

METEOROLOGICAL VARIATION EFFECT ON AEROBIOLOGY - NEW TOOLS ON POLLEN FORECASTING

C. Galán* (1), García-Mozo (1), H., Alcázar (1), P. & Dominguez (1)

SUMMARY: Spanish Aerobiology Network (REA) includes 22 research groups implied in the biological analysis of the air from 50 observation sites extended over the Iberian Peninsula and Baleares Islands. To offer in-advance information for pollen allergy sufferers, doctors and health authorities is one of REA priorities. One of our objectives is the study of the influence of meteorological variations on the quantity and occurrence of pollen in the atmosphere. Nevertheless, to include only weather parameters is not enough for build accurate forecasts. Field phenology data, vegetation land cover, topography data and previous aerobiological data should be included in the models. Meteorological conditions control the start, duration, intensity and end of the pollen season, but their effect depends on the different types of vegetation. The biological response of tree pollination is highly differentiated from the herbaceous one. Another important point is the adaptation of a given species phenology to different climatic areas. We showed the different phenoclimatic variables determining tree flowering in the Mediterranean climate areas and in the Atlantic climate ones of the Iberian Peninsula, and the consequences on the development of our forecasting models. Finally we comment our more recent studies that use geostatistic algorithms as a tool for including all the cited parameters and also space variables as altitude, latitude and orientation to sun.

Key-words: Pollen - Aerobiology - Meteorology - Forecasting - REA.

INTRODUCTION

In the field of Aerobiology, one of the main objectives of a great number of European researching groups, is to obtain effective models for pollen forecasting [13] and this is also for the Spanish Aerobiology Network (REA). REA is the technical branch of the Spanish Aerobiology Association (AEA). REA comprises 22 researching groups implied in the biological analysis of the air, the majority of them belonging to Spanish Universities. These groups control more than 50 sampling sites over Spain (figure 1). The Coordinator Centre is located at the Department of Botany, Ecology and Plant Physiology of the University of Cordoba.

Aerobiological studies at the University of Cordoba started in 1982 and from that year, they have become a usual activity. In 1992, some Spanish Universities working on Aerobiology decided to join their efforts under the frame of REA with the goal to exchange information and to promote national and regional Aerobiology studies and to establish a system of public diffusion of air biological contents [13]. Today REA offers pollen information and forecasts on the

atmospherical biological quality. These forecasts have become fundamental for the allergy sufferers, doctors, and health authorities (2, 7, 12, 15).

METHODS AND POPULATION

Associated REA centres follow the same standardized methodology based on the use of Hirst type spore-trap, the use of silicone fluid as adhesive for samples and by

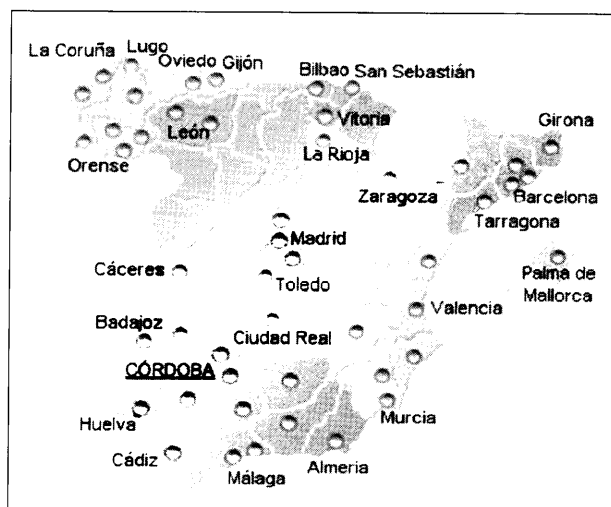


Figure 1 : Spanish Aerobiology Network (REA) monitoring sampling sites. The coordinator centre is located in Cordoba (Andalusia, South Spain).

(1). Dpto. Botánica, Ecología y Fisiología Vegetal, Edif. Celestino Mutis (C4), Campus de Rabanales, Universidad de Córdoba, 14071, Córdoba (Spain) - *E-mail: bv1gasoc@uco.es

counting four horizontal lines of the slide under the microscope (6, 11). They send their daily pollen data once a week to the coordinator centre which transmits them to the European pollen data bank, EAN/EPI (European Aeroallergen Network/European Pollen Information) located at Vienna (Austria) (7). Quality control is a priority for the members of REA (14, 12).

For the development of REA forecasts, meteorological data, weather forecasting supplied by the Spanish Institute of Meteorology, and field phenological data from some places are used. Anemophilous species phenology is surveyed during the flowering season and pre-season.

RESULTS AND COMMENTS

Meteorology and Aerobiology

In aerobiological studies the knowledge of pollen production per anther from the different species is important information. On the other hand, pollen production by the plant depends on cumulated rain, temperature and evapo-transpiration. Aerobiological processes comprise emission, dispersion and transport, deposition and re-suspension. Weather parameters influencing them are different (figure 2). Pollen emission is determined by the plant biological cycle but it is also strongly influenced by temperature and photoperiod. In this process, the capacity of dehiscence of the anthers has been proved very important, and it is where environmental humidity intervenes. The mechanism of pollen grains release is usually passive, except in some exceptional cases like Urticaceae, Cannabaceae and Moraceae.

In the transport process intervene two phenomena, the thermal convection, which facilitates vertical transport, and turbulences, which transport pollen grains

both vertically and horizontally. Pollen grain transport and dispersion in the atmosphere are influenced by pollen size and density, but also by atmospheric stability, wind velocity and precipitations. Pollen deposition can be dry or wet due to rainfall, and by sedimentation or impaction. Re-suspension process turns pollen grains over to the aerobiological road. This process would explain the appearance of pollen in the air once flowering season is over.

Daily forecasts

The first stage to produce a pollen forecast must be to study the pollen curve in order to determine the evolution of daily pollen concentration compared to the principal weather parameters. Temporal pollen distribution should be understood as a time series with a marked seasonal character (figure 3). The second stage is to define the main pollen season. Selecting the best method to calculate the main pollen season depends on the phenological behaviour of the plant. There are some methods to define pollen season: percentage methods (9, 16, 28, 29, 30) and daily or cumulative methods (3, 8, 18, 22, 31, 33). The use of percentages originates certain problems as the lack of information at the beginning of the season and the variability in elimination of days according to annual pollen concentrations.

After a first approach to pollen data, an analysis of correlation can indicate the level of association between the weather variables and the pollen concentrations in the air, and also if the correlation is positive or negative. Previously, it is important to test if the data are normal or not to apply the parametric or not-parametric statistics. In Aerobiology, normal data distribution is by far an ideal model. However, in most cases, aerobiological data do not adjust themselves to a normal distribution pattern, since airborne particle content is modified constantly by rain, wind, and the

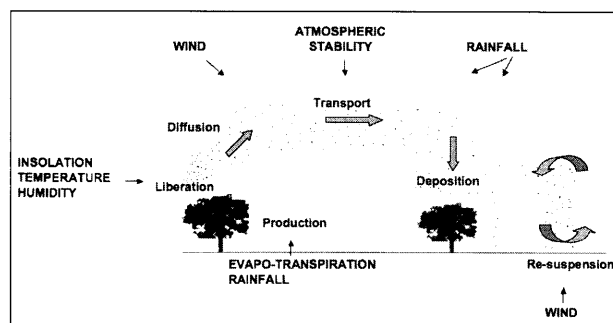


Figure 2 : Main aerobiological processes and meteorological parameters that control them.

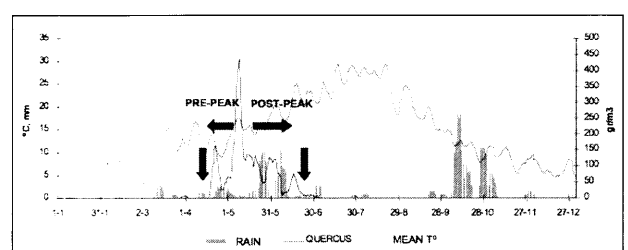


Figure 3 : Example of daily pollen, temperature and rainfall curve. Vertical arrows indicate the start and end of the pollen season. Horizontal arrows indicate Pre-Peak and Post-Peak periods of the pollen season.

effect of local topography. For daily forecasts, a separate evaluation of the Pre-Peak and Post-Peak curves should be study (figure, 3). Probably, there are different weather parameters that control them, i.e. in the Mediterranean region, during the spring; statistical correlation analysis for the whole season can indicate a negative relationship with temperature. This result is due to the own phenology of plant that finish their flowering season when temperature is higher (25, 37).

To obtain forecasting models, the analysis of regression is one of the most used statistic methods. Weather variables are usually used as independent variables to explain daily pollen variations. Although there is a certain autocorrelation, the use of pollen data of previous days can improve the predictions (17, 25, 37). In any case, it must be noticed that external validation on years not included in the model is essential to confirm their accuracy (25).

For different taxa and years, forecast equations can change according to bioclimatic conditions, for this reason, before performing the regression analysis several years can be grouped according to similar weather conditions and pollination intensity. In figure 4, an example of classification is showed. It was done by using the K-average cluster analyzes for Poaceae pollen, regards to weather and pollen data from 22 years of the city of Cordoba (Spain). The results gave

three types of curves with similar characteristics and consequently three types of regression equations were applied (32).

Currently, Neural Networks models are being employed in daily pollen forecasting (33). Figure 5 shows the diagram of a simple Neural Network model. Input Layer corresponds to independent variables. Hidden Layer includes various functions like linear or sigmoid regression, temporal series, etc Lastly, in the Output Layer represents the predicted dependent variable. The advantage is the possible multiple relationships between the various statistical functions and the various levels of work. However, the models require computer programming of different software for each taxon in each site. Software must be training once they are finished.

In the Iberian Peninsula, weather parameters that exert an influence on daily airborne pollen change for each taxon and especially with regard to trees and shrubs, herbs and grasses. Parameters also depend on the climatic zone. Table 1 presents a summary of the most important parameters for Poaceae and Quercus daily pollen concentrations in three climatic zones in Spain. There are remarkable differences: i.e. wind is important on the coast area while humidity negatively influence pollen concentrations in the wet climate area of North Spain (10, 22, 25).

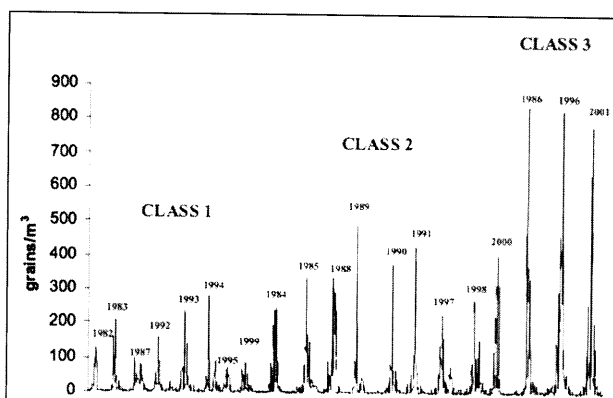


Figure 4 : Year classification of 22 years of Poaceae pollen records in Cordoba (Spain), by using k-average cluster analysis.

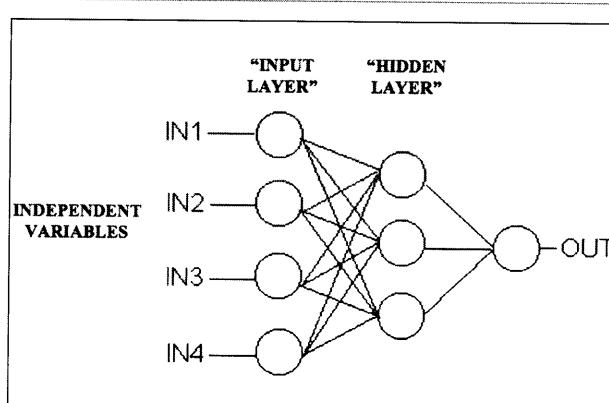


Figure 5 : Simple diagram of a Neural Network.

POACEAE			QUERCUS		
Mediterranean Inland Climate	Mediterranean Coast	Atlantic Climate (Eurosiberian Bioclimatic Region)	Mediterranean Inland Climate	Mediterranean Coast	Atlantic Climate (Eurosiberian Bioclimatic Region)
Humidity (+)	Wind Speed & Direction	Humidity (-)		Humidity (-)	
Mean T° (+)	Mean T° (+)	Max T° (+) Mean T° (+)	Max T° (+) Mean T° (+)	Wind Direction	Max T° (+)
Insolation (+)	Insolation (+)	Insolation (+)		Insolation (+)	Insolation (+)

Table 1: Meteorological parameters influencing flowering intensity of Poaceae and Quercus in three different climatic areas of Spain.

Seasonal forecasts

Traditionally, seasonal forecasts for trees are based on the assumptions that the date of flowering of each species is determined by its genetics but also by adaptation to local climate conditions. After having spent a chilling period during winter, trees accumulate a given quantity of "useful temperature" for their development over a determined threshold. This "useful temperature" is known as Growing Degree Days, GDD^o. There are many methods to calculate them (24). One of the most accurate is that where the daily temperature curve seems to a sine wave (34). GDD^o quantity and temperature threshold vary according to species and climate and they must be calculated for the different taxa and bioclimatic zones (21, 35). For herbaceous plants, although the flowering start also depends on temperature, in Mediterranean climates there is another factor to be taken into account: the rainfall (32, 33). Being given that temperature controls the floral season start, the global temperature warming detected in last years has caused an advance of flowering in many European species. It has been especially strong in Spain, and especially for trees (figure 6) (18, 19, 23, 25). By using Climate Change models, some works have studied the future effect on pollen seasons in Spain (4, 19, 23, 25). The advance will be greater for early spring trees and minimum for herbaceous species, due to a more important rise in the winter temperatures (19).

Phenology

The use of meteorological parameters to develop forecasting models is a very useful tool, but it is not enough to offer precise information. Weather conditions control the start, the duration, intensity and the pollen season end, but the effect depends on different vegetation and their location. In base to a methodological point of view, a forecasting system must include meteorological parameters, aerobiological data, but also field floral phenology and vegetation land cover data. In-situ phenology can help us to explain certain second peaks occurring out of the main season which sometimes correspond to second autumn flowerings. It is also very useful when several species or genus are included into a pollen type. We can determine the correspondence between each peak of the curve and the flowering of the various species (26). I.e., thanks to field phenology data it has been demonstrated that different peaks of the pollen curve of olive-tree in Cordoba, correspond at populations located at different altitude through the Guadalquivir River valley (37).

GIS

Geographical Information Systems (GIS) gives us information about the vegetation land cover; this information indicates where the species are and their abundance. These data are essential for the pollen map development. Within the GIS, it is also possible to combine phenological information with the information of land cover. figure 7 shows an example of the phenology map of olive-tree flowering in the province of Cordoba (Spain). Different colours indicate different altitude olive populations that flower at different time. This information makes possible to help us to determine the exact moment when peaks of the pollen curve will take place.

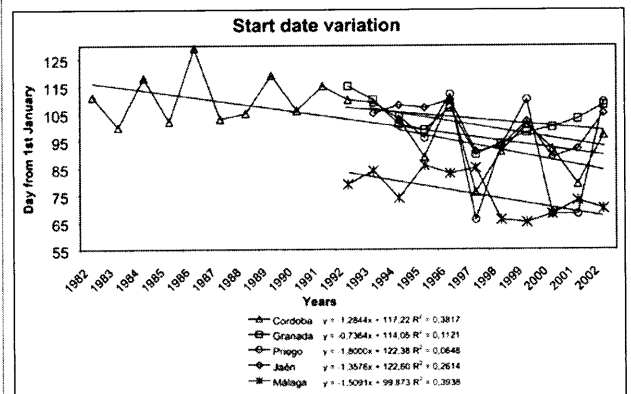


Figure 6 : Season start variations of Olea pollen at different sites of Spain (Galán *et al.*, 2005).

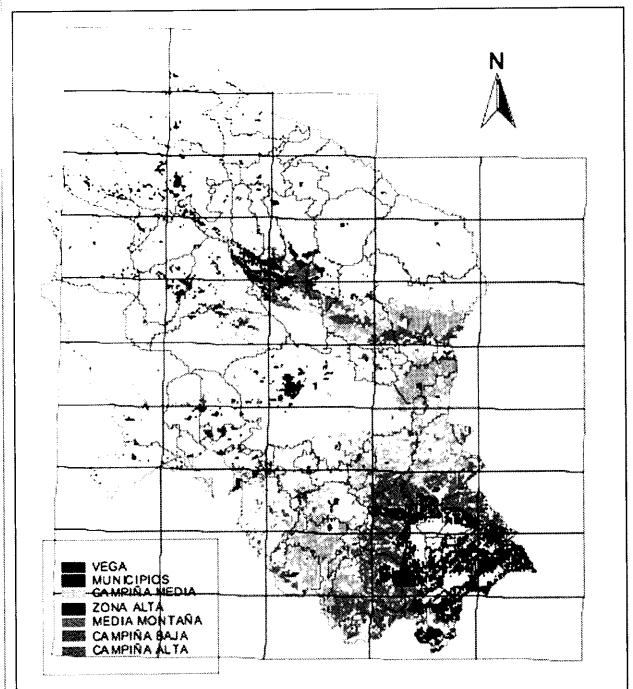


Figure 7 : GIS map representing different phenology olive populations flowering at different time due to altitude in the province of Cordoba (Spain).

Geostatistics

Most recent studies on aerobiology forecasts use geostatistic algorithms as a tool which includes all the already quoted variables: meteorology, pollen data preceding, phenology, and also space variables such as altitude, latitude and sun orientation within GIS (1, 20). Geostatistics consist of the study of phenomena correlated in space or time, by means of a statistical tool: the theory of the regionalized variables. The principal stages of the geostatistic analysis applied to the pollen data are: an analysis of descriptive statistics, the calculation of the "variogram" which will determine the mathematical function adjusting itself best with the data, the interpolation of data in unsampled sites and the automatic creation of pollen maps (figure 8). The development of this tool which combines the maximum of predictive variables will be of a great interest for the homogenisation and improvement of forecasts and to build automatic pollen maps. External validation will be essential to prove the reliability on extended zones.

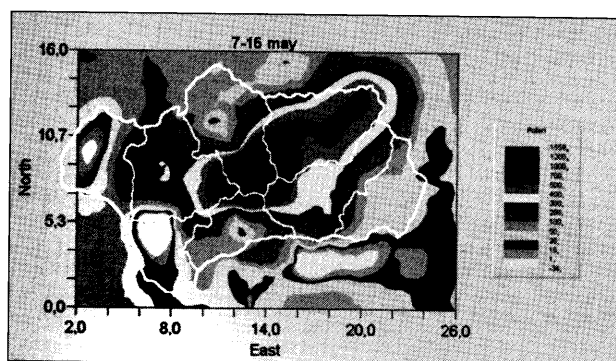


Figure 8 : Olive concentration pollen map of Andalusia Region in a given date of spring by using geostatistic interpolation analyses.

To include only weather parameters is not enough to offer accurate airborne pollen forecasts. Field phenology data, vegetation land cover, topography data and previous aerobiological data must be included in prevision models. In-situ phenology data can help us to explain certain second peaks occurring out of the main season and they are also very useful when several species or genus are included into a pollen type.

Selecting the best method to calculate the main pollen season depends on the phenological behaviour of the plant. For daily forecasts, a separate evaluation of the Pre-Peak and Post-Peak curves should be study.

Temperature controls the floral season start, especially in trees, the global temperature warming detected in last years has caused an advance of flowering in many European species.

By the combined use of GIS and Geostatistics, it is also possible to include phenological information, information of vegetation land cover, topography data, and aerobiological and meteorological data to obtain interpolation pollen maps of extended areas from a restricted data set.

References

1. BURROUGH P.A. -GIS and geostatistics; essential partners for spatial analysis. *Environmental and Ecological Statistics*, 2001;8:361-377.
2. CARIÑANOS P., VELASCO A., GALÁN C., ALCÁZAR P., DOMÍNGUEZ E. - La información polínica de la Red Española de Aerobiología (REA) según sus seguidores a través de Internet. *Rea*, 2002;7:23-27.
3. CLOT B. - Forecast of the Poaceae pollination in Zurich and Basle (Switzerland). *Aerobiologia*, 1998;14:267-268.
4. D'ODORICO P., YOO J., JÄGER S. - Changing seasons: an effect of the North Atlantic Oscillation?. *Journal of Climate*, 2002;15:435-445.
5. DOMÍNGUEZ E., GALÁN C., CARIÑANOS P., ALCÁZAR P. - Dissemination of data from the Spanish Aerobiology Network (REA). Second European Symposium on Aerobiology, 2000, Viena (Austria).
6. DOMÍNGUEZ E., GALÁN C., VILLAMANDOS F., INFANTE F. - Handling and evaluation of the data from the aerobiological sampling. Monografías REA/EAN N° 1. Ed. Departamento de Biología Vegetal y Ecología, Universidad de Córdoba. 1992. (D.L.: CO-476-1992).
7. DOMÍNGUEZ E., VELASCO A., GALÁN C., CARIÑANOS P. & ALCÁZAR P. - Aerobiological information by mean of Internet. 1º European Symposium on Aerobiology. 1996, Santiago de Compostela (Spain).
8. DRIESSEN M., MOELANDS M. - Estimation of the commencement of the grass pollen season and its prediction by means of the phenological method. *Acta Bot. Neerl.*, 1985, 34, Abstract 131.
9. EMBERLIN J., JONES S., BAILEY J., CAULTON J., CORDEN S., DUBBELS S., EVANS J., McDONAGH N., MILLINGTON W., MULLINS J., RUSSEL R., SPENCER T. - Variation in the start of the grass pollen season at selected sites in the United Kingdom 1987-1992. *Grana*, 1994;33:94-99.
10. FERNÁNDEZ-GÓZALEZ D., VALENCIA-BARRERA R.M., VEGA A., DÍAZ DE LA GUARDIA C., TRIGO M.-M., CARIÑANOS P., GUARDIA A., PERTÍÑEZ C., RODRÍGUEZ-RAJO F.-J. - Analysis of grass pollen concentrations in the atmosphere of several Spanish sites. *Polen*, 1999;10:127-136.
11. GALÁN C. - Introducción a la REA. *Rea*, 1998;3:5-6.
12. GALÁN C. - Quality control in aerobiological networks. *Postepy Dermatologii i Alergologii*, 2003;XX(4):244-245.
13. GALÁN C., CARIÑANOS P., ALCÁZAR P. & E. DOMÍNGUEZ. X - Aniversario de la Red Española de Aerobiología. *Rea*, 2002;7:29-30.
14. GALÁN C., CARIÑANOS P., ALCÁZAR P., DOMÍNGUEZ E. - Quality control of aerobiological data in the Spanish Aerobiology Network. Second European Symposium on Aerobiology, 2000, Viena (Austria).
15. GALÁN C., CARIÑANOS P., DE NUNTIIS P., EMBERLIN J., JÄGER S., JÄGER C., LEON G., MANDRIOLI P., MASSOT O., THIBAUDON M. - SPRING project: a tool to help prevent symptoms of pollen allergy at the european level. The 7th International Congress on Aerobiology, 2002, Montreal (Canada).
16. GALÁN C., EMBERLIN J., DOMÍNGUEZ E., BRYANT D., VILLAMANDOS F. - A comparative analysis of daily variations in the Gramineae pollen counts at Córdoba, Spain and London, UK. *Grana*, 1995;34:189-198.
17. GALÁN C., FUILLERAT M.J., COMTOIS P., DOMÍNGUEZ E. - Bioclimatic factors affecting daily Cupressaceae flower-

- ring in Southwest Spain. *International Journal of Biometeorology*, 1998;41:95-100.
18. GALÁN C., GARCÍA-MOZO H., CARIÑANOS P., ALCÁZAR P., DOMÍNGUEZ E. - The role of temperature in the onset of the *Olea europaea* L. pollen season in South-western Spain. *International Journal of Biometeorology*, 2001;45:8-12.
 19. GALÁN C., GARCÍA-MOZO H., RUIZ-VALENZUELA L., DÍAZ DE LA GUARDIA, C., TRIGO-PÉREZ M. - Heat requirement 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*, 2005, In press.
 20. GARCÍA-MOZO H., GALÁN C., VÁZQUEZ L. - The reliability of geostatistic interpolation in olive field floral phenology. *Aerobiologia*, 2006, In press.
 21. GARCÍA-MOZO H., GALÁN C., AIRA M.J., BELMONTE J., DÍAZ DE LA GUARDIA C., FERNÁNDEZ D., GUTIÉRREZ A.M., RODRIGUEZ F.-J., TRIGO M.M., DOMINGUEZ, E. - Modelling start of oak pollen season in different climatic zones in Spain. *Agricultural and Forest Meteorology*, 2001;110:247-257.
 22. GARCÍA-MOZO H., GALÁN C., CARIÑANOS P., ALCÁZAR P., MENDEZ J., VENDRELL M., ALBA F., SÁENZ C., FERNÁNDEZ D., CABEZUDO B., DOMINGUEZ E. - Variations in the *Quercus* sp. pollen season at selected sites in Spain. *Polen*, 1999;10:59-69.
 23. GARCÍA-MOZO H., GALÁN C., DOMINGUEZ-VILCHES E. - The impact of future climate change in the start of *Quercus* flowering in the Iberian Peninsula. In: Quaternary Climatic Changes and Environmental crises in the Mediterranean Region, 2002, Eds: M.B. Ruiz Zapata, M. Dorado Valiño, A. Valdeolmillos Rodríguez, M.J. Gil García, T. Bardaji Azcarate, I. de Bustamante Gutierrez & I. Martínez Mendizabal. Pags: 279-285.
 24. GARCÍA-MOZO H., GALÁN C., GÓMEZ-CASERO M.-T., DOMINGUEZ E. - A comparative study of different temperature accumulation methods for predicting the *Quercus* pollen season start in Córdoba (Southwest Spain). *Grana*, 2000;39:194-199.
 25. GARCÍA-MOZO H., GALÁN C., JATO V., BELMONTE J., DÍAZ DE LA GUARDIA C., FERNÁNDEZ D., GUTIÉRREZ A.-M., AIRA M.J., ROURE J.-M., RUIZ L., TRIGO M.-M., DOMÍNGUEZ-VILCHES E. - *Quercus* pollination dynamics in the Iberian Peninsula: response to meteorological parameters and consequences of the Climate Change. *Global Change Biology*, in press.
 26. HIDALGO P.-J., GALÁN C., DOMINGUEZ E. - Male phenology of the genus *Cupressus*: correlation with airborne pollen. *Trees*, 2003;17:336-344.
 27. JÄGER S., EMBERLIN J., MANDRIOLI P. - The European Pollen Information in the web. Abstracts of the Second European Symposium on Aerobiology, 2000, Vien, (Autriche).
 28. JÄGER S., NILSSON S., BERGGEREN B., PESSI A., HELANDER M., RAMFJORD, H. - Trends of some airborne tree pollen in the Nordic countries and Austria, 1980-1993. A comparison between Stockholm, Trondheim Turku and Viena. *Grana*, 1996;35:171-178.
 29. LEJOLY-GABRIEL M., LEUSCHNER R.-M. - Comparison of airborne pollen at Louvaine-la-Neuve (Belgium) and Basel (Switzerland) during 1979-1980. *Grana*, 1976;22:59-64.
 30. NILSSON S., PERSSON S. - Tree pollen spectra in the Stockholm region (Sweden), 1973-1980. *Grana*, 1981;20:179-182.
 31. PATHIRANE, L. - Graphical determination of the main pollination season. *Pollen et Spores*, 1975;17:609-610.
 32. SÁNCHEZ-MESA J.-A., GALÁN C., MARTÍNEZ-HERAS J.-A., HERVÁS-MARTÍNEZ C. - The use of an neural network to forecast daily grass pollen concentration in a Mediterranean region: the southern part of the Iberian Peninsula. *Clinical and Experimental Allergy*, 2002;32:1-7.
 33. SÁNCHEZ-MESA J.-A., SMITH M., EMBERLIN J., ALLITT U., CAULTON E., GALÁN C. - Characteristics of grass pollen season in areas of southern Spain and the United Kingdom. *Aerobiologia*, 2003;19:243-250.
 34. SNYDER R.-L., SPANO D., CESARACCIO C., DUCE P. - Determining degree-days thresholds from field observations. *Int. J. Biometeorol.* 1999;42:177-182.
 35. SNYDER R.-L., SPANO D., DUCE P., CESARACCIO C. - Temperature data for phenological models. *Int. J. Biometeorol.*, 2001;45:178-183.
 36. SPIEKSMAN, F. TH., EMBERLIN J., HJELMROOS M., JÄGER S., LEUSCHNER, R.-M. - Atmospheric birch (*Betula*) pollen in Europe: Trends and fluctuations in annual quantities and the starting dates of the seasons. *Grana*, 1995;34:51-57.
 37. VÁZQUEZ L.-M., GALÁN C., DOMÍNGUEZ E. - Influence of meteorological parameters in *Olea* pollen. *Int. J. Biometeorol.*

