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ORIGINAL PAPER

Alternaria spores in Emilia-Romagna, Northern Italy: current diffusion and trends

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Abstract Since the end of the 1990s, the aerobiological network managed by the Regional Environmental Agency in Emilia-Romagna, Italy, started a systematic monitoring of different types of fungal spores, in particular Alternaria. This activity is of outstanding interest due to the various detrimental effects on human beings and on vegetation associated with Alternaria spores presence in the atmosphere. Daily concentration values of Alternaria spores are available from the Emilia-Romagna network in 10 stations. The availability of these data allows to set up a detailed analysis of the presence of Alternaria spores in different climatic and environmental settlements. The 19-year database of daily spore concentrations in most of the stations (1999–2017) can also support a preliminary analysis of climatic trends. A synthetic characterization of the main features associated with the presence and amount of Alternaria spores will be presented in this work. The period with the highest values of concentration in most of the measuring stations covers the warm season, with two main peaks of spore production in early and late summer. The most relevant trends for Alternaria season are mainly associated with an increase in the length of the period when spores are present. As for the amount of spores, signals are generally less evident, indicating a predominant decrease in the spore amount.

Keywords Aerobiological monitoring · Alternaria spores · Geographical analysis · Trend analysis

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1 Introduction

Alternaria is certainly one of the most allergenic spores, causing respiratory diseases in humans (D'Amato et al. 1997; Gioulekas et al. 2004). In addition, *Alternaria* can be the cause of different plant diseases, with negative effects on agriculture (fruit trees, potatoes and tomatoes among the others) and on natural vegetation (Harteveld et al. 2014; Gur et al. 2017; Escuredo et al. 2011; Jambhulkar et al. 2016).

The aim of the study is to describe the major features of the current distribution of *Alternaria* spores in the Emilia-Romagna Region, located in the southern part of the Po Valley, in Northern Italy. The aerobiological network managed by the Regional Environmental Agency in Emilia-Romagna (Arpae-ER) is dedicating a substantial effort to the monitoring of some fungal spores since the end of the 1990s.

Daily concentration data of *Alternaria* spores are available from Arpae-ER aerobiological network, and the monitoring activity dates back to the end of the 1990s in 10 stations of the network (PC1: Piacenza;

PR2: Parma; RE1: Reggio Emilia; MO1: Modena; BO1: Bologna; FE1: Ferrara; RA3: Ravenna; FO1: Forlì; FO2: Cesena; RN1: Rimini): the availability of such data allows to set up a detailed analysis of the presence of *Alternaria* spores in different climatic and environmental settlements inside Emilia-Romagna territory, following aerobiological and phytopathological aspects related to the presence of these spores.

Another focus of this study is related to a preliminary analysis of long-term trends for *Alternaria* spores, which can effectively been supported by the 19-year database (1999–2017) of daily spores concentration in most of the stations. To our knowledge, only few studies have been focused on the analysis of long-term trends for *Alternaria*, as well as for other fungal spores. Decreasing trends for *Alternaria* concentration are shown in Corden et al. (2003) for two UK cities and in Grinn-Gofron et al. (2016) for two Polish cities. Also in Damialis et al. (2015), where 14 fungal taxa are examined in a city in Greece, decreasing concentration is found for 11 taxa; in addition, a later onset of the spore season together with a shortening of the season length is found, although only few significant trends are present.

2 Methods

Daily concentration of *Alternaria* spores collected in the 10 monitoring stations belonging to Arpae-ER aerobiological network has been used in order to compute the average daily concentration of *Alternaria* in each location and to define some seasonal indicators to synthesize the main characteristics of the spore season.

The selected indicators are: the annual spore integral, which is obtained summing the daily concentration of *Alternaria* spores during the whole year; the peak value, which is the highest daily concentration during the year; the peak date, which is the day of the year when the peak value occurs; the starting and ending date of the spore season, which represent the day when the 5% (start) and 95% (end) of the annual spore integral are reached; finally, the number of days between these two calendar dates is the length of the spore season.

Time series of the previous indicators are submitted to different statistical tests. First of all, the annual median of the time series for each indicator in the period 1999–2017 is computed, in order to point out the average (climatic) conditions in each monitoring station. A geographical analysis focused on the distribution of the median of the seasonal indicators is performed. Such analysis is meant to point out the geographical coherence of *Alternaria* seasonal characteristics throughout Emilia-Romagna territory, according to the statistical relationship between the indicators and the geographical coordinates of the stations (latitude and longitude).

The statistical index used to outline the geographical analysis is the Moran's index (Moran 1950), which measures the degree of spatial autocorrelation.

In addition, a trend analysis of the 1999–2017 annual time series is carried out computing the nonparametric Kendall rank correlation coefficient τ (Kendall 1976) in order to evaluate the monotonic increasing/decreasing trend in the time series (together with its statistical significance level, p level). In addition, the Theil–Sen estimator is computed in order to quantify the unit (annual) variation in each station over time (Theil 1950; Sen 1968).

The median of the distribution of Kendall τ coefficients in the 10 monitoring stations is computed for each seasonal indicator, and the Mann–Whitney test (1947) is used in order to check whether the median values are different from zero, being then a reasonable approximation of the presence of a prevalent trend (positive or negative) for the specific indicator.

All the statistical analyses have been carried out using R software (R Core Team 2018).

3 Results

Alternaria spores are present in the atmosphere from May to November, and null concentrations appear only in winter (Fig. 1). During summer, daily concentration of *Alternaria* spores shows two distinct peaks almost in all the stations: the first is in June and the second in September. On average, the latter peak is more pronounced at least in the stations located in the western and central Po Valley.

The median values of the *Alternaria* season indicators in each station of the Arpae-ER aerobiological network are given in Table 1; medians are computed in the 1999–2017 period. As for the magnitude of the peak, highest values (above 1000 spore/m^3) are

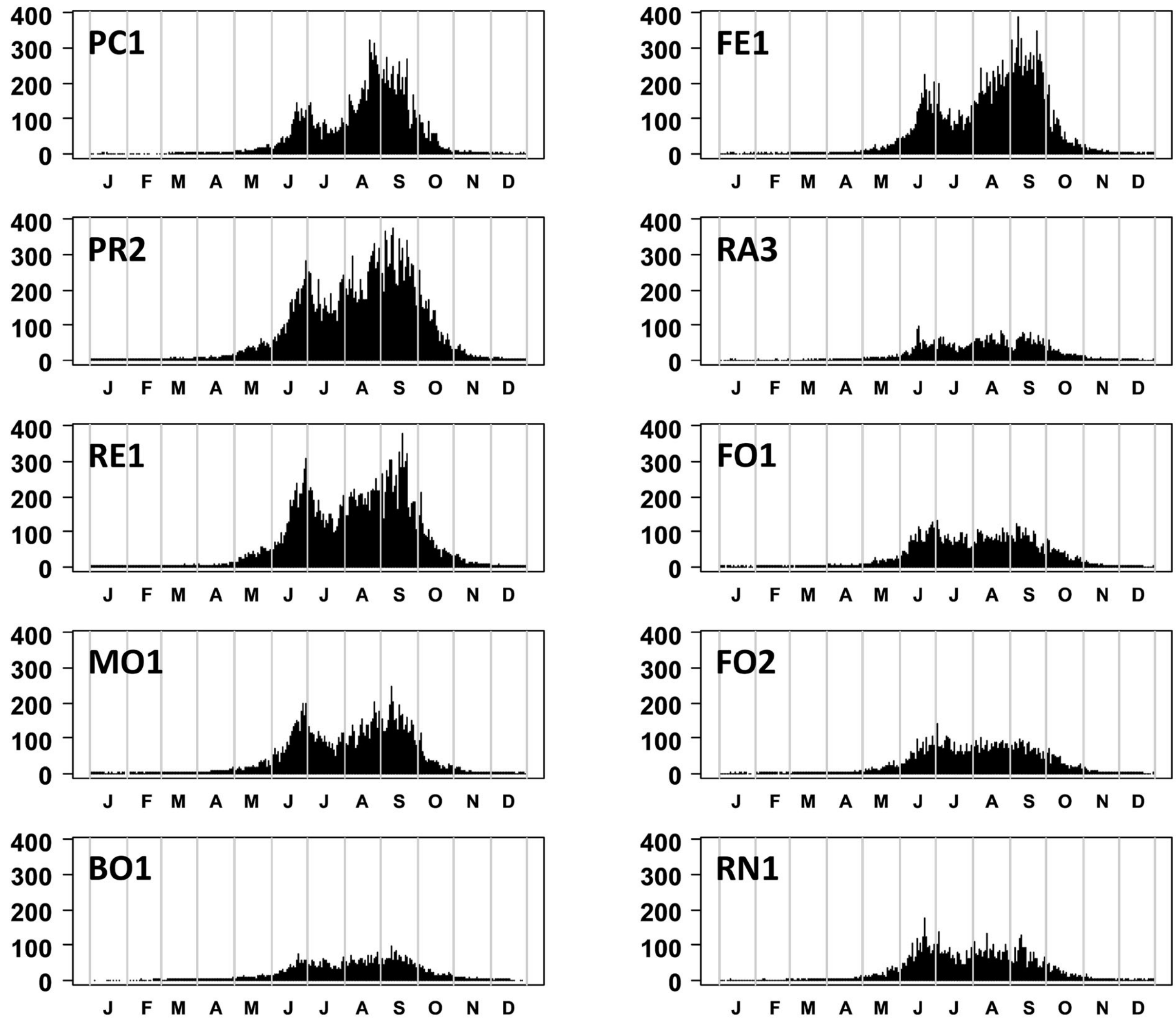

Fig. 1 Daily average concentration of Alternaria spores (expressed in spores/m^3) in the monitoring station of Arpae-ER network

Table 1 Median of the distribution of spore season indicators in each station of the Arpae-ER aerobiological network for the period 1999–2017

	PC1	PR2	RE1	MO1	BO1	FE1	RA3	FO1	FO2	RN1	Moran
Start date	19 Jun	2 Jun	1 Jun	29 May	26 May	11 Jun	4 Jun	26 May	26 May	25 May	0.42**
End date	10 Oct	19 Oct	16 Oct	6 Oct	17 Oct	9 Oct	21 Oct	17 Oct	17 Oct	11 Oct	0.02
Season length	119	139	138	131	149	122	135	140	146	144	0.25*
Peak date	5 Sep	4 Sep	30 Aug	14 Aug	27 Aug	10 Sep	14 Aug	10 Aug	16 Jul	14 Aug	0.52**
Peak value	1162	1305	1023	701	273	1210	367	559	482	632	0.44**
Spore index	25,830	35,500	32,547	19,746	8871	27,153	9746	14,435	13,430	15,376	0.56**

The label "Moran" introduces Moran's index for spatial autocorrelation with corresponding confidence levels (*p level < 0.05; **p level < 0.01)

observed in the westernmost stations (PC1, PR2 and RE1) and in FE1.

Alternaria season indicators show high level of spatial autocorrelation: Moran's indices associated with all indicators (except for ending date) are statistically significant (p level < 0.01 for starting and peak date of the season, for spore integral and peak value; p level < 0.05 for the season length).

The Kendall τ coefficients and the Theil–Sen estimator of the time series of each seasonal indicator for *Alternaria* spores in the period 1999–2017 are given in Table 2.

Stations of PC1, FE1 and RA3 show the most relevant signals, the first two stations for spore season indicators and the latter for spore production indicators. In general, only few coefficients reaching statistical significance are present in Table 2a; nevertheless, many stations are characterized by relevant trends for spore season indicators, with advancing starting dates (in eight stations; two of them are statistically significant), delaying ending dates and lengthening of seasonal duration as a consequence (in eight stations; four of them are significant, for both indicators).

Therefore, the overall situation in Emilia-Romagna shows that major changes in *Alternaria* season are mainly related to variations of the ending date and the length of the season, for which the median of Kendall τ coefficients distribution is significantly positive (p level < 0.01). In addition, the median is significantly negative (p level < 0.05) for the starting date of the season.

An increase of 1–2 day/year for the *Alternaria* season length and a delay of about 1 day/year of the ending date of the season can be assessed considering the values of Theil–Sen estimator (Table 2b). Also the advance in the starting date (about 0.7 day/year) contributes to the lengthening of the season.

As for spore production indicators, the median of Kendall τ coefficients is negative ($-$ 0.22 for peak value, p level < 0.05, and $-$ 0.23 for spore integral, not significant). However, the amount of spores is generally decreasing in most of the stations, with a reduction of about 30–40 spore m^{-3} per year for the peak value and of more than 400 spore per year (with a maximum of 1200 spore per year) for spore integral.

4 Conclusions

The main features of *Alternaria* spore season show a relevant geographical coherence in the Emilia-Romagna territory. The *Alternaria* seasonal indicators are characterized by a high level of spatial autocorrelation for spore production indicators as well as for the onset and peak of the spore season.

The trend analysis shows a general decrease in the amount of *Alternaria* spores, but statistical significance is reached only locally. In addition, a longer duration of the sporulation period (statistically significant in almost half of the stations) is also present in the analysis, with a simultaneous advance of the starting date and delay of the ending date. The latter signal is more pronounced, being statistically significant in a larger number of stations.

The resulting net effect of the previously outlined signals related to the presence of *Alternaria* in the Emilia-Romagna territory can be summarized as longer spore seasons, with delaying ending date and advancing onset of *Alternaria* presence with smaller spore amount, both in terms of the peak values and the spore integral.

The comparison of previous results with those emerging from the few other studies focusing on long-term trends for fungal spores in the European area shows remarkable similarities. The most important ones are related to spore season indicators, for which tendencies to earlier start and peak dates as well as to a longer season are in close agreement with the Polish study (Grinn-Gofron et al. 2016), in which the time window (2004–2013) is quite similar to that of present study (1999–2017). Results in Thessaloniki (Damialis et al. 2015) specific for *Alternaria* spores, which contribute to 10% of the whole fungal spore spectrum in the study period (1987–2005), do not show any relevant trend.

As for spore production, some differences emerge, since both Polish and UK studies (Corden et al. 2003) indicate a decrease in the spore amount (both annual integral and peak value) in the coastal stations (Szczecin and Cardiff, respectively) and an increase in the inland stations (Cracow and Derby, respectively). However, negative signs for the tendencies of spore production indicators are almost ubiquitous in Emilia-Romagna stations, thus supporting the generally decreasing trends for *Alternaria* spore amount in the area, even though the territory is certainly

Table 2 (a) Kendall τ coefficient; (b) Theil–Sen estimator in each station for the different indicators of Alternaria season for the period 1999–2017

	PC1	PR2	RE1	MO1	BO1	FE1	RA3	FO1	FO2	RN1	Med
(a)											
Start date	− 0.38*	− 0.26	− 0.21	− 0.08	0.15	− 0.36*	− 0.07	− 0.33	− 0.26	− 0.14	− 0.23*
End date	0.37*	0.32	0.15	− 0.01	0.37*	0.43*	0.42*	0.06	0.26	0.11	0.29**
Season length	0.45**	0.39*	0.39*	0.03	0.18	0.55**	0.31	0.25	0.32	0.08	0.32**
Peak date	0.11	− 0.13	− 0.24	− 0.07	− 0.15	− 0.06	− 0.31	− 0.15	0.13	0.15	− 0.10
Peak value	− 0.20	− 0.27	− 0.32	− 0.03	− 0.24	− 0.26	− 0.59**	0.04	0.07	− 0.09	− 0.22*
Spore index	0.08	− 0.24	− 0.37*	− 0.23	− 0.24	− 0.19	− 0.74**	0.20	0.35	− 0.31	− 0.23
	PC1	PR2	RE1	MO1	BO1	FE1	RA3	FO1	FO2	RN1	
(b)											
Start date	− 0.83*	− 0.75	− 0.40	− 0.21	0.33	− 0.67*	− 0.14	− 1.00	− 0.67	− 0.18	
End date	1.20	0.63	0.40	0.00	1.00	1.00*	1.00*	0.17	0.67	0.50	
Season length	2.07*	1.40*	1.21*	0.00	0.50	1.67**	1.00	1.00	1.52	0.33	
Peak date	0.77	− 0.63	− 2.00	− 0.50	− 1.60	− 0.30	− 3.18	− 0.86	0.93	1.71	
Peak value	− 34.43	− 41.02	− 47.69	− 6.67	− 15.70	− 41.40	− 26.22**	3.44	2.71	− 7.26	
Spore index	176.90	− 453.99	− 1259.99*	− 394.87	− 99.31	− 388.96	− 732.20**	217.65	416.46	− 416.79	

Label "Med" introduces the median of the corresponding row. Symbols for confidence level are shown (*p level < 0.05; **p level < 0.01) characterized by a relevant agricultural vocation, which some studies associated with the atmospheric diffusion of *Alternaria* spores.

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