and study area

	Andújar			Jaén			Alcalá la Real		
	2007	2008	2009	2007	2008	2009	2007	2008	2009
Start date	24 April	18 April	25 April	28 April	15 April	23 April	10 May	5 May	6 May
End date	16 June	29 May	22 June	11 July	7 July	7 July	20 July	8 July	5 July
Duration	54	42	59	75	84	76	72	65	61
PI	22,171	27,111	50,613	47,569	30,858	57,721	62,792	21,005	72,652
Peak_day	8 May	7 May	7 May	20 May	6 May	16 May	20 June	15 June	21 May
[Peak_d]	2,984	3,116	4,877	5,421	2,904	6,007	3,970	1,192	5,624

Duration in days of the pollen season, *PI* pollen index, *[Peak_day]* concentration of pollen grains/m^3 air in the peak day

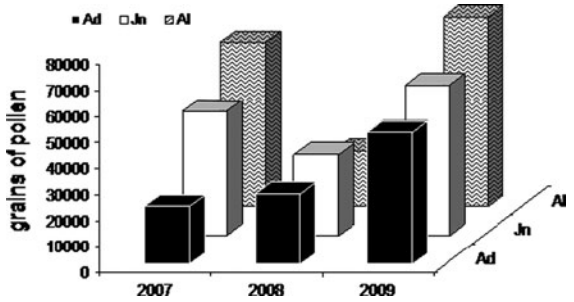

Fig. 3 Pollen Index values for each study area in the years 2007, 2008 and 2009. *Ad* Andújar, *Jn* Jaén and *Al* Alcalá la Real

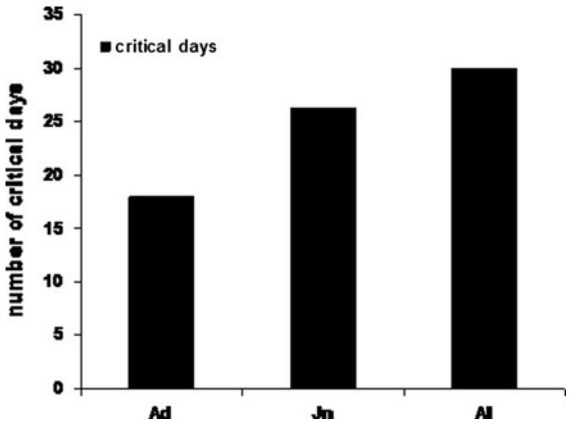

Fig. 4 Severity of the olive pollen season. *Ad* Andújar, *Jn* Jaén and *Al* Alcalá la Real

Accumulated variables of temperature and precipitation showed a strong relationship with daily olive pollen concentrations (Fig. 5). These variables correlated significantly and positively with the pre-peak period and negatively with the post-peak period in all study areas. The daily maximum and minimum temperatures showed significant correlation coefficients in both periods. In general, the daily maximum temperature had a positive effect on the pre-peak period, while both, the daily maximum and minimum temperatures, had a negative influence on the post-peak period. Similarly occurred respect to the radiation values, although a well-defined pattern was not observed. The inverse effect was observed with respect to the humidity coefficients. The daily precipitation only showed significant and negatives values in the pre-peak period. Finally, and with respect to wind, only significant correlation coefficients in pre-peak period were observed. Wind velocity showed negative values in Andújar, while wind direction correlated positively in all study areas.

4 Discussion and conclusions

The present study has revealed the existence of altitudinal and temporal fluctuations in both the behaviour and intensity of the olive pollen season. The first pollen grains were detected in the olive growing areas located within the area of the Guadalquivir River, where are found the lowest levels of altitude into the province. Nevertheless, a notably delay in the pollen season of the olive groves located at higher altitudes, concentrated in the south and south-east of the province, was detected. This fact is in consonance with previous phenological studies which observed a consecutive flowering of olive groves located from Guadalquivir Valley to the Subbetic Cordillera (Fornaciari et al. 2000; Galán et al. 2008; Aguilera and Ruiz Valenzuela 2009).

The highest quantities of olive pollen grains in the air of the province were recorded during two sections of the pollen season. On the one hand would be the peak days caused by the flowering period of the olive groves situated at altitudes ranging from 200 m to over 600 m, mainly recorded in the first fortnight of May. On the other hand would be the peak days registered between the end of May and the middle of June, due to the delay of the flowering period in olive trees located at higher altitudes.

Since a quantitative point of view, geographical fluctuations in the daily pollen concentrations were also detected. Jaén showed peak-day values significantly higher than the other study areas, but it was not the locality with the highest PI average values. According to the previous studies (Aguilera and Ruiz Valenzuela 2009), the maximum pollen concentrations in the city of Jaén were recorded when the olive groves located in the Guadalquivir valley were in full flowering. These olive-growing areas occupy large surface of land in the north and west of the province and clearly has a great influence on the olive pollen curves in the city of Jaén. For this reason, this area generally registered the highest peak values. Nevertheless, the most important PI values were detected in the areas located at higher altitudes. Two main reasons can probably explain this fact. Firstly, the sampling unit located in Alcalá la Real recorded, during a long period of time, pollen grains emitted by olive trees located in lowest altitudes. This conclusion found support in phenological studies (Aguilera and Ruiz Valenzuela 2009) and the results herein, which

Table 2 Spearman's correlation coefficients between daily *Olea europaea* pollen during the pre-peak period and meteorological parameters in each year and study area

	Pre-peak period								
	Andújar			Jaén			Alcalá la Real		
	2007	2008	2009	2007	2008	2009	2007	2008	2009
Tmax	–	0.49	0.75	0.53	0.63	0.40	–	0.39	–
Tmin	–	–	–	–	–	0.42	–	–	–
Tac_PRE	–	0.90	0.66	0.78	0.88	0.89	0.71	0.31	0.98
H	–	−0.65	−0.64	−0.80	−0.76	–	–	−0.31	–
Rad	–	–	0.58	–	–	–	–	0.33	–
Pp	–	−0.51	–	−0.41	−0.43	–	–	–	–
Pacp_PRE	–	–	0.82	–	0.48	0.80	0.56	–	0.87
Wv	–	−0.59	−0.51	–	–	–	–	–	–
Wd	–	0.59	0.27	–	0.39	–	–	0.28	–

Tmax daily values of maximum temperature, *Tmin* daily values of minimum temperature, *Tac_PRE* cumulative values of mean temperature since the start of the pre-flowering period until each day of the pre-peak period, *H* daily values of relative humidity, *Rad* daily values of solar radiation, *Pp* daily values of precipitation, *Pacp_PRE* cumulative values of precipitation since the start of the pre-flowering period until each day of the pre-peak period, *W.v* wind velocity, *W.d* wind direction. Values significant at $\alpha < 0.05$

Table 3 Spearman's correlation coefficients between daily *Olea europaea* pollen during the post-peak period and meteorological parameters in each year and study area

	Post-peak period								
	Andújar			Jaén			Alcalá la Real		
	2007	2008	2009	2007	2008	2009	2007	2008	2009
Tmax	0.44	–	−0.44	−0.73	−0.48	−0.35	−0.40	–	−0.46
Tmin	−0.36	–	−0.57	−0.52	−0.30	−0.64	–	–	−0.43
Tac_PRE	−0.55	−0.94	−0.87	−0.94	−0.78	−0.95	−0.83	−0.89	−0.83
H	−0.47	0.58	0.39	0.73	0.48	0.39	0.57	–	0.41
Rad	–	–	–	−0.61	−0.43	−0.30	–	–	–
Pp	–	–	–	–	–	–	–	–	–
Pacp_PRE	−0.58	−0.95	−0.89	−0.90	−0.75	−0.81	–	−0.75	−0.67
Wv	–	–	–	–	–	–	–	–	–
Wd	–	–	–	–	–	–	–	–	–

Tmax daily values of maximum temperature, *Tmin* daily values of minimum temperature, *Tac_PRE* cumulative values of mean temperature since the start of the pre-flowering period until each day of the post-peak period, *H* daily values of relative humidity, *Rad* daily values of solar radiation, *Pp* daily values of precipitation, *Pacp_PRE* cumulative values of precipitation since the start of the pre-flowering period until each day of the post-peak period, *W.v* wind velocity, *W.d* wind direction. Values significant at $\alpha < 0.05$

demonstrate that the pollen season starts over a month before that the flowering period (around end of May or middle of June) in these olive-growing areas. This distant source of pollen in addition to the pollen produced by the olive trees around the volumetric trap of Alcalá la Real could explain the increase in their IP values. Secondly, this filed research leads us to believe that pollen production could be conditioned by the location of the olive grove. Anemophily is based on an extremely indiscriminate and random dispersal mechanism. Hence, a higher amount of pollen could be produced by olive trees to compensate both the limited pollination efficiency and the short period of flowering in higher altitudes, being other reason which would explain the general trend to increase the PI value in function to altitude.

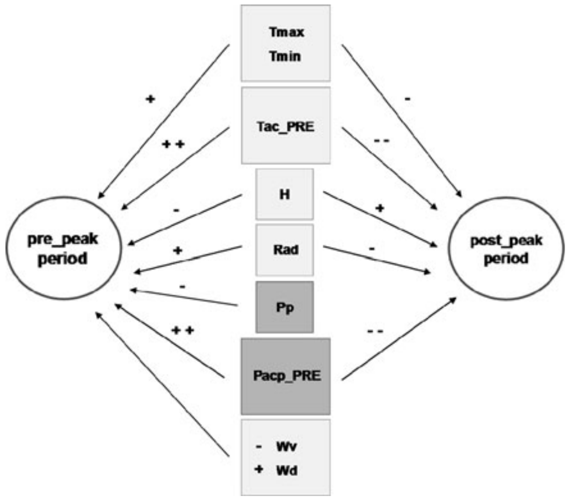

Fig. 5 Effect of the meteorological parameters on both pre-peak and post-peak periods. *Tmax* daily values of maximum temperature, *Tmin* daily values of minimum temperature, *Tac_PRE* cumulative values of mean temperature since the start of the pre-flowering period until each day of the olive pollen season (pre-peak and post-peak periods), *H* daily values of relative humidity, *Rad* daily values of solar radiation, *Pp* daily values of precipitation, *Pacp_PRE* cumulative values of precipitation since the start of the pre-flowering period until each day of the olive pollen season (pre-peak and post-peak periods), *W.v* wind velocity, *W.d* wind direction

Relating this work with previous studies realized in the provinces of Córdoba and Granada (southern Spain), the existence of a differential aerobiological behaviour based on the geographical location of the grove could be confirmed. The aeropalynological dynamic registered in the olive growing areas located in the lower altitude levels in our province was similar to the seasonal behaviour of the olive groves located in Córdoba (Galán et al. 2001; Vázquez et al. 2003). Nevertheless, the peak days recorded in our highest altitudinal areas were closed in date to those in the province of Granada, much more delayed in comparison with the valley area, due possibly to present an accentuated continentality level (Díaz de la Guardia et al. 2003).

The influence of the meteorological parameters on both pollen emission and pollen dispersion have been widely studied (Recio et al. 1996, 1997; Galán et al. 2001, 2005; Orlandi et al. 2002, 2010; Díaz de la Guardia et al. 2003; Vázquez et al. 2003; Bonofiglio et al. 2008). According to the present study, accumulated variables of temperature and precipitation since the start of the pre-flowering period have been shown to be two of the main factors affecting olive pollen levels. These parameters increase the pollen concentrations during the pre-peak period, with opposite influence during the post-peak period. This dual effect, although with less intensity, was also detected with the maximum and minimum temperature confirming the strong relationship between spring temperature and olive pollen emission, previously detected by authors as Galán et al. (2005) and Orlandi et al. (2010). In addition, and according to Recio et al. (1996), heat favours anthesis and anther dehiscence during the pre-peak period, which results in a higher pollen concentration. The opposite effect detected during post-peak period would be due to acceleration in the floral senescence.

Water is a very important parameter. Previous studies showed that the cumulative rainfall during the pre-flowering months delayed and shortened the length of the flowering period, but, at the same time, increasing the quantity of atmospheric pollen (Aguilera and Ruiz Valenzuela 2009). For this reason, we believe that heavy spring rainfall recorded in 2009 was able to increase notably the IP values of the different localities. Rainfall is also clearing related to the humidity, which increases pollen grain weight, causing pollen to fall and therefore a decrease in the airborne pollen concentration (Domínguez et al. 1993). In our field research, we recorded that humidity affected the result in two contrary ways. This parameter affected negatively to the process of release and dispersal of pollen during the pre-peak period, but its influence became positive in the post-peak period. This last fact could be the result of reducing the negative effect that higher temperatures have in this period, since most of the post-peak period takes place on dates close to the summer season in which there is a strong increase in daily temperatures. Moreover, this conclusion also could found support in the results obtained by Vázquez et al. (2003), which suggest that humidity has a positive effect on pollen concentration during dry periods.

Wind has a fundamental influence on the dispersion and transport of liberated pollen during the pre-peak period. Many authors have underlined that the wind activity depends on many factors such as the wind regimen characteristics of each area, the phenological state of the olive trees during wind activity, the distribution of the crops and the topography near to the sampling station (Alba et al. 2000; Díaz de la Guardia et al. 2003; García-Mozo et al. 2008). The prevailing winds in Jaén province blow from west and southwest during the spring months (Sousa Alaejos 1988), and they could easily transport olive pollen grains from cultivated areas of the Guadalquivir valley to the crops located at highest altitudes into the province, where the flowering period is considerably delayed (Aguilera and Ruiz Valenzuela 2009). Therefore, wind activity could be other reason to explain the high amounts of pollen registered in Alcalá la Real, which clearly received pollen grains in periods in which there was not effective flowering in the around area.

Although meteorological parameters have a clear effect on the olive pollen season, several studies have demonstrated that the olive tree reproductive development is also conditioned by the satisfaction of certain chilling and heat requirements, which differ geographically (Wielgolaski 1999; Orlandi et al. 2005; Galán et al. 2005; Bonofiglio et al. 2008, 2009). Hence, it would be interesting to be able to widen the present study and to relate the altitudinal fluctuations observed in the olive pollen season with different bioclimatic parameters and, therefore, should be considered in subsequent researches.

According to Ribeiro et al. (2008), the combination of several samplers has proved successful in olive crop areas characterized by the presence of olive trees growing at different altitudes, that is, under specific meteorological conditions. The fact that the olive pollen season begins so early in Andújar, suggesting that this area might serve as an indicator to the onset of the pollination season into the province of Jaén. Moreover, the existence of geographical variability on both distribution and intensity of the critical days is clear. For these reasons and for the clinical consequences of the findings presented here, we believe that it would be advisable to install a micro-aerobiological network permanently in the province. In addition, the fluctuations observed in the olive pollen season may occur similarly in the case of other allergenic plant species such as cypress (*Cupressaceae*), plane tree (*Platanaceae*) or grasses (*Poaceae*), supporting the need to provide local aerobiological information to the allergic population.

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