

# Aerobiological and meteorological factors' influence on olive (*Olea europaea* L.) crop yield in Castilla-La Mancha (Central Spain)

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**Abstract** Knowledge of the main biological and climate factors influencing final harvest is becoming increasingly necessary in order to obtain reliable crop estimates and, thus, ensure optimised, effective private crop management. This knowledge is also of great value to public agricultural institutions for the planning of government subsidies. Castilla-La Mancha (Central Spain) is the second largest olive-oil-producing region in Spain, the highest olive-oil-producing country in the world. This study sought to identify the main factors influencing olive fruit production in this region, including atmospheric pollen as an index of flowering intensity, and meteorological data over the flowering and fruiting seasons in two main olive-producing provinces of the region: Ciudad Real and Toledo. Statistical analysis indicated that the annual pollen index (PI) was the variable influencing most the final olive crop in both provinces. The maximum temperature in March was the meteorological variable affecting most the annual olive crop. Also, the rainfall registered in October influences the final fruit production. The integration

of aerobiological and meteorological data represents an important step forward in the development of future crop forecasting models in the region of Castilla-La Mancha.

**Keywords** Olive · *Olea europaea* · Crop · Olive fruit · Pollen · Aerobiology · Phenology · Castilla-La Mancha

## 1 Introduction

In Europe, knowledge of the main biological and climate factors influencing final harvest is becoming increasingly necessary in order to obtain reliable crop estimates and, thus, ensure optimised, effective private crop management. This knowledge is also of great value to public agricultural institutions for the planning of government subsidies (Sinclair and Seligman 2000). Effective olive crop forecasting is proving to be essential in optimising human and economic resources for olive-fruit harvesting, marketing strategies and global commercial distribution. This is of particular importance for the olive crop in the Mediterranean area, a major target of European Union agricultural economic policy (Abassi 2001).

In this study, aerobiological data related to flowering and pollen emission and meteorological data are analysed in order to determine the influence of these factors in the final olive crop production in Castilla-La Mancha (Central Spain). In this region,

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the two main olive producer provinces, Ciudad Real and Toledo, have been investigated.

Castilla-La Mancha is the second largest region in Spain producing olive fruits, with an average production of 500,000 metric tonnes per year (<http://www.ine.es>).

The use of airborne pollen data as an indicator of final harvest is a tool of proven utility, particularly in anemophilous crops. A number of published papers have charted the relationship between pollen release and fruit production in different species, such as *Vitis vinifera* L. (Baugnent 1991), *Corylus avellana* L. (Lletjos et al. 1993) and *Quercus* spp. (García-Mozo et al. 2007). In the Mediterranean area, different studies have dealt with the relationship between the *Olea europaea* L. pollen index and olive fruit production (Fornaciari et al. 2002, 2005; Moriondo et al. 2001). In Spain, most of these studies have been performed in the Andalucía region, the largest olive-oil-producing region in the world (Galán et al. 2004, 2007b). Therefore, there is little information about the influence of aerobiological and meteorological factors on the olive crop production in the Castilla-La Mancha region, which is climatically different from the Andalucía region (Sáenz Laín et al. 2003).

This study sought to identify the main factors influencing olive fruit production in this region by studying pollen release as an index of flowering intensity, and meteorological data over the flowering and fruiting season in the two main olive-producing provinces of Castilla-La Mancha. Given the economic importance of olives in the Mediterranean area, the aim of this study could help to provide a reliable harvest estimation to be used in agronomic and economic planning strategies.

## 2 Materials and methods

The study was performed in the Ciudad Real and Toledo provinces (Fig. 1). We analysed aerobiological and harvest data from 1997 to 2006 in Ciudad Real and from 2003 to 2006 in Toledo. The pollen traps are located in the capital cities, Ciudad Real (38°59' N, 3°55' W) and Toledo (39°51' N, 4°01' W).

In the Castilla-La Mancha region, the climate is Mediterranean-Continental, with a high thermal range during the year overall in the province of Toledo. The mean annual temperature is 14.2°C in

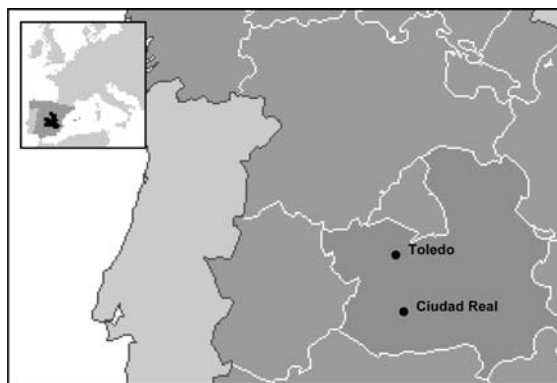


**Fig. 1** Location of the Castilla-La Mancha region

Ciudad Real and 15.4°C in Toledo. The average rainfall is 450 mm/year in Ciudad Real and 382 mm/year in Toledo. The Spanish National Institute of Meteorology supplied meteorological data from their weather stations situated in the administrative capitals of the two provinces.

The studied period has been characterised by summers with extremely high temperatures, especially in Ciudad Real, where the summer average temperature was 28.4°C, while the average summer temperature from 1971 to 2000 was 24°C. As regards to vegetation, in the Ciudad Real surroundings is a plane area where different crops dominate the landscape: olive trees, cereals and grapes. In Toledo, the vegetation is the Mediterranean “dehesa,” a semi-natural landscape that conjugates pasture areas and *Quercus* spp. trees, except for mountains areas, where the Mediterranean forest is the dominant vegetation. In the Montes de Toledo mountains are located the most extended olive crop area.

Olive groves in Castilla-La Mancha cover a surface area of roughly 335,698 ha: 122,441 ha in the province of Ciudad Real and 118,619 ha in Toledo. The study covered about 72% of the total olive area in Castilla-La Mancha. Over the studied years, the olive crop has averaged 120,000 tonnes per year in Ciudad Real and 122,000 tonnes per year in Toledo (<http://www.ine.es>).

Pollen data were recorded using Hirst-type volumetric traps (Hirst 1952). The traps were placed in the administrative capitals, located in the centre of the provinces. Traps were placed 15 m above ground level. Standardised data management procedures followed the rules laid down by the Spanish Aerobiology

Network (REA) (Galán et al. 2007a). Daily airborne pollen was analysed under a light microscope (400×). The pollen season start date was defined as the first day on which at least one pollen grain/m<sup>3</sup> was reached, with subsequent days containing one or more pollen grains/m<sup>3</sup>. The end of the season was the last day on which one pollen grain/m<sup>3</sup> was recorded and when subsequent days presented concentrations below this level. The pollen index (PI) is defined as the sum of the daily average pollen concentration per cubic metre during the pollen season. The peak pollination date was considered as the day on which the highest pollen count was recorded. The pre-peak pollen index (PPI) represented the sum of the daily pollen counts from start to peak.

Spearman's non-parametric correlation test was performed to detect significant relationships between olive fruit production and aerobiological and meteorological variables. Given the number of observations, a principal components and factor analysis (PCFA) was performed to detect any structure in the relationships between variables and to classify variables according to their influence on dependent variables' variation (Tipping and Bishop 1999). The advantage of this non-parametric analysis is its hardness when the number of variables is high but there are a scarce number of observations (Sabatier et al. 1989). The statistical software used was STATISTICA 6 for Windows.

### 3 Results

The average daily olive pollen release curves for the two study sites are shown in Fig. 2. The average curves were obtained after aligning the main peak in accordance with the methods proposed by Rogers (1997). Olive flowering started in early April in Ciudad Real and in May in Toledo. The highest pollen counts for the season were recorded in Toledo. Both curves displayed a main peak over the season. Regarding the total airborne pollen concentration, an inter-annual variation was observed in both provinces.

Figure 3 shows the relationship between olive fruit production in Ciudad Real and Toledo and the pollen counts recorded over the main pollen season during the study years. The same tendency of inter-annual variability was observed for olive crop production and pollen concentrations in both provinces. The

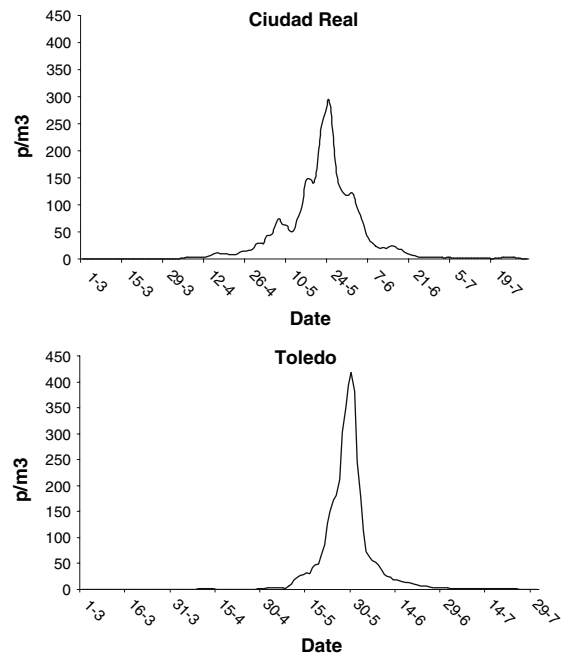


**Fig. 2** Average daily pollen counts at the two study areas. p/m<sup>3</sup>: pollen grains per cubic metre

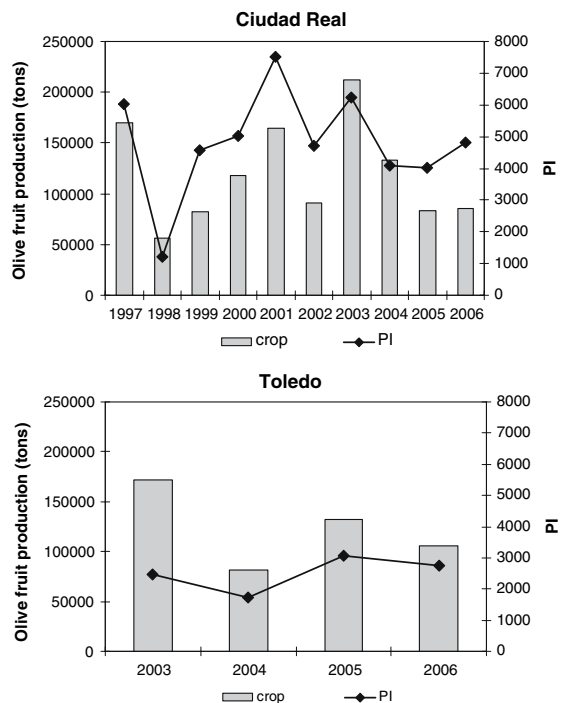


**Fig. 3** Annual olive crop production (*crop*) versus pollen index (*PI*)

**Table 1** Significant results of the Spearman correlation analysis

| Province    | Variables    | Valid N | Spearman R | p-level |
|-------------|--------------|---------|------------|---------|
| Ciudad Real | Crop & PI    | 10      | 0.81       | 0.00    |
|             | Crop & PPI   | 10      | 0.56       | 0.04    |
|             | Crop & Mx M  | 10      | 0.73       | 0.02    |
|             | Crop & Mx Sp | 10      | 0.60       | 0.04    |
| Toledo      | Crop & PI    | 4       | 0.60       | 0.05    |
|             | Crop & PPI   | 4       | 0.40       | 0.05    |
|             | Crop & Mx M  | 4       | 0.80       | 0.02    |
|             | Crop & Rf O  | 4       | 0.74       | 0.05    |

Crop=annual fruit production; PI=pollen index; PPI=pre-peak pollen index; Mx M=maximum temperature of March; Mx Sp=maximum temperature of September; Rf O=rainfall of October

Spearman correlation analysis confirmed the relationship among these variables (Table 1). It was found that the annual pollen index was the variable influencing most the final olive crop. During the flowering period, the temperature in March was the meteorological variable affecting most the annual olive crop in both provinces. Regarding the fruiting period, the correlation analysis also showed that maximum temperature recorded in September also influenced the final fruit production in Ciudad Real. On the other hand, the rainfall registered in October in Toledo is also correlated. A factor analysis was used as a classificatory method of more influencing variables on crop production. In Fig. 4, the plots of the PCFA results are shown. The nearest variables to the crop variable that represent the variables exerting the highest loading in the analysis are marked in a circle. The bi-dimensional factor loading analysis also indicated that pollen emission (both PI and PPI) and the maximum temperature of March were the variables with the highest loadings in both provinces. In a second-order analysis, we found that, in Ciudad Real, the maximum temperature of September and June and the rainfall of October, and in Toledo, the rainfall of October and the maximum and minimum temperature of August influenced crop production.

#### 4 Discussion

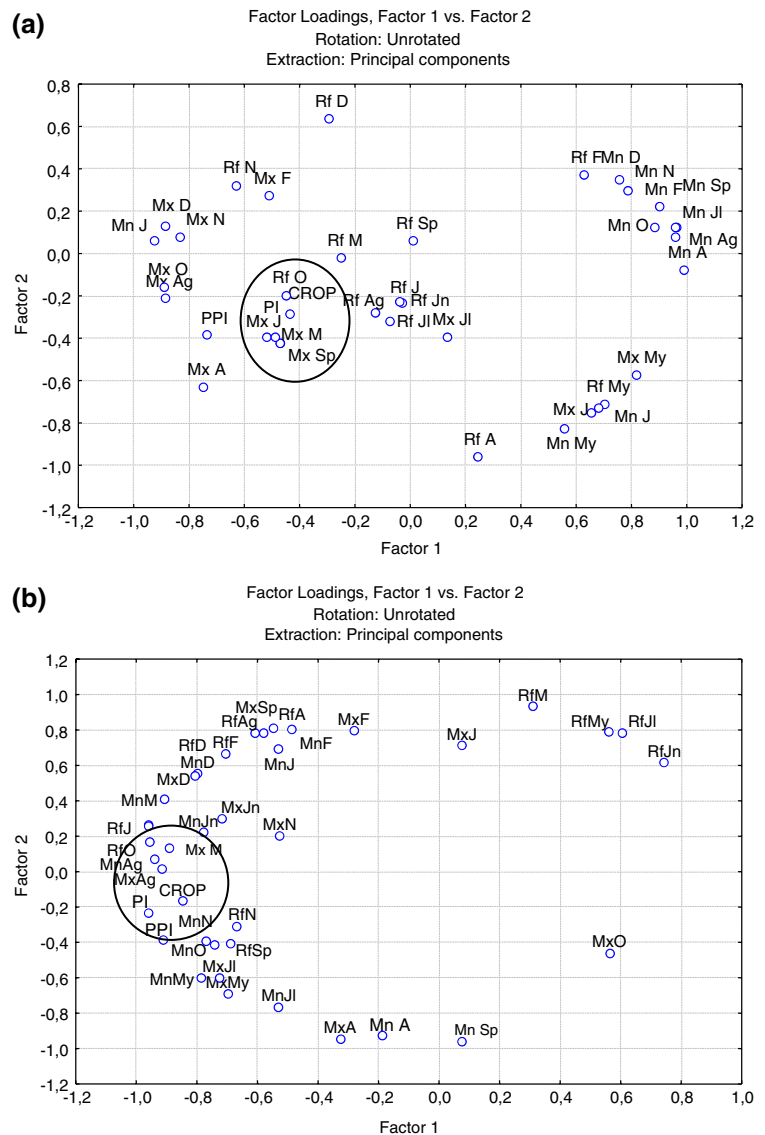
The pollination season in the studied region occurred later compared to the southern regions of the Iberian Peninsula (Galán et al. 2007b) and earlier compared

to the northern olive producer regions located in Portugal (Ribeiro et al. 2007). In fact, earlier olive pollen season start, peak and ending dates are observed in the Iberian Peninsula from south to north.

The characteristics of the observed curves differ from the observed ones in South Spain, where the topography provokes different phenological olive flowering patterns that forms a curve with different peaks throughout the season (Díaz de la Guardia et al. 2000). Central Spain is characterised by a plane plateau, where the two study provinces are located. The phenology patterns are more homogeneous, which generates a well-defined curve with only a main peak. Nevertheless, it is possible to observe that the Ciudad Real curve is wider than the Toledo curve and that it shows some little peaks during the pre-peak period. These peaks could be provoked by the long-range transport phenomena of olive pollen from the Andalucía region. This fact was also observed in Almodovar del Campo (Ciudad Real) by Sáenz Laín et al. (2003). These authors compared the olive pollen curve with field phenological data and observed that olive pollen was recorded in the study area up to 15 days before local flowering.

The olive fruit production of *Olea europaea* shows considerable annual fluctuations, with high production years tending to alternate with years of low production. Therefore, to know the most influencing parameters on the final harvest is of great interest, especially in this species with a high economic importance. Several studies have indicated a close link between the quantity of emitted pollen and fruit production in wind-pollinated plants (Frenguelli 1998). Our results showed that airborne pollen is a good bio-indicator of the total olive fruit production in Central Spain. Pollen emitted during the whole pollen season (pollen index) was revealed as the variable influencing most the final olive crop. Our results agree with the only related research performed in the town of Almodovar del Campo (Ciudad Real). In that work, Sáenz Laín et al. (2003) indicated that, during the 3 years studied (1998–2000), pollen emission and olive crop production followed a similar trend. Previous works performed in the Andalucía region (Southern Spain) indicated that the pre-peak pollen index was the most influencing variable (Galán et al. 2004; Galán et al. 2007b). This fact could be explained because of the great area devoted to olive crops in the Andalucía region and also because of the

**Fig. 4** **a** Plot of principal components and factor analysis (PCFA) for Ciudad Real data. **b** Plot of PCFA for Toledo data. PI=pollen index; PPI=pre-peak index; Rf=rainfall; Mx=maximum temperature; Mn=minimum temperature; J, F, M, A, My, Jn,...=months of the year



topography of olive areas. This implies that, in the post-peak period, large quantities of pollen are recorded during a longer period after flowers have already been fertilised. Also, pollen from late-flowering crops located at higher altitudes is detected in the post-peak period.

As reported in similar studies in other climate areas, the relationship between yield and weather-related variables becomes evident at the critical time of flower growth and ripening. It has been demonstrated that rainfall during fruit ripening exerts a considerable influence on final fruit production in areas with a dry climate, such as the Andalusia region

(Galán et al. 2007b). In other sites of the Mediterranean area, temperature has been revealed as the main factor (Fornaciari et al. 2005). The presented results indicated that the main meteorological variable in the region during the development of flowers was the maximum temperature of March. In general, the differences among influencing factors in the two provinces were not relevant. In both provinces, the temperature registered during this month exerted an important role in the development of flower buds. Obviously, the quantity and quality of mature flowers directly influence the final fruiting. Also, it has been revealed that the rainfall registered during the final

phases of fruit growing (October) also has a positive influence on the harvest. Finally, the temperature of the summer also influences the development of fruits, albeit in a second order.

An integrated study of aerobiological and meteorological data in the region of Castilla-La Mancha (Central Spain) represents the first step forward in the development of future crop forecasting models in the area. The results reported here would enable farmers and the regional government to have better knowledge of factors influencing olive fruit production and also to be able to better plan olive oil marketing strategies and distribution within the framework of the European Union agricultural policy.

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