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Model for forecasting *Olea europaea* L. airborne pollen in South-West Andalusia, Spain

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Abstract Data on predicted average and maximum airborne pollen concentrations and the dates on which these maximum values are expected are of undoubted value to allergists and allergy sufferers, as well as to agronomists. This paper reports on the development of predictive models for calculating total annual pollen output, on the basis of pollen and weather data compiled over the last 19 years (1982–2000) for Córdoba (Spain). Models were tested in order to predict the 2000 pollen season; in addition, and in view of the heavy rainfall recorded in spring 2000, the 1982–1998 data set was used to test the model for 1999. The results of the multiple regression analysis show that the variables exerting the greatest influence on the pollen index were rainfall in March and temperatures over the months prior to the flowering period. For prediction of maximum values and dates on which these values might be expected, the start of the pollen season was used as an additional independent variable. Temperature proved the best variable for this prediction. Results improved when the 5-day moving average was taken into account. Testing of the predictive model for 1999 and 2000 yielded fairly similar results. In both cases, the difference between expected and observed pollen data was no greater than 10%. However, significant differences were recorded between forecast and expected maximum and minimum values, owing to the influence of rainfall during the flowering period.

Keywords Aerobiology · Forecasting · *Olea europaea* · Pollen Index · Pollen Production

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Introduction

The olive tree *Olea europaea* L. is one of the most characteristic features of Mediterranean flora. Olives and olive oil are among the oldest and most important products in this part of the world. The region of Andalusia has by far the largest area of olive plantations, amounting to 1,192,107 ha in 1999 with more than 154×10^6 trees. It therefore accounts for 80% of the Spanish total, the province of Córdoba ranking second to Jaén in terms of output, with 277.237 ha in 1999. From the total of 3,481,558 Tonnes were picked in Córdoba (Andalusia Statistical Yearbook, Anuario Estadístico de Andalucía 1999).

Studies of the *O. europaea* pollen season are important for two major reasons. First, because of the surface area it occupies in Andalusia, the olive crop is among the most significant local causes of allergy; this tree produces allergenic pollen grains both in Mediterranean and general climates (D'Amato and Liccardi 1994) and in the city of Córdoba in particular (Domínguez-Vilches et al. 1993), where pollen even 70 km away is detectable (Fornaciari et al. 2000). Florido et al. (1999) reported that more than 400 g/m^3 is enough to provoke symptoms in patients clinically sensitive to olive pollen in the south of Spain. Second, atmospheric pollen can be used as a bioindicator of fruit production, which is then applicable in agronomic studies (González-Minero et al. 1998). For this reason, several papers have focused on the aerobiology of olive trees in Spain (Candau et al. 1981; Domínguez et al. 1993; Díaz de la Guardia et al. 1993; Recio et al. 1996; González-Minero and Candau, 1997; Gutierrez Bustillo and Sáenz-Laín, 2000; Ruiz et al. 1998).

Some authors have attempted to define the pollen season of the olive, while others have studied the start of the pollen season using meteorological data from the pre-flowering period. It is generally agreed that temperature is one of the main parameters affecting onset (Alba and Díaz de la Guardia, 1998; Frenguelli et al. 1989; Fornaciari et al. 1998; González-Minero and Candau Fernández-Mensaque, 1996; Galán et al. 2001). However, only a few papers have forecasted the total annual airborne olive pollen (Fornaciari et al. 1997), which is a key parameter for forecasting the severity of the pollen season. It is also important to take this variable into consideration when studying fruit production.

Although many fruit trees display alternate bearing, in which a heavy crop in one year is followed by a light crop or no crop the next year, largely determined by flowering load, sometimes this inter-annual variation is not observed (Díaz de la Guardia et al. 2000), probably because of the particular meteorological characteristics of each area. The aim of this paper was to attempt to forecast the annual total pollen (pollen index), the maximum average pollen per day and the date on which this maximum would be reached. These figures are valuable for allergologists and allergy-sufferers, who can use them us the basis for preventive measures, and for agronomists, who can obtain an idea of the pollen load several weeks prior to the flowering period and several months before the harvest.

Materials and methods

The city of Cordoba is located in the south-west of the Iberian Peninsula. It has a Mediterranean, slightly Continental, climate. National Institute of Meteorology reports for the last 40 years indicate an annual average temperature of 18°C although a slight increase was detected this year. Greater differences were observed in the rainfall: the annual rainfall over the last 5 years was substantially above the 600 mm reported as average.

Aerobiological data were collected using a Hirst-type sporetrap (Hirst 1952) located on the roof of the Faculty of Science, 15 m above ground level. Data corresponding to 18 years of pollen monitoring were used in this study. The standard sampling procedures proposed by the Spanish Aerobiology Network (REA) were employed (Dominguez et al. 1992).

It is widely accepted that the meteorological parameters in the months prior to tree flowering affect the features of the pollen season (Galán et al. 1998; Fornaciari et al. 1997). Monthly maximum, mean and minimum temperatures, and the monthly total rainfall from the period prior to flowering (January to March) were used to obtain a predictive model for forecasting the total pollen detected in a year (pollen index) by multiple regression analysis. Moreover, two biometeorological parameters, chilling units and evapotranspiration, were included as variables to be considered in equations. In Cordoba, the chilling requirement for arboreal species usually occurs from mid–December to late January; a previous paper reported a mean of 348 chilling hours on the basis of the model proposed by Aron (1983). Since it has been shown that winter chilling is required to release previously initiated floral buds from dormancy (Rallo and Martín 1991), the chilling hours of the preceding year were also taken into account. Evapotranspiration was computed according to the Food and Agriculture Organization rules (FAO 1998). The National Institute of Meteorology supplied temperature and rainfall data from the Cordoba Airport station.

For predicting maximum daily values and the dates on which they were reached, the start of the pollen season was used as a further independent variable. The start of the *Olea* pollen season was defined as the date on which 1 pollen grain/m^3 was recorded as long as 1 or more pollen grains/m^3 were subsequently recorded on 5 consecutive days (Galán et al. 2001). The maximum-value variable and the date of the maximum-value variable were used in two different ways: first, as the maximum average value per cubic meter recorded on a given day and the date on which this maximum was reached; and second, as the maximum 5-day moving average (a method that yielded smooth curves) and the date on which this maximum was reached; this did not necessarily coincide with the former date.

In order to establish a predictive model, pollen grains and meteorological data for 18 years (1982/1999) were used. Formulae were tested in order to predict the 2000 pollen season. However, because of heavy rainfall in spring 2000, the 1982/1998 database was also used to test models in 1999.

Results

Figure 1 shows the pollen index and the total annual rainfall, from September to August, over the 18 years studied. This reveals alternate pollen production cycles from 1982 to the end of the 1980 s; however, at the end

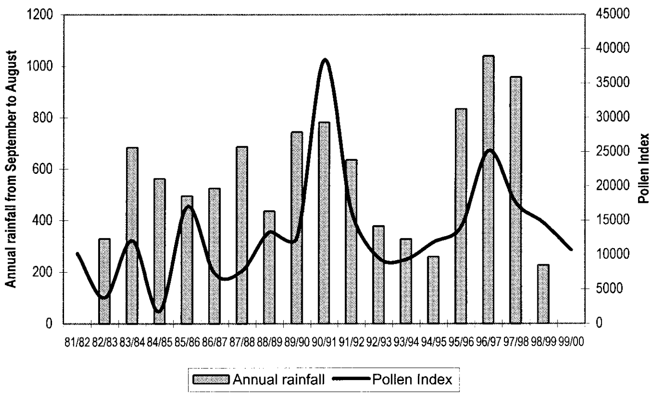

Fig. 1 Evolution of the pollen index and total annual rainfall during the 18 studied years. The period was taken from September to August

Table 1 Predictive formulae to be applied in 1999, using the 1982/1998 dataset. R^M rainfall March, T^M_{av} average temperature March, T^J_{max} maximum temperature January, T^M_{max} maximum temperature March, T^A_{max} maximum temperature April, T^J_{av} average temperature January, R^J rainfall January, R^F rainfall February, T^F_{max} maximum temperature February, T^A_{min} minimum temperature April, C chilling units, T^F_{av} average temperature February

Dependent variable	Predictive formulae	Adjusted r^2
Pollen index	y=–1,113.92+87.38 R^M+3,309.85 T^M_{av}–2,448.11 T^J_{max}	0.74
Maximum value	y=10,506.21+18.13 R^M+543.26 T^M_{max}–1,216.53 T^J_{max}–311.70 T^A_{max}+497.74 T^J_{av}–5.66 R^J	0.73
Max. value date	y=269.62–3.83 T^M_{max}–0.14 R^F–3.46 T^F_{max}+1.80 T^A_{min}	0.70
Maximum value[a]	y=3,096.58+12.46 R^M+114.62 T^F_{max}–1.22 C–201.32 T^A_{min}–343.37 T^J_{max}+197.97 T^M_{av}	0.85
Max. value date[a]	y=278.78–4.19 T^M_{max}–3.63 T^F_{av}–0.03 C–0.05 R^J–0.02 R^M	0.81

[a] Using 5 days moving average

Table 2 Observed versus predicted data for (1999)

Parameter	Observed	Expected
Pollen index	14,650	15,622
Maximum value	1,051	1,385
Max. value date	124	143
Maximum value[a]	210	528
Max. value date[a]	125	134

[a] Using 5 days moving average

Table 4 Observed versus expected data for 2000

	Observed data	Expected data
Pollen index	10,703	11,860
Maximum value	1,423	3,067
Max. value date	167	128
Maximum value[a]	285	1,991
Max. value date[a]	167	114

[a] Using 5 days moving average

Table 3 Predictive formulae to be applied in 2000, using the 1982/1999 dataset. R^M rainfall March, T^M_{av} average temperature March, T^J_{max} maximum temperature January, T^J_{min} minimum temperature January, T^M_{max} maximum temperature March, T^A_{max} maximum temperature April, T^J_{av} average temperature January, R^J rainfall January, T^F_{max} maximum temperature February, R^F rainfall February, T^A_{min} minimum temperature April, T^M_{min} minimum temperature March, S_P start of pollen season, T^A_{av} average temperature April, R^J rainfall January, T^F_{min} minimum temperature February

Dependent variable	Predictive formulae	Adjusted r^2
Pollen index	y=–2,720.95+87.28 R^M+3,058.88 T^M_{av}–2,220.11 T^J_{max}+438.51 T^J_{min}	0.74
Maximum value	y=10,553.22+18.20 R^M+545.92 T^M_{max}–1,235.01 T^J_{max}–308.42 T^A_{max}+505.50 T^J_{av}–5.66 R^J	0.74
Max. value date	y=271.3947–7.64 T^M_{av}–3.26 T^F_{max}–0.012 R^F+1.96 T^A_{min}+2.57 T^M_{min}	0.68
Maximum value[a]	y=1,882.56+14.03 R^M+69.58 T^F_{max}–456.82 T^J_{max}+215.26 T^M_{max}–185.20 T^A_{av}+227.769 T^J_{av}+6.41 R^A	0.86
Max. value date[a]	y=101.46–2.06 T^M_{max}–4.56 T^F_{max}–0.19 R^F+0.80 S_P+4.67 T^A_{av}–0.04 R^J+1.76 T^F_{min}	0.82

[a] Using 5 days moving average

of that decade, the alternation was interrupted, probably because of the particular meteorological characteristics of this period.

The results of the two formulae applied to the two sets of data are fairly similar. Only rainfall and temperature were included, since evapotranspiration and chilling hours were not deemed to be good variables. Table 1 shows forecasting models obtained from multiple regression analysis, taking into account the period 1982/1998 to forecast year 1999. The pollen index, the maximum-value per day and the maximum value date proved to be highly influenced by meteorological parameters. The variable exerting the greatest influence on the pollen index and the maximum daily pollen count was rainfall in March, with a determinant coefficient of 54% and 47% respectively. However, when monthly temperatures were taken into account, the coefficient improved to 74%. Another dependent variable used was the 5-day running mean average; with this value, the results of regression analysis improved, with a determinant coefficient of 85%. However, in the case of the maximum-value date, temperature was the best variable, yielding a determinant coefficient of 70%. This coefficient improved when the 5-day running mean average was taken into account, yielding a coefficient of 81%.

Analysis was performed using only data from 1982/1998, in order to test models in 1999. Table 2 shows recorded data and forecasts. The difference between the forecast pollen index and recorded pollen index was only 10%. However, there was a significant difference between forecast and recorded maximum values and the dates on which these were recorded. Light rainfall during the period represented by the first part of the curve prevented dispersal of olive pollen grains, so the tree could only release the pollen during the dry period, which was probably not the normal time of release.

Analysis was also performed using data from 1982/1999 in order to test the models in 2000 (Table 3). As indicated earlier, results may have been affected by rainfall at the time of pollen dispersal, although they are fairly similar to those in Table 1.

Table 4 shows recorded data and forecasts for 2000. Once again the percentage error between the two variables was very similar to those obtained earlier (Table 2), although the more abundant rainfall during the spring of 2000 meant that differences in the maximum-value date and maximum value were higher.

Discussion

The typical biannual pattern of alternate bearing, in which a heavy crop in one year is followed by a light crop or no crop in the following year, was observed during the 1980 s in Córdoba (Galán et al. 1988; Domínguez et al. 1993). However, from the beginning of the 1990 s this alternation disappeared. In fact, at the beginning of the decade a significant increase in atmospheric pollen was expected, prompted by the new agricultural policy that benefited olive growing in Spain in the mid-1980 s, with large areas being devoted to this crop. However, a downward trend was observed from 1991 to 1995, coinciding with a very dry period, followed by an upswing from 1996 to 2000, coinciding with a wetter period. (Díaz de la Guardia et al. 2000). This finding has been reported by other authors, who confirm that rainfall during the vegetative period of this species has a positive effect on pollen production (Recio et al. 1996; González Minero et al. 1998; Fornaciari et al. 1997), despite the fact that this effect was not observed in Madrid during the period studied (Gutierrez Bustillo and Sáenz Laín, 2000). Notably in Córdoba, rainfall in March was the parameter that most affected pollen production. It was therefore the best variable for predicting both the total annual pollen (pollen index) and the maximum daily value, and should therefore be borne in mind by both allergists and pollen-allergy sufferers.

Although winter chilling is required to release previously initiated floral buds from dormancy, Rallo and Martín (1991) and Fornaciari et al. (1997) reported a correlation between this variable and the pollen index. In this experiment, neither this variable nor evapotranspiration was included in models.

Temperature was the best variable for forecasting the maximum temperature date. Some authors have reported a highly significant relationship between the start of the olive pollen season and the temperature recorded during the months prior to the flowering period. This has been shown previously in Spain by the following authors: Alba and Díaz de la Guardia (1998) in Granada, González-Minero and Candau Fernández-Mensaque (1996) in Seville, and Galán et al. (2001) in Córdoba, and also in Perugia, Italy, by Frenguelli et al. (1989) and Fornaciari et al. (1998). In all cases, one of the variables exerting the greatest effect on the onset of the pollen season was the mean temperature in February and March. This was particularly the case in Córdoba, where the maximum temperature during the first fortnight of March was the best predictor of the onset of the pollen season (Galán et al. 2001, García-Mozo et al. 2001). However, no authors have forecasted the maximum temperature date.

In this study, themaximum temperature appeared to be the best parameter, although the determinant coefficient increased when the other variables were taken into account. Nevertheless, the results reveal that there is no close relationship between the recorded and forecasted date. As mentioned in Results, rainfall was found to play a crucial role in determining pollen dispersal time, thus modifying the expected results. Another fact to be borne in mind is the large surface area devoted to olive growing in the south of the province; most of these areas are some distance from the city, hence the higher concentration of airborne pollen sometimes depends less on floral phenology and meteorological conditions than on transportation by the wind.

For allergists this study might have revealed a very useful variable, since it could be used in allergy prevention. In the area of agronomy the pollen index can be used as a variable to predict fruit production in advance.

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