Agricultural and Forest Meteorology 250–251 (2018) 308–318

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

journal homepage: www.elsevier.com/locate/agrformet

Intensity and temporality of airborne *Quercus* pollen in the southwest Mediterranean area: Correlation with meteorological and phenoclimatic variables, trends and possible adaptation to climate change

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ARTICLE INFO

Keywords:
Aerobiology
Pollen
Quercus
Mediterranean basin
Meteorology
Phenology
Correlations
Trends
Climate change
Adaptation

ABSTRACT

This paper deals with aerobiological analyses realised during last 25 years in the atmosphere of Malaga, a coastal city located in the southwest of the Mediterranean Basin. Air sampling was performed by means of 7-day recording volumetric pollen and spore traps, and pollen grains were counted with the aid of a light microscope, according to the methodology proposed by the Spanish Aerobiology Network. Pollen data were expressed as number of pollen grains per cubic metre of air. A peak in *Quercus* pollen production approximately every four years was detected, coinciding with drought periods. Although the natural vegetation of the studied area has been altered by urban growth and reforestation with pines, it is still represented by a disperse natural population of cork oak, holm oak and kermes oak (predominantly located to the northwest and northeast of the city). In this period the seasonal behaviour of anemophilous pollination of *Quercus* was studied, along with the relation between its intensity (pollen production) or temporality (phenophase of flowering) and meteorological or climatic variables. Also a study of trends in production and phenology of flowering was carried out. The annual intensity of anemophilous pollination of *Quercus* was significantly associated with the meteorological conditions of each spring, with the same parameters involved and in the same way as were seen on the daily and weekly scale (positive correlation with temperature and insolation, and negative with precipitation and relative humidity). The tendency for temperature and atmospheric aridity to increase is probably the cause of the trend observed in the spring *Quercus* pollen production to increase in the western Mediterranean. The temporality of *Quercus* anemophilous pollination (start date, peak date, end date and duration) changes each year and is positively associated with accumulated temperature and sun hours from 1st January until the dates in question. An accumulation of approximately 796 °C above the 9 °C threshold temperature from 1st January is necessary to trigger the start of the flowering period. We conclude that the effect of climatic change is mainly reflected in the pollination intensity of woody anemophilous species, which, in turn, have adapted their flowering time (phenology) to climate change. It is important to remember that climate change is leading to more arid conditions and that Mediterranean plants are adapted to this macrobioclimate (Mediterranean), which is characterized by a long dry period and high temperatures.

1. Introduction

Mediterranean forest and "dehesas" (traditional, semi-natural, man-made systems present in the Iberian Peninsula) (Gómez-Casero et al., 2007) represent the natural and seminatural characteristic vegetation of Andalusia (south of Spain). The dominant tree species of these forests and dehesas mainly belongs to *Quercus* genus. These natural forests are characterized by high biological diversity (flora and fauna) and constitute one of the most diverse ecosystems in Europe, hence the interest in conserving these forests. In addition, the presence of trees of *Quercus* species in these forests indicate ecological maturity, as they are responsible for maintaining the physical-chemical and microclimatic characteristics of these ecosystems.

The Mediterranean Basin is considered as a hot spot of biodiversity worldwide (Médali and Quézel, 1999). The south of the Iberian Peninsula is characterized by its strategic settingt, between two seas and between two continents, with a particular geological and biological history that has decisively influenced the present day diversity observed. The flora and vegetation of this part of the western Mediterranean is a consequence of the adaptation to climatic, geological,

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https://doi.org/10.1016/j.agrformet.2017.11.028
Received 8 March 2017; Received in revised form 2 November 2017; Accepted 25 November 2017
0168-1923/

orographic, topographic and environmental changes that it has been exposed to for thousands of years. For this reason, the south of the Iberian Peninsula contains examples of plant species of very different origins. These include Mediterranean perennial species such as the oak (*Quercus rotundifolia* Lam.), which lives in thermomediterranean and mesomediterranean thermotypes, but also in the supramediterranean where it forms mixed forests with maples and gall oak (*Quercus faginea* Lam.) (Cabezudo and Pérez Latorre, 2004). Another Mediterranean perennial species is the cork oak (*Quercus suber* L.) which lives in the same termotypes as oak, but with subhumid ombrotypes and acid soils. *Quercus pyrenaica* Willd. is a deciduous species that lives in the mountain areas with cold winters and acid soils. *Quercus canariensis* Willd. is a relict deciduous species of laurel subtropical forests (currently protected) which originated in the Tertiary in areas exposed to mountain fog. One endemic species is threatened, *Quercus alpestris* Boiss., cataloged by UICN Red List as endangered (EN) (Cabezudo et al., 1999). It lives in the high-mountain acciculitic forests (fir forest) that survived glaciations. As consequence of recent climate change, distribution of these *Quercus* species are expected to shift.

Through the study of the presence, quantity and production dates of *Quercus* pollen in the atmosphere, changes in distribution, phenology and ecological conservation state of Mediterranean forest can be detected. The importance of detecting such changes lies in the high economical interest of these vegetal formations for the timber industry, agriculture and animal husbandry. The most valued pig herds are fed with acorns produced by *Quercus* species, as are sheep and cattle, which produce high quality meat. Acorns production for a particular year can be estimated from the quantity of pollen produced and, therefore, agricultural production (both crops and animals) can also be estimated (García-Mozo et al., 2002, 2008, 2010; Gómez-Casero et al., 2004, 2007; Jato et al., 2007; Hernández-Ceballos et al., 2011, 2015).

Quercus pollen is considered as a moderate respiratory allergies cause in many areas of Europe because the high amounts of pollen which this anemophilous taxon produce. Furthermore, the flowering periods of the different species of the genus are overlapped in time, which produce allergenic symptoms in population during long periods of time. A cross reactivity process with other pollinic types such as *Alnus, Betula, Castanea, Olea* and Poaceae, has also been detected. This process increases the allergenic potentiality of this pollen type (Recio et al., 1999; García-Mozo et al., 2002; Rodríguez-Rajo et al., 2005; Jato et al., 2007).

The great abundance of these taxa increases their impact on allergy sufferers, especially people who live or work in areas covered with natural or semi natural vegetation such as holm-oak forests, cork oak forests and dehesas (García-Mozo et al., 2006a). The study of the seasonal behaviour and the different ways to forecast variations of *Quercus* pollen levels will provide useful information for treating allergy symptoms a few days before exposure to the allergen or even enable people to avoid them. Many research teams are engaged in detecting the pollen types which are present in the atmosphere at any moment of the year, designing models and analyzing the causes of the variations in airborne pollen levels (Jato et al., 2002; Rogers et al., 2006; Docampo et al., 2007; Gómez-Casero et al., 2007; Martínez-Bracero et al., 2015; Rojo et al., 2015).

The information obtained through a study of the starting date and peak date of the atmospheric main pollen season of some taxa during long series of years can also be used as bioindicator of climate change. Some authors have used *Quercus* pollen levels as a bioindicator for climate change (Gómez-Casero et al., 2007; Tormo-Molina et al., 2010). Any influence of global warming on *Quercus* species phenology is of great relevance because of the great economic and ecological importance of this taxon in the Mediterranean area (García-Mozo et al., 2008).

An increase of 1.5 °C per year in the minimum temperature has been detected in Spain, an increase that is more intense in the south of Spain, where precipitation has decreased a lot (Gordo and Sanz, 2005; García-Mozo et al., 2010). Climatic factors have a strong influence over airborne pollen concentration, underlining the effect of climate change on atmospheric pollen concentration (García-Mozo et al., 2002, 2008; Peñuelas et al., 2004, 2009; Rogers et al., 2006; Hedhly et al., 2009; Recio et al., 2009; Tormo-Molina et al., 2010; Guo et al., 2014).

Over the last 50 years, the majority of the Mediterranean macrobioclimate plants have shown alterations in their phenological behaviour (Peñuelas et al., 2002; Wolkovich et al., 2012). This change has been detected with much more intensity in the winter and early spring phenophases since it is the temperatures of these seasons that have changed the most during the recent years (Bertin, 2008). In general, the flowering phenophase of *Quercus* species has been brought forward (Peñuelas et al., 2002). As regards atmospheric pollen studies, some authors have detected a trend towards an earlier start and earlier end of the main pollen season in Mediterranean macrobioclimate areas. This behaviour slightly differs from that temperate macrobioclimate species which show a tendency to a later start and earlier end of the pollen season. This trend is especially pronounced in anemophilous trees, which flower in early spring. An example of such trees members of the *Quercus* genus, whose reproductive buds development is very sensitive to temperature. Moreover, an earlier start to the spring season as a result of increased temperatures also affects vegetative growth and other late-flowering species (Rogers et al., 2006; Tormo-Molina et al., 2010). An increase in temperature and reduced rainfall have been identified as the causes of the increase in airborne pollen quantity during the months with the highest concentrations (Wolkovich et al., 2012). However, despite these general trends, some studies have not found any significant change (Bertin, 2008).

In Malaga (a Spanish city located on the western Mediterranean coast) the temperature has increased by 0.06° C per year since the 1970s (see Fig. 1 in Recio et al., 2010). In the western Mediterranean region changes in rainfall have been observed (Maheras 1988; Piervitali et al., 1997; Esteban-Parra et al., 1998; De Luís et al., 2000). As regards the wind, although this is one of the variables that most influences pollen registers, few studies have looked at any trends in this climatic variable. In Malaga, there has been a very significant decrease in calm periods since the 1970s and an increase in the frequency of Levant winds (from the second quadrant, off the sea) (Recio et al., 2010). The uninterrupted aerobiological sampling carried out in Malaga during the last 25 years permits us to make some interesting observations about global change. Therefore, the objectives of this study were: to determinate the seasonal pollen behaviour, detect correlations between pollen concentrations and meteorological variables, and identify trends in *Quercus* pollination intensity and time. We use “pollination” to refer the final potential effect in aerobiological trajectory (deposition) (Spieksma, 1992).

2. Materials and methods

2.1. Study area

The city of Malaga is situated in the south of the Iberian Peninsula (36°47′N, 4°19′W), on the western Mediterranean coast, and lies in an alluvial plain that is partially surrounded by mountains. The climate is Mediterranean (Martonne, 1964), the mean annual temperature being 18 °C, with a mean maximum of 22.8 °C and mean minimum of 13.8 °C. Annual rainfall is 575 mm on average, falling mainly in autumn (October to December) and winter (January to March), while the summer (June to September) is the driest period. Due to the city’s orography and geographical situation, the dominant winds have a SE (blowing off the sea) and NW (from the interior) component. Calms represent 14% on average, while the predominant winds have a NW component (blowing off the land) and a SE component (blowing off the sea), known locally as “terral” and “levante” winds, respectively (Domínguez Rodríguez 1984; Viedma Muñoz 2001, 2002).

The natural vegetation of the area has been much altered by the