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ORIGINAL PAPER

Study of the floral phenology of *Olea europaea* L. in Jaén province (SE Spain) and its relation with pollen emission

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Abstract Phenological and aerobiological studies provide important information regarding the reproductive biology of cultivated species such as the olive. This article presents the results of an exploratory study of the floral phenology of *Olea europaea* L. at different altitudes in Jaén province (SE Spain) and an analysis of the main meteorological factors affecting flowering. As well, this study aimed to detect the relationship between phenology and olive pollen emission as a means of interpreting *Olea* pollen curves in the city of Jaén. Phenological observations were performed on olive trees at six sites, each at different altitudes and distributed over the whole area of olive cultivation in the province. Pollen data were obtained using a Hirst-type volumetric spore trap located within the city of Jaén. Phenological and aerobiological data were recorded in 2006 and 2007. This study shows that the chronology of the start of the flowering period depends on altitude. Statistical analyses indicate that the temperature, humidity, cumulative rainfall and cumulative solar radiation are the meteorological parameters that most affect olive floral phenology. The pollen season in Jaén generally lasts from May to June, with an annual total emission of over 40,000 pollen grains, the highest annual level of olive pollen emission in the world. The airborne pollen concentrations recorded in the city of Jaén are above all influenced by the olive groves located in the Guadalquivir valley.

Keywords Aerobiology · Correlation analysis · *Olea europaea* L. · Phenology · Pollen emission

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1 Introduction

Aerobiological and phenological studies provide important information regarding the reproductive biology of plant species, especially in cases such as the olive (*Olea europaea* L.). This species is of great economic and social importance in Andalusia—the most important olive oil-producing area in the world—and accounts for 80% of all Spanish olive oil production. In all, 41.5% of the surface area of the province of Jaén (SE Spain) is given over to olive cultivation, the highest percentage of any Spanish province. It is thus evident that the olive oil sector is highly important from both an economic and a public heath point of view. Models forecasting yields can be calculated in agricultural systems (Orlandi et al. 2001; Sáenz Laín et al. 2003; Galán et al. 2008) and are essential for optimising the technical and human resources needed for olive harvesting and for planning olive oil marketing and distribution. In terms of public health, this knowledge is also of great value for forecasting the length and intensity of the olive flowering period, which is vital since olive pollen is one of the main causes of pollinosis in the Mediterranean area (Macchia et al. 1993; Díaz de la Guardia and Blanca 1994).

Olea europaea L. is an anemophilous species that produces many flowers and large amounts of pollen (Barranco et al. 1999). In Andalusia, olive trees usually flower in the second fortnight of April, but there is a patent time lag from west to east (Galán et al. 2008). In the province of Jaén olive flower buds begin to develop at the end of March, and trees usually flower in May; the flowering peak occurs mid-May, although it varies in accordance with temperatures during the preceding period (Galán et al. 2005).

Field phenological observations are an essential complement to aerobiological studies, and knowledge of the flowering sequence is therefore a vital part of any attempt to improve knowledge of olive pollen curves (Jato et al. 2007). The phenological behaviour and the airborne olive pollen concentrations depend on the geographical location and weather conditions (Galán et al. 2008), where the temperature and the rainfall are the meteorological parameters that most affect olive flowering (Vázquez et al. 2003; Jato et al. 2007).

The aim of this study was to test the extent of the altitude effect on both olive floral phenology and pollen emission, as well as to identify the main meteorological factors influencing the start and length of the flowering period.

2 Materials and methods

2.1 Study area

Jaén province (13,498 km^2) is located in SE Spain, between the Sierra Morena to the north and the Sierras Subbéticas to the south (37°46′N; 3°47′W). Its climate is Mediterranean continental in type, and the province is characterised by cold winters and hot dry summers. The annual average temperature is 15.82°C and annual average rainfall is 667.4 mm, although these parameters vary significantly with altitude and topography.

Olive groves in Jaén province cover a surface area of 590,000 ha and are the dominant crop in the fertile valley of the Guadalquivir Basin and mountains of the Sierras Subbéticas (Fig. 1).

Olive cultivation is an intensive monoculture: more than 97% of olive trees are of the Picual cultivar, which is appreciated for its high productivity and excellent oil production (Barranco et al. 1999). Furthermore, agricultural techniques are similar throughout all the main olive-growing areas and make the Jaén region an adequate experimental model for studying the possible effects of altitude on the phenological behaviour of olive trees.

For the present study, six sites with different geographical and meteorological variables lying on an altitudinal gradient (Fig. 2) were selected (Table 1): Andújar, Alcaudete, Arroyo, Jaén, Úbeda and Alcalá la Real.

2.2 Phenological survey

Phenological observations were performed in 2006 and 2007 on a weekly basis on ten olive trees selected randomly at each study site. Data recording took place from the end of March until the end of the flowering period, by which time the flowers had clearly been fertilised.

The phases proposed by Maillard (1975) were used to characterise the floral phenophases (Ph). The Ph were grouped into two groups: (1) the pre-flowering period (Ph 2–5: Ph 2—onset of flower bud development; Ph 3—flower bud development and presence of a node; Ph 4—swelling of the flower buds and nodes well-defined; Ph 5—yellow flowers almost open and with a well-developed corolla) and (2) the flowering period (Ph 6–8; Ph 6—start of flowering with <15% flowers open; Ph 7—full flowering with >15% flowers open; Ph 8—end of flowering with withered petals).

In this study, the phenological trends for each study site were identified and compared from 1 year to another. As well, the length of the pre-flowering and flowering periods for each study site and study year were analysed.

2.3 Aerobiological survey

Pollen data were recorded in 2006 and 2007 using a Hirst-type volumetric spore trap (Hirst 1952) located in the city of Jaén at 15–20 m above ground level (to ensure free air circulation). The standard data management procedures were employed following the rules proposed by the Spanish Aerobiology Network (REA) (Galán et al. 2007).

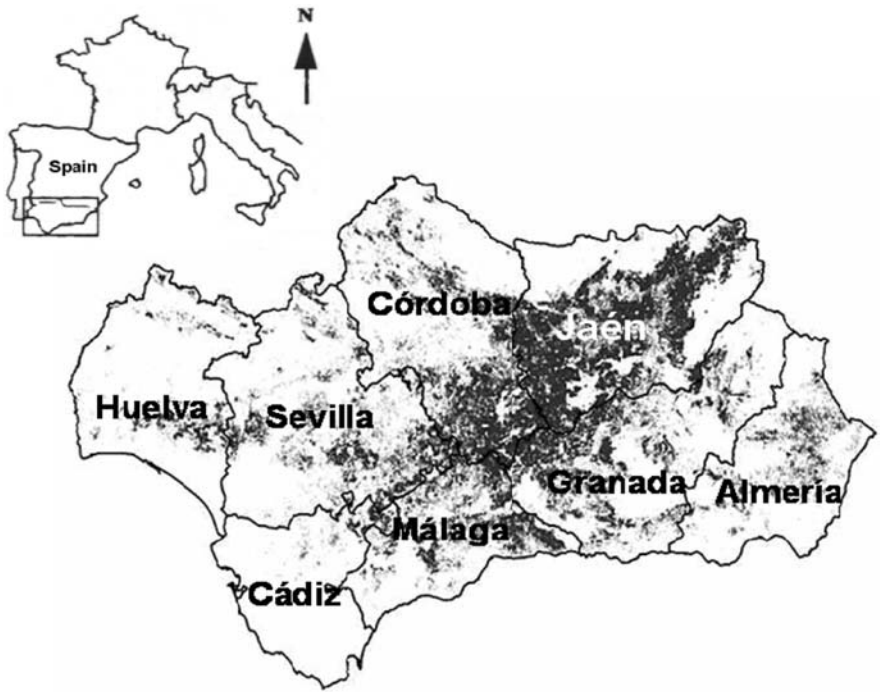

Fig. 1 Location of Andalusia in Europe and the distribution of olive groves in Andalusia

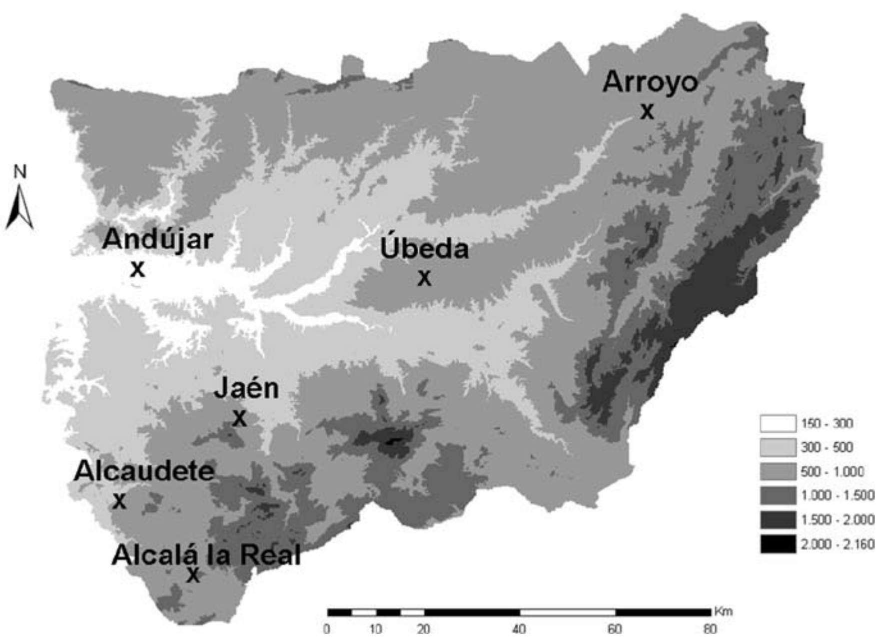

Fig. 2 Location of the study sites. (The numerical ranges refer to altitudinal ranges in meters)

The main pollen season (MPS) was determined at 95%, following the methodology proposed by Nilsson and Persson (1981). The peak pollen day was considered to be the day on which the maximum mean daily pollen concentration was registered.

The most relevant data recorded during the main pollen season—the starting and ending date, the duration of the pollen season, the peak day and the total value for the olive pollen season in Jaén—are summarised in a table. Furthermore, average daily

Table 1 Principal geographical characteristics of the study sites

Site	Altitude (m)	UTM X	UTM Y	Distance to the monitoring station (km)
Andújar	248	0410124	4205838	37
Alcaudete	477	0400161	4160642	32
Arroyo	531	0518811	4245968	112
Jaén	590	0430034	4179021	6
Úbeda	715	0464058	4207376	43
Alcalá	942	0417558	4146172	36

pollen concentrations in every study year are shown and compared, and are related to phenological tendencies.

2.4 Statistical analysis

To study the effect of meteorological parameters on floral phenology, Spearman's non-parametric correlation test was performed. The meteorological variables considered in this study were subdivided into two categories: (1) daily average observations for the pre-flowering and flowering periods (average maximum, mean and minimum temperature, relative humidity) and (2) the cumulative values for the pre-flowering and flowering periods (cumulative rainfall and cumulative sunshine) (Díaz de la Guardia et al. 2003; García-Mozo et al. 2008). In addition, this study aimed to use linear regressions to test for the existence of a relationship between the length of the flowering period and altitude.

3 Results

The phenological trends for *Olea europaea* L. according to the study site and year are shown in Fig. 3. The onset of the development of flower buds is practically simultaneous in the majority of the study sites, occurring from late March to early April. The exception was the site Alcalá la Real, in which bud development in the pre-flowering period was notably delayed in comparison to other sites. In Ph 5, just before the flowering period, the phenological trends begin to diverge, and a chronology in the onset of the flowering period occurs: site Andújar is the first to begin the flowering period (on May 2–8 in 2006 and May 14–20 in 2007) and is then followed by sites Alcaudete and Jaén. Site Arroyo starts the flowering period later, and sites Úbeda and Alcalá la Real are the last to flower, on 16–22 May in 2006 and 25 May–11 June in 2007. This order was the same in both study years and reveals the effects of altitude on consecutive flowering: olive groves located at 200–700 m are the first to start the flowering period, while olive groves at altitudes above 700 m are the last, beginning to flower 7–10 days later.

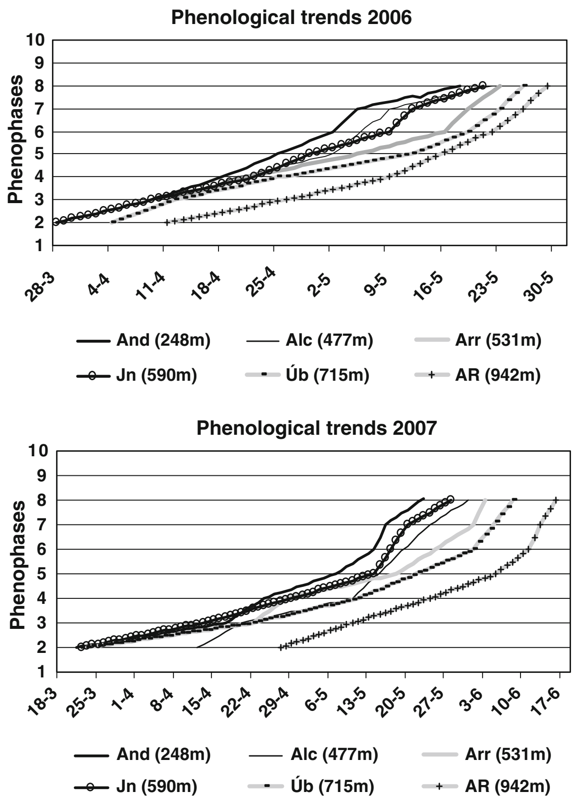

Fig. 3 *Olea europaea* L.: phenological trends for sites and study years. Andújar (And), Alcaudete (Alc), Arroyo (Arr), Jaén (Jn), Úbeda (Úb) and Alcalá la Real (AR)

Figure 4 shows the length of the pre-flowering and flowering periods at all study sites. The pre-flowering

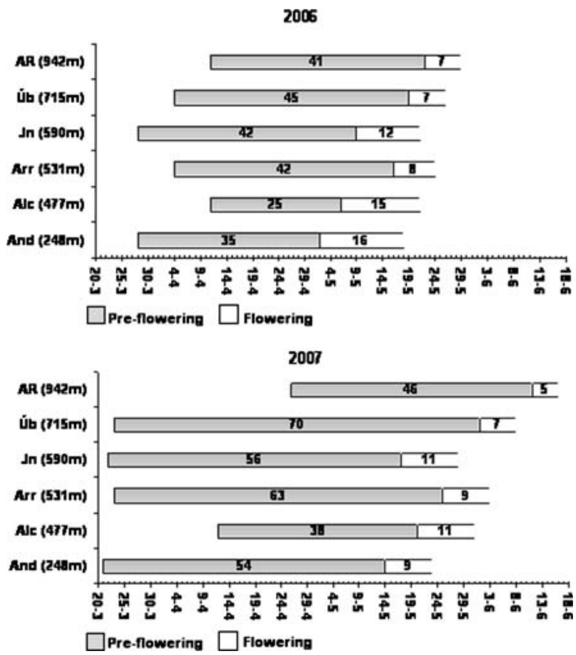

Fig. 4 Length of the pre-flowering and flowering periods at the study sites (2006 and 2007). Codes in this figure represent the sites codes in Fig. 3

period is longer than the flowering period, with a mean length of 48 days. The average length of the flowering period, during the study period, was 10 days. This period decreases with altitude, being shorter in olive groves at higher altitudes. The consecutive flowering of the study areas located at different altitudes is patent, and only at site Jaén was a different pattern noted; here, the flowering period started a few days before that of site Arroyo, despite being located at a greater altitude. The pre-flowering period in 2007 started a week before that of 2006 and was longer. Nevertheless, the flowering period started 8–20 days later in 2007 and was shorter at all study sites.

The correlation analysis between meteorological parameters and floral phenology is shown in Table 2. The length of the pre-flowering period correlated significantly and positively with cumulative rainfall and cumulative sunshine during this period. Nevertheless, it was significantly and negatively correlated with the average minimum temperature during the latent period and during the pre-flowering period. The meteorological variables that most influenced the length of the flowering period were the humidity, the temperature and the cumulative sunshine. A high mean temperature during the latent period and a high humidity and cumulative sunshine during the flowering correlated positively with the length of this period. On the other hand, high cumulative sunshine during the pre-flowering period was negatively correlated with the length of the flowering period.

Table 2 Correlation coefficients between meteorological parameters and the length of the pre-flowering and flowering periods

Variables	Length of pre-flowering	Length of flowering
Length of flowering		1.00
TMxFLO		−0.17
TMnFLO		0.55
TMeanFLO		−0.07
HFLO		0.92*
SnFLO		0.95*
RfFLO		0.75
Length of latent	−0.33	−0.58
TMxLAT	0.68	0.20
TMnLAT	−0.92*	0.48
TMeanLAT	−0.45	0.87*
HLAT	0.73	0.08
SnLAT	−0.41	−0.45
RfLAT	−0.08	−0.60
Length of pre-flowering	1	−0.56
TMxPRE	0.8	−0.71
TMnPRE	−0.75*	0.00
TMeanPRE	0.03	−0.59
HPRE	0.44	0.44
SnPRE	0.85*	−0.86*
RfPRE	0.61*	−0.21

TMx average maximum temperature, *TMn* average minimum temperature, *TMean* average mean temperature, *H* average relative humidity, *Rf* cumulative rainfall, *Sn* cumulative sunshine, *FLO* flowering, *LAT* latent, *PRE* pre-flowering

* $p < 0.05$

Figure 5 shows a simple linear regression that tests the relationship between the length of the flowering period and geographical altitude, using the mean data from all the study sites from both study years. A significant negative relationship of $R^2 = 0.6067$ between these two variables was obtained with a simple regression analysis, $y = -55.684x + 1{,}132.2$, where y is the length of the flowering period (days), and x is the geographical altitude (metres).

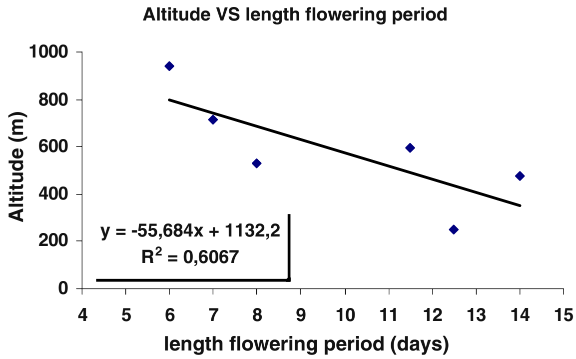

Fig. 5 Linear equation and fit of the regression between altitude (metres) and length of the flowering period (days)

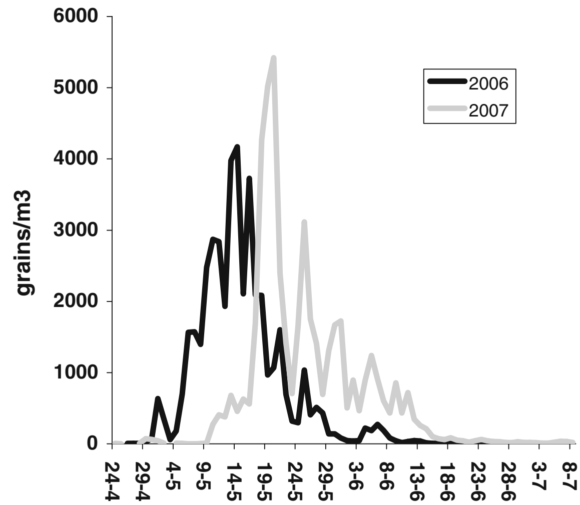

Fig. 6 Average daily of olive pollen emission in the two study years

The most relevant data during MPS in Jaén are shown in Table 3. The pollen season lasted for a similar length of time in both years (34–35 days), although in 2007 the start and end of the pollen season were delayed by 10 days with respect to 2006. Airborne olive pollen concentrations were higher in 2007. The pollen index during the MPS was 42,322 pollen grains in 2006 and 45,725 pollen grains in 2007. The greatest airborne concentrations occur in mid–May, a few days after the onset of flowering, with daily peaks of 4,169 pollen grains/m^3 in 2006 and 5,421 pollen grains/m^3 in 2007 (Fig. 6).

A comparative study of the olive floral phenology at the different study sites along with aerobiological data is shown in Fig. 7. The start of the pollen season in the city of Jaén coincided with the onset of flowering. The flowering period began first at the lowest altitudes, and the olive groves at sites Andújar, Alcaudete and Jaén were in full flower with daily peaks of between 4,000 and 4,500 grains/m^3 of air, whilst the other olive groves were still in phenophases 4–5. Site Arroyo was in phenophase 7 when the concentrations of olive pollen in the air in the city of Jaén had fallen to under 2,000 grains/m^3 and the pollen season had already entered its post-peak period. Finally, when olive pollen concentrations in the city of Jaén were under 1,000 grains/m^3, sites Andújar, Alcaudete, Arroyo and Jaén were at the end of the flowering period, while sites Úbeda and Alcalá la Real, located at altitudes of 700–1,000 m, were just beginning their flowering period. The height of the flowering period in these two latter olive groves coincided in both 2006 and 2007 with the end of the pollen season in the city of Jaén.

4 Discussion and conclusions

Knowledge of floral phenology provides important information regarding the reproductive biology of cultivated species such as the olive. The study of phenological trends is a useful means of determining the beginning and end dates of the pre-flowering and flowering periods, which in turn is vital for a better understanding of olive pollen curves (Jato et al. 2007).

This study showed that in 2007 in general the development of floral buds was late, and this delay was evident in the flowering period. Flower buds began to develop practically simultaneously in the majority of the study sites, from late March to early

Table 3 Principal characteristics of the MPS of *Olea europaea* L. pollen in the air during the study years

Year	Start date	End date	Duration (days)	Total season (pollen index)	Peak day	Peak day (grains/m^3)
2006	2 May	5 June	35	42.322	14 May	4.169
2007	12 May	14 June	34	45.725	20 May	5.421

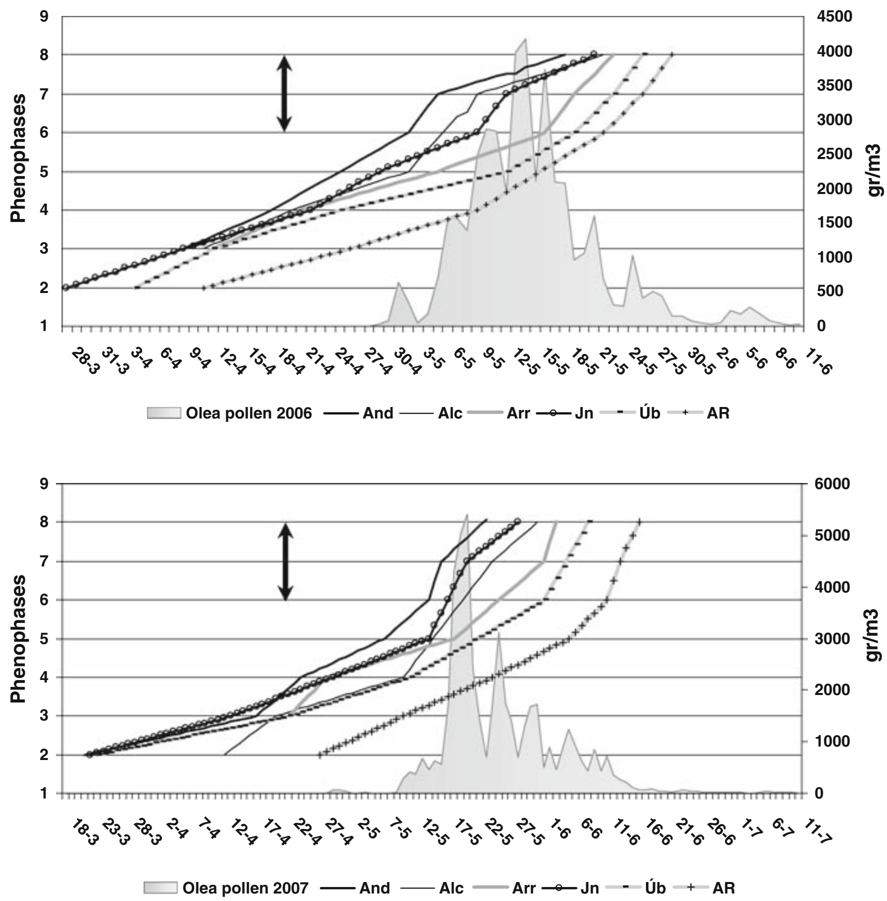

Fig. 7 Aerobiological data and a comparative study with the olive floral phenology at the different study sites. (The *black arrow* indicates the flowering period.) Codes in this figure represent the site codes in Fig. 3

April, with the exception of the olive groves located at higher altitudes, where there was a marked delay in the development of the flower buds. This is due to the fact that these sites have less temperate weather.

The pre-flowering period occurred from April to early May and was much longer than the flowering period. The underlying cause is probably due to the fact that during this period flower buds undergo important changes in morphology and need more time and energy to grow (Barranco et al. 1999). This period was similar in the majority of the study sites with the exception of the sites located at higher altitudes, where this period was delayed. Moreover, the pre-flowering was considerably longer in 2007, due possibly to the weather, with the rain and the temperature being two variables that are closely related to the length of this period (Barranco et al. 1999).

The phenophase just before the flowering period, where the flowers are almost open, is a critical moment in the phenological development of the olive given that represents the transition between two periods: the pre-flowering period, delayed by weather conditions and by structural changes in the flower buds, and the flowering period, at the beginning of which phenological trends begin to diverge, for example, in the chronology of the onset of flowering.

The flowering period occurred in mid-May, and it is generally characterised by a quick succession in the phenophases. The delay of this period in 2007 was probably due to the fact that the pre-flowering period was longer as a result of low temperatures and high rainfall or because of the weather conditions during the flowering period.

This exploratory study reveals the existence of a chronology in the onset of flowering in olive trees and shows how the length of this period depends on altitude, being delayed and shorter at higher altitudes. Many authors have noted this phenomenon before (Fornaciari et al. 2000; Galán et al. 2008) and have reported that the olive flowering period is delayed and shortened as one travels from the Guadalquivir Valley to the Sierras Subbéticas. In Jaén province the effect of altitude leads to consecutive flowering periods: thus, olive groves at altitudes of 200–700 m are the first to start flowering, while groves above 700 m flower 7–10 days later.

The correlation analysis, performed to study the effects of meteorological parameters on floral phenology, indicates that the temperature, humidity, cumulative rainfall and cumulative solar radiation are the meteorological parameters that most influence olive floral development. The length of the pre-flowering period depended on the average minimum temperatures before and during this period. Moreover, cumulative rainfall and cumulative sunshine during the pre-flowering period had, respectively, a positive effect on the length of the pre-flowering period. These parameters were responsible for lengthening the pre-flowering period, but delayed and shortened the length of the flowering period. Nevertheless, the flowering period correlated positively with a high mean temperature during the latent period and also with high humidity and cumulative sunshine levels during this period. Many authors have used accumulated meteorological parameters in different statistical analyses about *Olea* flowering, obtaining high correlation coefficients when variables such as accumulated sunlight hours or accumulated rainfall were used (Recio et al. 1996; Vázquez et al. 2003).

The pollen index during the MPS is generally higher than 40,000 pollen grains (Ruiz et al. 1998, 2002), with Jaén being the city with the highest concentrations of olive pollen in the air (Díaz de la Guardia et al. 2003)—considered to be the main cause of allergies in southern Spain—and around 89% of people are calculated to be sensitive to this pollen (Florido 1994). The delay observed in the pollen emission of 2007 could be attributed to the fact that spring was considerably wetter and the flowering period began late in all areas of olive cultivation. As well, airborne olive pollen concentrations were higher in 2007. This could be attributed to the pre-season rains (Candau Fdez-Mensaque and González Minero 1997; Díaz de la Guardia et al. 2003).

The olive groves located in the Guadalquivir valley occupy large areas of land in the north and west of the province at altitudes ranging from 200 to 700 m, and this study has shown that for a number of reasons they had the greatest influence on the olive pollen curves in the city of Jaén. The start of the pollen season in the city of Jaén coincided with the onset of the flowering period in these olive groves, and the maximum pollen concentrations were recorded when these areas were in full flower. However, the olive crops located at higher altitudes, above 700 m, began their flowering period when the olive pollen concentrations were low, and their full flowering coincided with the end of the pollen season. On the other hand, many authors report that olive pollen levels depend on the phenological state of the olive flowers during wind activity, the distribution of the olive groves and the topography near the sampling station (Alba et al. 2000; Díaz de la Guardia et al. 2003; García-Mozo et al. 2008). The olive pollen levels increase when the wind direction is favourable to the location of the crops and their phenological state is appropriate (Díaz de la Guardia et al. 2003). The prevailing winds in Jaén province blow from the west and southwest during the spring months (Sousa Alaejos 1988), and they could transport olive pollen from cultivated areas in the Guadalquivir Valley into the city of Jaén. Nevertheless, these same prevailing winds prevent pollen from the olive groves located in the northeast of the province from reaching the city of Jaén. This suggests that most of the olive pollen recorded in the city comes from the olive groves located in the north and west of the province, all of which are found at altitudes ranging from 200 to 700 m. The olive-growing areas located in the north-east of the province or at an altitude of 700 m do not seem to contribute significantly to the airborne pollen concentrations recorded in the volumetric trap located in the city of Jaén.

Our survey revealed some interesting facts about the olive flowering development, and it has important ramifications on adequate interpretations of airborne pollen curves by using phenological factors. Further studies will be needed to improve our understanding of the theories developed in this study.

References

Alba, F., Díaz de la Guardia, C., & Comtois, P. (2000). The effect of meteorogical parameters on diurnal patterns of airborne olive pollen concentration. *Grana, 39*, 200–208.

Barranco, D., Fernández-Escobar, R., & Rallo, L. (1999). *El Cultivo del olivo*. Madrid, España: Junta de Andalucía y Ediciones Mundi-Prensaaña.

Candau Fdez-Mensaque, P., & González Minero, F. J. (1997). Las predicciones en el olivar a través de la aeropalinología. Resultados de ocho años de muestreo en Sevilla (España). *Olivae, 65*, 46–51.

Díaz de la Guardia, C., Alba, F., Trigo, M. M., Galán, C., Ruiz, L., & Sabariego, S. (2003). Aerobiological analysis of *Olea europaea* L. pollen in different localities of southern Spain. *Grana, 42*, 234–243.

Díaz de la Guardia, C., & Blanca, G. (1994). *Flora Ornamental de Granada. Polen e incidencias en las alergias*. Granada: Universidad de Granada.

Florido, J. F. (1994). Aspectos clínicos-epidemiológicos del polen de olivo en Jaén. *Rev. Esp. Alergol. e Inmunol Clínica, 9*(2), 11–13.

Fornaciari, M., Galán, C., Mediavilla, A., Domínguez, E., & Romano, B. (2000). Aeropalynological and phenological study in two Mediterranean olive areas: Córdoba (Spain) and Perugia (Italy). *Plant Biosystems, 134*(2), 199–204.

Galán, C., Cariñanos, P., Alcázar, P., & Domínguez, E. (2007). *Manual de Calidad y Gestión de la Red Española de Aerobiología*. Córdoba: Servicio de publicaciones de la Universidad de Córdoba.

Galán, C., García Mozo, H., Vázquez, L., Ruiz-Valenzuela, L., Díaz de la Guardia, C., & Domínguez-Vilches, E. (2008). Modeling olive crop yield in Andalusia, Spain. *Agronomy Journal, 100*(1), 98–104.

Galán, C., García Mozo, H., Vázquez, L., Ruiz-Valenzuela, L., Díaz de la Guardia, C., & Trigo-Pérez, M. (2005). Heat requeriments for the onset of the *Olea europaea* L. pollen season in several places of Andalusia region and the effect of the expected future climate change. *International Journal of Biometeorology, 49*(3), 184–188.

García-Mozo, H., Pérez, R., & Galán, C. (2008). Aerobiological and meteorological factor's influence on olive (*Olea europaea* L.) crop yield in Castilla-La Mancha (Central Spain). *Aerobiología, 24*, 13–18.

Hirst, J. (1952). An automatic volumetric spore-trap. *The Annals of Applied Biology, 36*, 257–265.

Jato, V., Rodríguez-Rajo, J., & Aira, M. J. (2007). Use of Quercus ilex subs. ballota phenological and pollen production data for interpreting Quercus pollen curves. *Aerobiología, 23*, 91–105.

Macchia, L., Caiaffa, M. M., & Tursi, A. (1993). Olive pollen allergy in Bari, Italy. *Allergy, 48*, 551.

Maillard, R. (1975). *L'olivier*. Paris, France: Invuflec.

Nilsson, S., & Persson, S. (1981). Tree pollen spectra in the Stockholm region (Sweden), 1973–1980. *Grana, 20*, 179–182.

Orlandi, F., Fornaciari, M., & Romano, B. (2001). The use of phenological data to calculate chilling units in *Olea europaea* L. in relation to the onset of reproduction. *International Journal Biometeorology, 46*, 2–8.

Recio, M., Cabezudo, B., Trigo, M. M., & Toro, J. (1996). *Olea europaea* pollen in the atmosphere of Málaga (S. Spain) and its relationship with meteorological parameters. *Grana, 35*, 308–313.

Ruiz, L., Díaz de la Guardia, C., & Cano, E. (1998). Study of seasonal and daily variations in airborne Olea europaea L. pollen in Jaén (Spain), 1993–1995. *Aerobiología, 14*(27), 7–279.

Ruiz, L., Díaz de la Guardia, C., Cano, A., & Cano, E. (2002). Aerobiología en Andalucía: estación de Jaén: (2000–2001). *REA, 7*, 77–82.

Sáenz Laín, C., Gutiérrez Bustillo, M., & Alcolado Sánchez-Mateos, V. (2003). Fenología, aerobiología y producción del olivar en Almodóvar del Campo (Castilla La Mancha). *Anales Jardín Botánico de Madrid, 60*(1), 73–81.

Sousa Alaejos, R. (1988). *Notas para una Climatología de Jaén*. Madrid, España: Instituto Nacional de Meteorología.

Vázquez, L. M., Galán, C., & Domínguez-Vilches, E. (2003). Influence of meteorological parameters on olea pollen concentrations in Córdoba (South-western Spain). *International Journal Biometeorology, 48*, 83–90.