

Spatial and temporal distribution of *Alternaria* spores in the Iberian Peninsula atmosphere, and meteorological relationships: 1993–2009

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Received: 5 March 2012 / Revised: 16 April 2012 / Accepted: 16 April 2012 / Published online: 6 May 2012
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Abstract This paper provides an updated of airborne *Alternaria* spore spatial and temporal distribution patterns in the Iberian Peninsula, using a common non-viable volumetric sampling method. The highest mean annual spore counts were recorded in Sevilla (39,418 spores), Mérida (33,744) and Málaga (12,947), while other sampling stations never exceeded 5,000. The same cities also recorded the highest mean daily spore counts (Sevilla 109 spores m⁻³; Mérida 53 spores m⁻³ and Málaga 35 spores m⁻³) and the highest number of days on which counts exceeded the threshold levels required to trigger allergy symptoms (Sevilla 38 % and Mérida 30 % of days). Analysis of annual spore distribution patterns revealed either one or two peaks, depending on the location and prevailing climate of sampling stations.

For all stations, average temperature was the weather parameter displaying the strongest positive correlation with airborne spore counts, whilst negative correlations were found for rainfall and relative humidity.

Keywords *Alternaria* · Fungal environmental management · Temperature · Rainfall · Relative humidity · Iberian Peninsula

Introduction

Alternaria Nees ex Fr., is a cosmopolitan genus that includes many species able to colonize and degrade a wide

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range of substrates and also to contaminate food. It is considered an emerging pathogen, due to its potentially adverse effect both on agricultural production and on human health (De Lucca 2007). Various *Alternaria* species are known to damage cereals and other crops of major economic importance (Tournas 2005). Moreover, a number of species—among them *Alternaria alternata* and *Alternaria tenuis*—are a widely recognized cause of asthma and allergic conjunctivitis (Lin and Williams 2003), and a documented source of systemic and dermatological infection in transplant patients and other immunosuppressed subjects (Karozy et al. 2004). Characterization is a somewhat complex undertaking, since isolates of the same species may display different allergen profiles, while fungi as diverse as *Alternaria alternata* and *Cladosporium herbarum* may present common allergens (Simon et al. 2000).

Aerobiological research is of value in a number of fields, in that it enables rigorous predictions to be made based on a large number of spore-count records. These predictions can be used to optimize fungicide applications in crops, thereby improving yields. Moreover, detailed predictions of airborne fungal spore counts and distribution patterns may serve as an early warning to sensitized allergy-sufferers, and as a means of optimizing medical treatment.

Alternaria propagules are among the major components of the world fungal bioaerosol, together with *Cladosporium*, *Aspergillus* and *Penicillium* spores (Mitakakis and Guest 2001; Corden et al. 2003; Grinn-Gofroń and Rapiejko 2009); this reflects the large number of *Alternaria* species, their widespread distribution and their ability to grow on

different natural substrates. Research suggests that the abundance of these spores may also be linked to their melanin-like pigmentation, which confers resistance to ultraviolet radiation (El-Morsy 2006).

Early reports on airborne *Alternaria* counts in Spain and Portugal have studied a small number of stations. Some of these studies have provided local information about the content of spores in a given region, both urban and rural (Infante et al. 1999; Munuera et al. 2001; Sabariego et al. 2004; Oliveira et al. 2009; Muñoz et al. 2010). Others were oriented to clinical aspects (Astray et al. 2010) or for the study of meteorological factors that influence their behavior (Aira et al. 2008).

This paper examines spore-count data from 12 sampling stations in the Iberian Peninsula, in order to identify spatial/temporal distribution patterns in different bioclimatic areas, with a view to evaluate potential risks for atopic allergy-sufferers.

Materials and methods

Study area

The location of the aerobiological sampling stations included in this study is showed in Fig. 1, together with other locations used as references for the *Alternaria* atmospheric concentration. In Table 1 includes additional information about the location of the sampling points, their climatic characteristics and the database analyzed for this study (a

Fig. 1 Location of sampling stations used in this study in Spain and Portugal (black) and other aerobiological locations take for reference (gray)

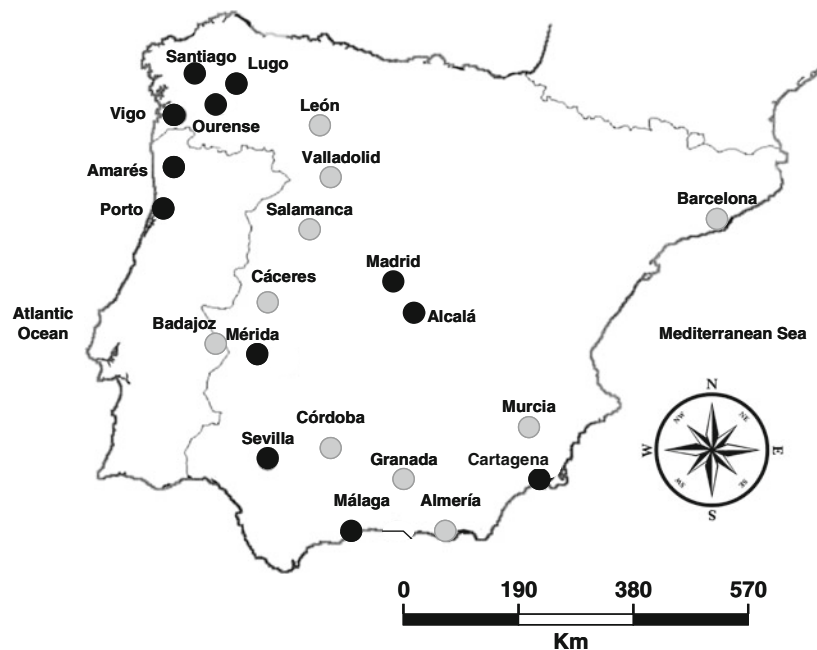


Table 1 Location of sampling points, climatical characteristics and database length. *RH* annual mean relative humidity, *Tmax* average maximum daily temperature, *Tmin* average minimum daily temperature, *Tmean* average mean daily temperature

Sampling station	Altitude	Geographical coordinates	Period of study	No. of years	Annual rainfall (mm)	RH (%)	Tmax	Tmin	Tmean
Lugo	50 m.a.s.l.	43°00'N, 7° 53'W	2001-2009	9	1,048	79.5	17.6	6.3	11.9
Santiago	270 m.a.s.l.	42°53'N, 8° 32'W	1996-2009	14	1,919	79.5	18.9	9.6	14.5
Ourense	130 m.a.s.l.	42°21'N, 7° 51'W	1993-1996; 1999-2009	15	855	73.0	21.5	8.5	15.0
Vigo	50 m.a.s.l.	42°14'N, 8° 43'W	1997-2009	13	1,797	74.0	18.4	11.0	14.7
Amares	80 m.a.s.l.	41°38'N, 8° 23'W	2005-2007	3	1,515	80.4	21.9	10.2	15.6
Porto	74 m.a.s.l.	41°11'N, 8° 39'W	2003-2007	5	992	75.2	20.1	11.2	15.2
Alcalá	587 m.a.s.l.	40°28'N, 3° 22'W	2005-2007; 2009	4	611	79.5	19.9	6.2	19.9
Madrid	600 m.a.s.l.	40°27'N, 3° 45'W	2000; 2003-2006	5	360	61.6	21.8	8.9	15.3
Mérida	220 m.a.s.l.	38°05'N, 6° 23'W	1997-1998	2	276	64.3	23.9	10.6	17.2
Cartagena	10 m.a.s.l.	37°36'N, 0° 59'W	2000-2008	9	294	79.8	24.1	16.6	20.4
Sevilla	18 m.a.s.l.	37°23'N, 5° 53'W	1997-1998	2	558	60.2	25.7	13.7	19.7
Málaga	5 m.a.s.l.	36°25'N, 4° 19'W	1996-1997; 2004	3	911	69.2	23.1	14.0	18.5

total of 84 annual records per year, ranging from 1993 to 2009).

Aerobiological sampling method

For the capture, sample preparation and counts of fungal spores, we used the methodology proposed by the Spanish Aerobiological Network (Galán et al. 2007). Daily spore concentrations were sampled using a Hirst-type 7-day volumetric trap (Burkard, Rickmansworth, UK) or a Lanzoni VPPS-2000 (Lanzoni, Bologna, Italy) with a rate of 10 L min⁻¹. Spores were trapped onto a melinex adhesive tape that was cut into daily segments. The daily mean concentration of the number of fungal spores was counted using an optical microscope at ×400 and ×1,000 magnification, along two full lengthwise traverses. The spore count was conducted at generic level, since the use of a non-viable method does not allow a specific differentiation.

The daily average concentrations are expressed as spores per cubic meter of air, while the total spore amounts are presented as spores per cubic meter of air per length of the period examined. To delimit the period of the year in which the main sporulation period (MSP) occurs, and with the aim to make comparable the data from all sampling stations, we have followed the method proposed by Nilsson and Persson (1981), which takes into account the 90 % of total annual, after removing a 5 % of the start and the end of each record.

Meteorological data and statistical methods

As the airborne spore concentrations are highly dependent on the main meteorological factors, we studied the relationship between spore concentration and weather factors of rain, temperature and relative humidity. Weather data from the Spanish stations were provided by the Meteorology State Agency (Lugo 43° 6' N, 7°27' W, height: 445 m.a.s.l.; Santiago airport 42° 53' N, 8° 24' W, height: 370 m.a.s.l.; Ourense 42°19'N, 7°51' W, height: 143 m.a.s.l.; Vigo airport 42° 14' N, 8°37' W, height: 261 m.a.s.l.; Alcalá 40° 29' N, 3° 27' W, height: 607 m.a.s.l.; Madrid Retiro 40° 24' N, 3° 40' W, height: 667 m.a.s.l.; Mérida 38° 54' N, 6° 23' W, height: 185 m.a.s.l.; Cartagena center 37° 36' N, 0° 59' W, height: 10 m.a.s.l.; Sevilla airport 37° 25' N, 5° 52' W, height: 34 m.a.s.l., Málaga airport 36° 40' N, 4° 29' W, height: 7 m.a.s.l.), and Portuguese stations as Amares (41° 38' N, 8° 23' W; height: 5 m) and Porto (41°11' N, 8° 39' W; height 20 m) with weather data provided by Direção Regional de Agricultura e Pescas do Norte, Estação de Avisos de Entre Douro e Minho and Instituto Geofísico da Universidade do Porto, respectively. The record length of the weather characteristics of each station is the same as that of aerobiological data.

To establish the influence of these factors on airborne spore counts, Spearman's test was applied with two levels of statistical significance (P -value≤0.01 and P -value≤0.05) using the Statistica v. 6.0 software package for Windows

(Stat Soft, 2001, Cary, N.C.). Data are expressed as total annual counts from a sum using daily concentrations. Locations appear sorted in tables and figures according to latitude.

Results

Data analysis

For interpretation of the data, as well as the annual average counts reflecting the relative importance of spores in each locality with respect to the others, we also considered as important the year with the highest values for each locality, in order to determine in which geographical area of the study may have a higher incidence on human health.

The highest average annual counts were recorded in Sevilla (39,418 spores), Mérida (33,744) and Málaga (12,947); elsewhere, annual counts ranged from 1,096 spores in Santiago to 4,808 in Madrid (Table 2). Mean daily spore concentrations were also higher in these cities, as was the number of days on which counts exceeded the mean. In the Portuguese town of Amares, the threshold of 10 spores m^{-3} air was exceeded on a total of 108 days.

The highest peak daily concentration was recorded in Mérida followed by Sevilla; elsewhere, peak daily concentrations ranged between 85 spores m^{-3} air (Porto) and 667 spores m^{-3} air (Málaga). Most stations recorded the highest concentrations in spring–summer, although absolute values varied considerably.

We used standard criteria in Northern Hemisphere for defining the spring period (March, April, May), summer (June, July, August), autumn (September, October, November), and winter (December, January, February).

At most stations, the main sporulation period (MSP) started before 26 March; in only two stations was the start-date not recorded until April. At all stations, the MSP ended between late October and December. Analysis of mean data showed that the MSP was longest in Madrid, Mérida, Sevilla, Cartagena and Málaga, whilst MPS duration elsewhere ranged from 134 days (Lugo) to 193 days (Porto).

Spatio-temporal variation

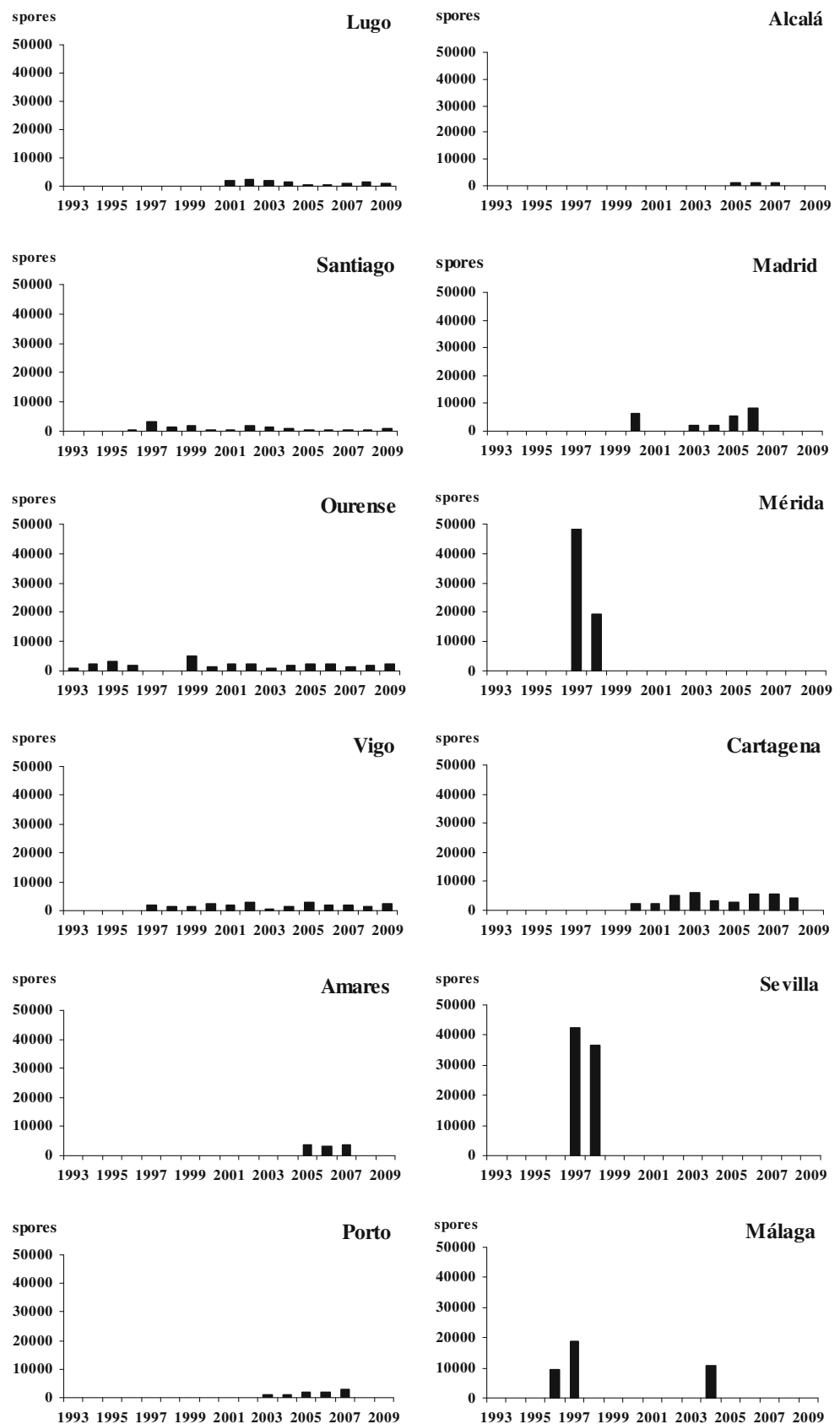
Total annual counts for each study year and each sampling station are shown in Fig. 2. Sampling stations in north-western cities recorded annual counts of less than 3,000 spores, with the exception of Amares, Santiago in 1997 and Ourense in 1999. At stations in the center of the

Table 2 Average annual spore data and main sporulation period data. *Total annual* Average of the total annual spores, *Daily mean* mean daily spore counts (spores m^{-3}), *Days > mean* number of days on which the mean daily spore counts are higher than the average concentration, *Peak date* date of the maximum daily value, *Peak value*

maximum daily value (spores m^{-3}), *Start-end date* date of the start and the end of the MSP, *Days > mean* number of days on which the mean daily spore counts are higher than the average concentration, *Daily mean* mean daily spore counts (spores m^{-3} —during the study period)

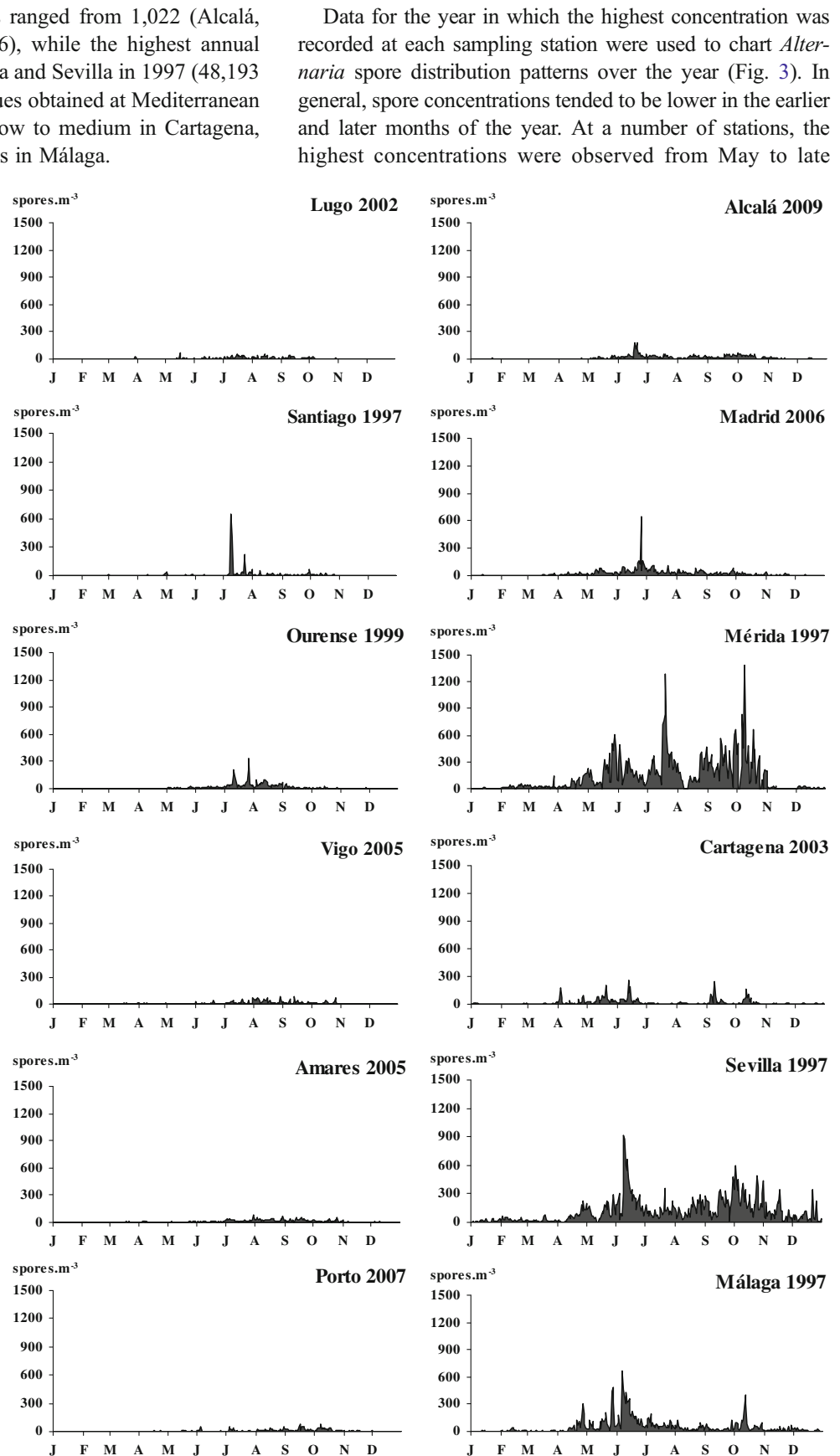
Sampling station	Alternaria annual data				Main sporulation period			
	Total annual	Daily mean	Days > mean	Peak date	Peak value	Start-end date	Daily mean	Days > mean
Lugo	1,322	4	83	26 July 2003	87	18 April–25 October	9	134
Santiago	1,096	3	82	9 July 1997	653	25 March–10 November	7	152
Ourense	2,156	6	95	27 July 1999	332	12 January–14 November	12	183
Vigo	1,858	5	84	11 July 1999	370	03 March–13 November	10	181
Amares	3,487	10	108	4 October 2007	109	7 April–17 November	17	183
Porto	2,625	9	54	8 October 2007	85	18 February–30 October	8	193
Alcalá	2,204	9	60	20 June 2009	181	26 March–31 October	12	185
Madrid	4,808	13	86	25 June 2006	642	15 March–19 November	23	213
Mérida	33,744	53	77	9 October 1997	1380	22 March–27 November	162	209
Cartagena	4,088	12	81	11 April 2006	384	16 January–28 December	15	251
Sevilla	39,418	109	125	9 June 1997	910	17 February–24 November	148	244
Málaga	12,947	35	104	7 June 1997	667	22 March–21 November	55	221

Fig. 2 Total annual counts for each study year and each sampling station. *Lu* Lugo, *Sa* Santiago, *Ou* Ourense, *Ví* Vigo, *Am* Amarés, *Po* Porto, *Al* Alcalá, *Md* Madrid, *Me* Mérida, *Ca* Cartagena, *Se* Sevilla, *Ma* Málaga



peninsula, total annual counts ranged from 1,022 (Alcalá, 2005) to 8,471 (Madrid, 2006), while the highest annual counts were recorded in Mérida and Sevilla in 1997 (48,193 and 42,395, respectively). Values obtained at Mediterranean coastal stations ranged from low to medium in Cartagena, but reached much higher levels in Málaga.

Fig. 3 Seasonal *Alternaria* spore distribution patterns during the year in which the highest concentration was recorded at each sampling station



October, with monthly peaks in June (Madrid), July (Lugo), August (Vigo, Amares) or September (Porto). In others, peaks were recorded only in July (Santiago; Ourense). Elsewhere two peaks were observed (summer and autumn); this bimodal distribution was particularly marked in Málaga and Sevilla, with monthly peaks in June (6,253 and 9,017 spores respectively) and again in October (2,468 and 8,283, respectively), but was also noted in Mérida (10,318 spores in July and 9,245 in October), Cartagena (1,380 spores in May and June, 992 in September) and Alcalá (1,438 spores in June, 946 in October).

To compare spore concentrations at different stations, the annual totals counts for 2005 and 2006 were plotted graphically (Fig. 4), since complete data were available for these two years at 9 of the 12 stations. In the absence of data for Sevilla and Mérida, the highest concentrations were recorded in Madrid, Amares and Cartagena (including a maximum of 8,471 spores in Madrid in 2006), while the lowest values were observed in Lugo and Santiago in both years.

Meteorological study

Due to the large number of records used, yielding around 500 bilateral correlations (Spearman tests), Table 3 shows only results for the whole study period at each sampling station. A negative correlation was found between spore concentrations and both rainfall and relative humidity at all sampling stations; the most significant negative correlations were with rainfall in Vigo and with humidity in Alcalá. Analysis of bilateral correlations for every year at each sampling station yielded even higher values: the strongest correlation with rainfall was obtained in Vigo in 2000 (-0.520^{**}) and with humidity in Madrid in 2006 (-0.618^{**}); in both cases, values were highly significant ($P\text{-value} \leq 0.01$). At all stations, a positive correlation was found between airborne *Alternaria* spore concentrations and temperature. The strongest correlations were with maximum temperature in Amares (0.696^{**}), with minimum temperature in Madrid (0.617^{**}) and with mean temperature in Ourense (0.673^{**}). Year-by-year analysis at each station revealed that the strongest correlation was with maximum

temperature in Ourense in 2006 (0.794^{**} , $P\text{-value} \leq 0.01$) and with minimum and mean temperature in 1999, also in Ourense (0.778^{**} and 0.819^{**} respectively, $P\text{-value} \leq 0.01$).

Discussion

The highest annual airborne *Alternaria* spore concentrations were recorded in the south-western part of the Iberian Peninsula, with peak values of 48,193 spores in Mérida and 42,395 in Sevilla, both in 1997. The lowest values were found in the northern city of Santiago, where a total spore count of 441 was recorded in 2001. This considerable variation suggests that airborne spore concentrations are influenced by numerous biogeographical factors and by local weather conditions. Mitakakis and Guest (2001), for example, reported a significant increase in *Alternaria* spore concentrations during wheat and cotton harvesting in rural areas of Australia, and Corden et al. (2003) reported increase related with cereal production in United Kingdom. Moreover, since *Alternaria* is a dry-air spore type, airborne concentrations are favored by high temperatures and low relative humidity (Troutt and Levetin 2001); these are the prevailing weather conditions in those areas of the Peninsula where the highest concentrations were recorded.

Studies carried out in other cities in Spain and Portugal report maximum annual *Alternaria* spore concentrations lower than those recorded here for Mérida and Sevilla, although levels observed for some southern Spanish cities (Infante et al. 1999) are higher than those observed in the present study (e.g., Córdoba, 33,331 spores in 1997; Granada, 18,297 spores in 1998). High values have also been reported for Salamanca, 26,276 spores in 1995 (Perez-Gorjón et al. 2003). Earlier studies in Mediterranean coastal cities recorded total annual concentrations of around 12,498 in Murcia during the year 1997 (Munuera et al. 2001), 11,774 in Barcelona during 2001 (Belmonte et al. 2002) and 6,356 in Almería in the year 2000 (Sabariego et al. 2004). Finally, spore concentrations reported in León (5,047 in 1994) are closer to those obtained here in the north-western part of the

Fig. 4 Total annual *Alternaria* spores in 2005 and 2006 (abbreviations as in Fig. 2)

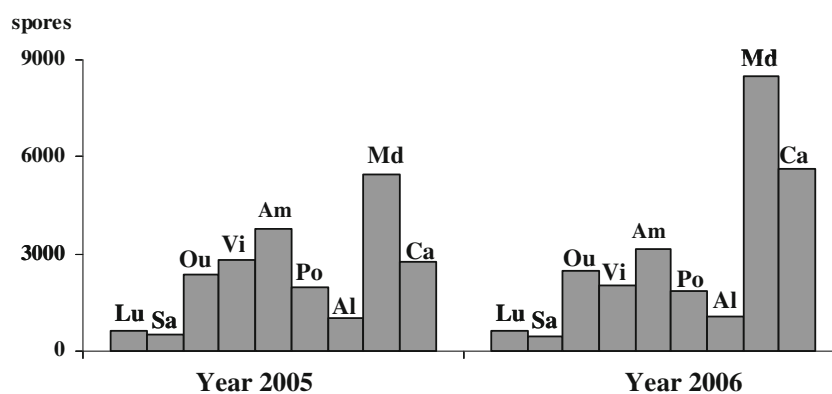


Table 3 Correlation Spearman coefficients between the spore concentration in the period of study and the main meteorological variables

Sampling station	Rainfall	Rhmean	Tmax	Tmin	Tmean
Lugo	-0.285**	-0.329**	0.621**	0.542**	0.630**
Santiago	-0.270**	-0.238**	0.621**	0.552**	0.636**
Ourense	-0.288**	-0.453**	0.637**	0.562**	0.673**
Vigo	-0.361**	-0.209**	0.640**	0.571**	0.638**
Amares	-0.336**	-0.284**	0.696**	0.543**	0.666**
Porto	-0.274**	-0.223**	0.578**	0.500**	0.556**
Alcalá	-0.155**	-0.464**	0.649**	0.601**	0.651**
Madrid	-0.070**	-0.437**	0.624**	0.617**	0.631**
Mérida	-0.220**	-0.419**	0.620**	0.554**	0.621**
Cartagena	-0.059**	-0.122**	0.242**	0.231**	0.262**
Sevilla	-0.108**	-0.144**	0.549**	0.590**	0.588**
Málaga	0.067	-0.365**	0.639**	0.550**	0.623**

**Significant at the $P \leq 0.01$ level except rainfall in Málaga, which is not significant

peninsula (Infante et al. 1999). In other European countries, such as Holland, total annual *Alternaria* spore counts range from 20,000 to 30,000 (Nikkels et al. 1996).

Seasonal distribution displayed varying patterns: in cities with a continental climate (e.g., Madrid), and in some cities close to the sea (e.g., Vigo, Amares, Porto), *Alternaria* spores were recorded continuously from spring to autumn, whereas cities with mild winter temperatures (e.g., Málaga and Sevilla) displayed secondary peaks during midwinter (Recio et al. 2011). This bimodal distribution has also been observed by other authors (De Linares et al. 2010). Finally, in cities with cooler temperatures and higher rainfall (e.g., Santiago, Ourense, Lugo) the main sporulation period is concentrated in the summer, a finding also reported for central and northern Spanish cities, including Valladolid (Sánchez et al. 2009).

The peak daily spore count for Mérida (1,380 spores m^{-3} air on 9 October 1997), is surpassed by that reported for the nearby town of Badajoz, where a count of 1,635 spores m^{-3} of air was recorded on 11 July 1995 (Paredes et al. 1997). A similarly high value of 1,152 spores was recorded for Córdoba on 4 October 1997 (Infante et al. 1999). Lower values, similar to those observed here for other sampling stations, have been found for Salamanca (795 spores m^{-3} of air on 23 July 1995), Murcia (366 on 5 October 1997), Granada (361 on 2 June 1998) and Barcelona (311 on 22 June 1996).

These seasonal and daily variations in spore counts are attributable in part to various weather-related factors that influence fungal development, propagule production and airborne spore dispersal (Angelosante et al. 2007). A negative correlation was observed between *Alternaria* spore

concentrations and both rainfall and relative humidity at all sampling stations, while a positive correlation was found with temperature, and particularly average temperature. The mean temperature in Murcia is 16.8°C (Munuera et al. 2001), i.e., lower than that of Cartagena (20.4°C), whereas the relative humidity in Cartagena (79.8 %) is considerably higher than that of Murcia (58 %). As a result, mean daily spore concentrations of 43 spores m^{-3} of air have been reported in Murcia over a 6-year period, compared with a lower figure of 12 spores m^{-3} of air recorded here for Cartagena. Generally speaking, in years with higher overall spore concentrations, warm rainy spells, favouring sporulation, alternated with hot dry spells favouring the persistence of airborne spores. By contrast, years with lower overall concentrations were characterized by prolonged periods of rain and low temperatures, which probably inhibited sporulation until late spring. Moreover, airborne spore concentrations were reduced due to the washout effect.

The highest daily peaks were recorded on days with little or no rainfall (Lugo), humidity values of between 52.2 % (Madrid) and 92.9 % (Amares) and average temperature ranging from 15.0°C (Mérida) to 25.2°C (Alcalá). Analysis of weather conditions over the 7 days prior to the peak revealed a rising trend for rainfall, with cumulative values of 70 mm in Alcalá, 15 mm in Porto and 11 mm in Santiago, although rainfall remained scarce elsewhere, and non-existent in Cartagena. Average mean temperatures ranged from 16.3°C (Mérida) to 25.3°C (Ourense). In Cordoba, the highest airborne spore concentrations tend to be recorded at temperatures in the range 20–25°C (Angulo et al. 1999), while in León, with a colder climate, high peak daily concentrations are reported at temperatures of between 22 and 28°C (Fernández et al. 1998). Relative humidity strongly influences airborne spore release and dispersal. *Alternaria* spores are typical of dry environments (Troutt and Levetin 2001), and airborne spore concentrations tend to rise as relative humidity decreases. In the coastal city of Cartagena, relative humidity values for the 2 days prior to the peak spore count were 91.4 % and 95.9 %, respectively; in the nearby inland city of Murcia (Munuera et al. 2001), lower mean relative humidity (around 58 %, compared with 79.8 % for Cartagena) and higher spore concentrations are reported. By contrast, the mean temperature in Cartagena (20.4°C) is higher than that of Murcia (16.8°C). These differences between relatively close cities highlight the strong influence of local microclimate on airborne spore dynamics.

Given the geographical and climatic differences between sampling stations, the optimal period for *Alternaria* growth and sporulation differs from one station to another: maximum monthly concentrations tend to be recorded earlier in the south than in the north of the Peninsula. Research in a number of European cities has shown that peak

concentrations occur in the summer months (Stepalska et al. 1999). Knowledge of airborne *Alternaria* spore concentrations and distribution patterns is of particular interest, given the reaction prompted by these spores in atopic allergy sufferers. The World Health Organization (2000) notes that exposure to airborne fungi may constitute a health risk, and Sánchez and Bush (2001) report that *Alternaria* is recognized as a major risk factor for severe and fatal asthma.

The latest multicenter study conducted in Spain for the Spanish Society of Clinical Immunology and Allergy indicates that 6 % of patients with allergic rhinoconjunctivitis displayed a positive reaction to *Alternaria alternata*, this being the most common allergenic fungal species, accounting for 8.5 % of asthma-inducing airborne allergens in Spain (Quirce 2009), while around 3 % of allergic patients in Portugal (D'Amato et al. 1997).

Although the minimum exposure levels likely to prompt allergic symptoms may vary depending on local climate amongst other things, Stennett and Beggs (2004), in a review of the *Alternaria* sensitization thresholds suggested by various authors, note that Gravesen proposed a threshold value of 100 spores m⁻³ air, while Licorish et al. suggested 10⁴–10⁷ inhaled spores in 24 h, and Hasnain et al. report that a daily average of 50 spores m⁻³ air is sufficient to prompt an allergenic response. In terms of the number of days on which the threshold of 100 spores m⁻³ air was exceeded in the present study, the sampling points with the highest risk of *Alternaria* allergy, were Sevilla and Mérida, where the threshold was exceeded on 38 % and 30 % of days, respectively. Over the study period, several sampling stations recorded concentrations of over 500 spores m⁻³ air (on 16 days in Mérida, 13 days in Sevilla and 2 days in Málaga); indeed, concentrations in Mérida exceeded 1,000 spores m⁻³ air on 2 days.

Conclusions

In the Iberian Peninsula it seems that there is a seasonal pattern of airborne *Alternaria* conidia with latitude, with maximum concentrations reached in summer northward and in autumn or spring southward. As temperature seems to increase *Alternaria* spores in the atmosphere the highest concentration appear in the south. The most effective measure for preventing allergy symptoms would clearly be to eliminate exposure to the allergen triggering the reaction; unfortunately, this is rarely feasible. Exposure to fungal spores is quite different to pollen exposure, in terms of both quantity and duration. Intense, prolonged exposure to *Alternaria* thus induces symptoms closer to those associated with dust mite or dander allergy than to those triggered by pollen, although the latter may contribute to the severity of the allergic response.

Acknowledgments The authors wish to acknowledge the funding support served to obtain the data. Sampling stations of Galicia (Consellería de Medio Ambiente y Consellería de Sanidad, Xunta de Galicia); Porto and Amarés stations (Fundação para a Ciência e Tecnologia SFRH/BD/18765/2004); Madrid and Alcalá stations (Red Palinocam, Consejería de Sanidad, Comunidad de Madrid and Ayuntamiento de Alcalá); Mérida station (Junta de Extremadura, Projects PRI06A190 and BS10008 PRI) and sampling station of Sevilla (Project MEC I+D+I CGL2009-10683).

References

- Aira MJ, Rodríguez-Rajo FJ, Jato V (2008) 47 annual records of allergenic fungi spore: predictive models from the NW Iberian Peninsula. *Ann Agric Environ Med* 15(1):91–98
- Angelosante A, Pace L, Tomassetti B, Coppola E, Verdecchia M, Pacioni G, Visconti G (2007) Estimation of fungal spore concentrations associated to meteorological variables. *Aerobiologia* 23:221–228
- Angulo J, Mediavilla A, Domínguez E (1999) Conidia of *Alternaria* of the atmosphere of the city of Córdoba, Spain in relation to meteorological parameters. *Int J Biometeorol* 46:107–117
- Astray G, Rodríguez-Rajo FJ, Ferreira-Lage JA, Fernández-González M, Jato V, Mejuto JC (2010) The use of artificial neural networks to forecast biological atmospheric allergens or pathogens only as *Alternaria* spores. *J Environ Monit* 12(11):2145–2152
- Belmonte J, Gabarra E, Roure JM (2002) *Aerobiología en Cataluña: Estación de Barcelona (2000–2001)*. *REA* 7:131–136
- Corden JM, Millington WM, Mullins J (2003) Long-term trends and regional variation in the aeroallergen *Alternaria* in Cardiff and Derby UK. Are differences in climate and cereal production having an effect? *Aerobiologia* 19:191–199
- D'Amato G, Chatzigeorgiou G, Corsico R, Gioulekas D, Jager L, Jager S, Kontou-Fili K, Kouridakis S, Liccardi G, Meriggi A, Palma-Carlos A, Palma-Carlos ML, Pagan A, Parmiani S, Puccinelli P, Russo M, Spieksma ATM, Torricelli R, Withrich B (1997) Evaluation of the prevalence of prick skin test positively to *Alternaria* and *Cladosporium* in patients with suspected respiratory allergy. *Allergy* 52:711–716
- De Linares C, Belmonte J, Canela M, Díaz de la Guardia C, Alba-Sánchez F, Sabariego S, Alonso-Pérez S (2010) Dispersal patterns of *Alternaria* conidia in Spain. *Agric For Meteorol* 150:1491–1500
- De Lucca AJ (2007) Harmful fungi in both agricultures and medicine. *Rev Iberoam Micol* 24:3–13
- El-Morsy ESM (2006) Preliminary survey of indoor and outdoor airborne microfungi at coastal buildings in Egypt. *Aerobiologia* 22:197–210
- Fernández D, Valencia RM, Molnár T, Vega A, Sagües E (1998) Daily and seasonal variations of *Alternaria* and *Cladosporium* airborne spores in León (North-West, Spain). *Aerobiologia* 14:215–220
- Galán C, Cariñanos P, Alcázar P, Domínguez E (2007) *Manual de Calidad y Gestión de la Red Española de Aerobiología*. Servicio de Publicaciones de la Universidad de Córdoba, Córdoba
- Grinn-Gofroñ A, Rapiejko P (2009) Occurrence of *Cladosporium* spp. and *Alternaria* spp. spores in Western, Northern and Central-Eastern Poland in 2004–2006 and relation to some meteorological factors. *Atmos Res* 73:747–758
- Infante F, Castro A, Domínguez E, Guardia A, Méndez J, Sabariego S, Vega A (1999) A comparative study of the incidence of *Alternaria* conidia in the atmosphere of five Spanish cities. *Polen* 10:15–23
- Kározy A, Ducloux D, Reboux G, Blanc D, Faivre B, Halopin JM, Piarroux R (2004) Cutaneous *Alternaria* infection in renal

- transplant recipients: a report of two cases with an unusual mode of transmission. *Transpl Infect Dis* 6(1):46–49
- Lin RY, Williams KD (2003) Hypersensitivity to molds in New York City in adults who have asthma. *Allergy Asthma Proc* 24:13–18
- Mitakakis TZ, Guest DI (2001) A fungal spore calendar for the atmosphere of Melbourne, Australia for the year 1993. *Aerobiologia* 17:171–176
- Muñoz AF, Silva I, Tormo R, Rodríguez JA (2010) Distribution of airborne fungal propagule concentrations in an irrigated cropland zone. *J Phytopathol* 58(7–8):513–522
- Munuera M, Carrión JS, Navarro C (2001) Airborne *Alternaria* spores in SE Spain (1993–98). Occurrence patterns, relationship with weather variables and prediction models. *Grana* 40:111–118
- Nikkels AH, Terstege P, Spieksma FThM (1996) Ten types of microscopically identifiable airborne fungal spores at Leiden. The Netherlands. *Aerobiologia* 12:107–112
- Nilsson S, Persson S (1981) Tree pollen spectra in the Stockholm region (Sweden) 1973–1980. *Grana* 20:179–182
- Oliveira M, Ribeiro H, Delgado J, Abreu I (2009) The effects of meteorological factors on airborne fungal spore concentration in two areas differing in urbanisation level. *Int J Biometeorol* 53(1):61–73
- Paredes MM, Martínez FJ, Silva I, Tormo R, Muñoz AF (1997) Influencia de los parámetros meteorológicos en la dispersión de esporas de *Alternaria* Nees ex Fr. *Bol San Veg Plagas* 23:541–549
- Perez-Gorjón S, Rodríguez de la Cruz D, Suarez-González R, Sánchez-Sánchez J (2003) Variación anual de esporas en la atmósfera de Salamanca durante los años 1995 y 2000. *Polen* 13:289–297
- Quirce S (2009) Asthma. *Alergológica-2005*. *J Investig Allergol Clin Immunol* 19(2):14–20
- Recio M, Trigo MM, Docampo S, Melgar M, García-Sánchez J, Bootello L, Cabezudo B (2011) Analysis of the predicting variables for daily and weekly fluctuations of two airborne fungal spores. *Alternaria* and *Cladosporium*. *Int J Biometeorol*. doi:10.1007/s00484-011-0509-3
- Sabariego S, Díaz de la Guardia C, Alba F (2004) Estudio aerobiológico de los conidios de *Alternaria* y *Cladosporium* en la atmósfera de la ciudad de Almería (SE de España): relación con los parámetros meteorológicos. *Rev Iberoam Micol* 21:121–127
- Sánchez H, Bush RK (2001) A review of *Alternaria* sensitivity. *Rev Iberoam Micol* 18:56–59
- Sánchez E, Rodríguez D, Sanchis ME, Sánchez J (2009) Meteorological and agricultural effects on airborne *Alternaria* and *Cladosporium* conidia and clinical aspects in Valladolid (Spain). *Ann Agric Environ Med* 16:53–61
- Simon B, Probst G, Kajava AV, Oberkofler H, Susani M, Crameri R, Ferreira F, Ebner C, Breitenbach M (2000) IgE-binding epitopes of enolases, a class of highly conserved fungal allergens. *J Allergy Clin Immunol* 106(5):887–895
- Stennett PJ, Beggs PJ (2004) *Alternaria* spores in the atmosphere of Sydney, Australia, and relationships with meteorological factors. *Int J Biometeorol* 49:98–105
- Stepalska D, Harmata K, Kasprzyk I, Myszkowska D, Stach A (1999) Occurrence of airborne *Cladosporium* and *Alternaria* spores in Southern and Central Poland in 1995–1996. *Aerobiologia* 15:39–47
- Tournas VH (2005) Spoilage of vegetable crops by bacteria and fungi and related health hazards. *Crit Rev Microbiol* 31:33–44
- Troutt C, Levetin E (2001) Correlation of spring spore concentrations and meteorological conditions in Tulsa, Oklahoma. *Int J Biometeorol* 45:64–74
- World Health Organization (2000) Guidelines for concentration and exposure-response measurement of fine and ultra fine particulate matter for use in epidemiological studies. World Health Organization, Geneva