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First volumetric records of airborne Cladosporium and Alternaria spores in the atmosphere of Al Khor (northern Qatar): a preliminary survey

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Abstract Daily monitoring of airborne fungal spores was carried out for the first time in Al Khor city, Qatar, using a Hirst type 7-day recording volumetric spore trap, from May 2017 to May 2019. During the sampling period, the annual and monthly fluctuations, as well as intradiurnal variations of airborne fungal spore concentrations, were evaluated. *Cladosporium,* followed by *Alternaria,* were the spore types most abundant in the atmosphere of the city, with a strong interannual variability in the atmospheric concentrations being observed. The Annual Spore Integrals (ASIns) were 3334 and 1172 spore * day/m^3 (2017–2018), and 6796 and 1538 spore * day/m^3 (2018–2019) for *Cladosporium* and *Alternaria*, respectively. Total daily spore concentrations showed significantly positive correlations with mean, minimum, and maximum temperatures but significantly negative correlations with relative humidity. However, due to the scarce rainfalls' days, we did not find a statistically significant correlations between *Cladosporium* and *Alternaria* spore concentrations and this parameter. Despite this, the spore peaks were strongly related to precipitations that occurred during the previous month. In general, no significant correlations were found with wind speed but, regarding wind direction, the higher percentage of spores were collected when wind blows from the 4th quadrant (NW). According to the intradiurnal pattern, *Cladosporium* fungal spores displayed their maximum daily concentration during 8:00–10:00 h in the morning, with a second peak in the afternoon, while for *Alternaria*, the maximum peaks were observed between 08:00 and 14:00 h. Because no consistent previous aerobiological studies exist from Qatar, the aim of this study is to define the seasonality and intradiurnal behaviour of these two airborne fungal spore and the role that, in such arid scene, the meteorological parameters play on the spore concentrations.

Keywords Aeromycology · Aerobiology · Fungal spores · *Cladosporium* · *Alternaria* · Qatar

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1 Introduction

During the last decades, researchers have paid particular attention to the study of outdoor and indoor airborne fungal spores due to their impact on human

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health (Delfino et al., 1997; Burgue and Rogers 2000; Dales et al., 2000; Gioulekas et al., 2004; Behbod et al., 2015), its pathogenic effects on plants (Al-Nadabi et al., 2018; Isard et al., 2005; Skjøth et al., 2012; Tralamazza et al., 2018), as well as the mycotoxicity of specific fungal species (D'Mello et al., 1999; Perrone & Gallo, 2017; Sweeney & Dobson, 1998).

Cladosporium and *Alternaria* spores have been reported as the most prevalent aeroallergens present in the atmosphere of many cities worldwide, being considered responsible for many hospital admissions for acute severe asthma attacks in sensitised individuals, particularly children (Bush & Prochnau, 2004; Denning et al., 2014; Gabriel et al., 2016; Katotomichelakis et al., 2016). *Cladosporium* and *Alternaria* spores are also considered to be the most prevalent in many countries in the Middle East (Hasnain et al., 2016).

In the Middle East, many studies have been carried out about the content of fungal spores in the atmosphere. Some of them were based on studying the airborne mycoflora by using gravitational deposition methods, such as Petri dishes with a culture medium (Moustafa & Kamel, 1976; Muhsin & Adlan, 2012). Apparently, these sampling methods have no significant influence on the knowledge of the quantity of airborne spores in the air of a specific region (Abu-Dieyeh & Barham, 2014). However, using volumetric samplers allows uninterrupted data collection, 24 h a day, of the content of airborne particles in the atmosphere, including pollen grains and fungal spores, and helps in defining correlations between particle concentrations and meteorological parameters, such as temperatures, humidity, rainfalls, and wind speed and direction. Additionally, volumetric samplers can also ascertain the concentrations of pollen or fungal spores present in the air at a particular time of the day.

Fluctuations of airborne mycoflora using volumetric methods have been previously conducted in several cities of Saudi Arabia (Hasnain et al., 1998, 2005), Kuwait (Davies, 1969; Halwagy 1994; Khan et al., 1999), Palestine (Waisel et al., 1997), and Jordan (Abu-Dieyeh et al. 2010; Abu-Dieyeh and Barham, 2014), where *Cladosporium* and *Alternaria* were cited among the commonest and most abundant fungal spores outdoors. In Qatar, two aeromycological studies have been previously conducted, from March 1997 to March 1998 (Al-Subai, 2002), and from April 2015 to March 2016 (Fayad, 2016) using gravimetric methodology and agar Petri dishes and both showed the predominance of *Cladosporium* and *Alternaria* in Doha city.

This paper aims to present the results of a 2-year aerobiological study carried out in the atmosphere of the city of Al Khor (northern Qatar), describing the concentrations of the two spore types with the highest prevalence in the region, *Alternaria* and *Cladosporium*, using for the first-time volumetric spore traps. Seasonal behaviour, intradiurnal variations, and a correlation study between daily spore concentrations and the main meteorological parameters are displayed.

2 Material and methods

2.1 Study area

Qatar is a peninsula with an area of more than 11,347 km^2 and a coastline of 900 km in length, and is situated between latitude 24°27' and 26°10′ and longitude 50°45′ and 51°40′. The Qatar Peninsula is connected to Saudi Arabia in the south and bordered by a semi-enclosed sea, the Persian Gulf. Geographically, it is a flat, rocky, and arid desert, dunes being the predominant feature in the south. Soils are characterised by their hyper-salinity.

As a subtropical desert, Qatar has long and hot summers. Total annual rainfall is low, about 81 mm as average, and the mean maximum temperature is 31 °C although the absolute maximum temperature can be beyond 47 °C in summer. The humidity is exceptionally high, often reaching 80% in summer (Brook et al., 2006).

Natural vegetation in Qatar is determined by seasonal, erratic, and variable rainfalls and mainly dominated by shrubs and a limited number of trees species (Batanouny, 1981). Al Khor (25.6804° N, 51.4969° E), the selected city for this study, is a coastal city located 50 km, northern side of the capital Doha. Soils usually support more moisture and organic matter than other desert parts due to the presence of mangroves and halophytic vegetation in the surrounding places.

2.2 Monitoring of atmospheric fungal spores

The aerobiology study was conducted by using a Hirst type 7-days recording volumetric spore trap (Hirst, 1952) placed on the roof of the Al Khor Hospital, Al Khor province, at 20 m above ground level. The spore trap was adjusted to aspirate a continuous flow of 10 l/min, silicone fluid being used as adhesive substance. Aerobiological sampling continued uninterrupted through the 2-year study from 8 May 2017 to 7 May 2019. Slides were mounted using glycerine jelly as mounting mean and *Alternaria* and *Cladosporium* spores counted using a light microscope Olympus BX50, at a magnification of 400×, along two full lengthwise sweeps per slide (24 h), according to the methodology proposed by the Spanish Aerobiology Network, the REA, and the European Aeroallergen Society (EAS) (Galán et al., 2007, 2014).

The data used in the figures and tables correspond to the daily mean spore concentrations expressed as the number of spores per cubic meter of air (spores/m^3). The Annual Spore Integral (ASIn) was calculated as the sum of the daily mean concentrations of fungal spores over the whole period considered (spore * day/m^3), following the recommended terminology for aerobiological studies (Galán et al. 2017). In order to establish the seasonality of both fungal spore types, the main spore season (MSS) was determined by taking 90% of the annual period, following the method of Nilsson and Person (1981), assuming the beginning and the end of MSS when a 5% and a 95% of the annual spore sum, respectively, are reached.

2.3 Intradiurnal variation

The intradiurnal airborne fungal spore concentration behaviour was determined, taking the days when daily mean spore concentrations equalised or exceeded the mean of the main spore season (taking only rain-free days) (Galán et al., 1991). Data of relative concentrations of fungal spores sampled every 2 h were collected, with the time corresponding to official Qatar time (UT + 3 h). For that, daily counts were made hour by hour, with the aid of a grid attached to the back of the slide. The intradiurnal distribution index (IDI) evaluates the hourly spore distribution, allowing accurate numerical comparison of the years of study. For IDI calculation, the methodology proposed by Trigo et al. (1997) was followed.

2.4 Meteorological data

Meteorological parameters such as maximum, minimum, and mean temperatures (T_{max}, T_{min}, T_{mean}), expressed as °C, relative humidity (RH, %), rainfall (PP, mm), and wind speed (WS, km/h) were measured. Weather data were obtained by an automatic weather station that collect data every 10 min. Except in the case of rainfalls, in which daily cumulative values were used, daily means of the dataset of every day were used in the statistical analysis. To study the influence of wind direction on the quantities of spores collected, we have used the percentages of winds per quadrants.

In the case of wind direction, we have taken into account the percentages of spores collected when wind blows from the different quadrants: NE (1st Q), SE (2nd Q), SW (3rd Q), and NW (4th Q).

The meteorological data for the 2 years of study were supplied by an automatic weather station (Davis Vantage Pro2) located in the immediate neighbourhood of the spore trap.

2.5 Statistical analysis

Data analysis was performed using Statistical Package for Social Sciences (SPSS Chicago IL, USA) for windows, version 21. The level of statistical significance was set at $p \leq 0.05$. Due the data, in general, did not followed a normal distribution, especially the spore series, the Spearman's rank correlation was applied to examine the effect of selected daily meteorological parameters on daily mean spore concentration.

3 Results

3.1 Meteorological variables

The ranges for the monthly averages of the meteorological parameters, recorded during the studied period in Al Khor city, were the followings: T_{mean} 18.5–39 °C, T_{max} 22.9–44.2 °C, and T_{min}14.9–38.9 °C. The coldest months were December, January, and February and, the warmest, June, July, and August. The total annual rainfall regimes were very different in the two periods studied, since only 19.2 mm of precipitation was recorded in the period 2017–2018, compared to the 108.1 mm recorded in 2018–2019. There was also a difference in the number of rainy days, being 4 and 14 days, respectively. The highest monthly accumulated precipitation (PP) was 81.6 mm, recorded in October 2018, and the highest total rainy days was six days in April 2019. Relative humidity monthly average oscillated between 26 and 87% (Table 1).

3.2 Spore seasonal behaviour

Cladosporium, followed by *Alternaria*, were the spore types that reached the highest values in the city of Al Khor during the study period, *Cladosporium* representing 56.70 and 75.14% of the annual total counts for the periods 2017/2018 and 2018/2019, respectively, while the percentages reached by Alternaria were 19.93 and 17% for the same periods. The Annual Spore Integrals (ASIns) were 3334 and 1172 spore * day/m^3 (period 2017–2018), 6796 and 1538 spore * day/m^3 (period 2018–2019), and 10,130 and 2710 spores/day m^3 (during the overall studied period), for *Cladosporium* and *Alternaria*, respectively. The annual contribution of each spore type to the atmosphere of Al Khor city varied from year to year. The Annual Spore Integrals (ASIns) recorded for *Cladosporium* and *Alternaria* showed different values for the two periods studied. In both cases, the total spores collected were higher for the period 2018–2019, especially *Cladosporium* spores, which values significantly exceeded (doubled) the value of the previous period (Fig. 1).

The spores of the *Cladosporium* and *Alternaria* remained regularly present in the atmosphere of the city of Al Khor throughout the year, reaching several peaks recorded on monthly basis, and were significantly different for the two sampling periods. The highest monthly values were recorded in November 2018 for *Cladosporium* spores and in April 2019 for *Alternaria* spores (Fig. 2).

Table 1 Monthly values of the meteorological parameters registered in Al Khor (May 2017–May 2019)

Month	T^a mean (°C)	T^a max (°C)	T^a min (°C)	Rainfall (mm)	Days of rain	Humidity (%)
May 2017	35.8	41.9	30.9	0.2	1	36
June 2017	36.6	43.1	31.3	0	0	26
July 2017	36.6	42.4	33.2	0	0	60
August 2017	37.1	42.3	33.7	0	0	65
September 2017	34.5	39	31.6	0	0	68
October 2017	31.2	36.4	27.1	0	0	59
November 2017	26.1	29.7	23.2	0	0	59
December 2017	20.1	24.8	16.4	0.2	1	63
January 2018	18.5	23.2	14.9	0	0	61
February 2018	21.8	25.9	19.2	8	1	72
March 2018	24.9	29.8	21.3	0	0	55
April 2018	27.3	32.2	24.4	0.8	1	52
May 2018	33.3	37.6	29.6	0	0	33
June 2018	37.2	44.2	32.6	0	0	34
July 2018	39	39.4	38.9	0	0	35
August 2018	35.4	40.5	32.1	0	0	65
September 2018	35	40.5	32.3	0	0	68
October 2018	30.9	34.4	27.8	81.6	3	65
November 2018	27.8	30.7	25.6	11.6	1	67
December 2018	19.8	23.8	16.8	1.2	1	74
January 19	21.8	25.3	19.6	0	0	87
February 2019	19.3	22.9	16.6	0.2	1	56
March 2019	21.1	25.2	18.1	0.8	2	56
April 2019	26.7	26.7	23.1	12.4	6	58

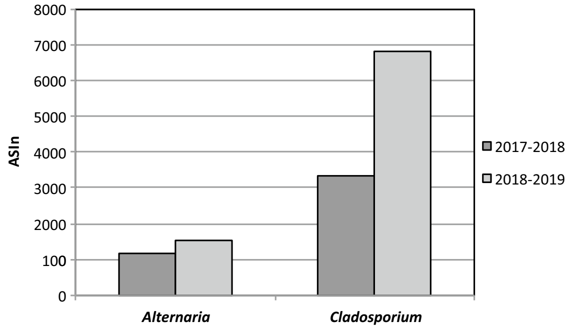


Fig. 1 The total annual count of *Alternaria* and *Cladosporium* spore types in Al Khor (May 2017 to May 2019). ASIn: Annual Spore Integrals

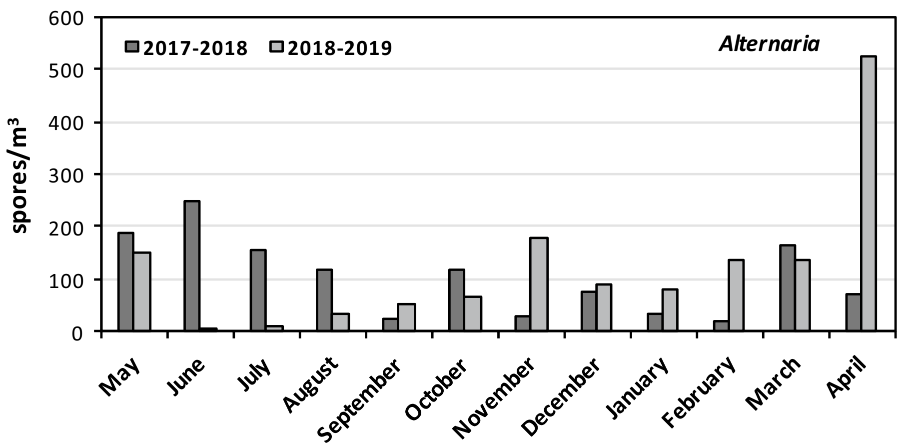
Both fungal spores showed distinctive patterns in the 2 years of the study with significant differences in regard to the date on which the spore concentration peaked. In the first sampling year, the highest concentrations of *Cladosporium* fungal spores were recorded in March, with a maximum daily peak of 485 Spores/m^3. However, during the second sampling year, the highest values occurred in November, with a maximum daily peak of 1003 spores/m^3. In regard to *Alternaria*, the highest levels were reached in June for the period 2017–2018 (52 spores/m^3), and in April for 2018–2019 (125 spores/m^3) (Fig. 3, Table 2).

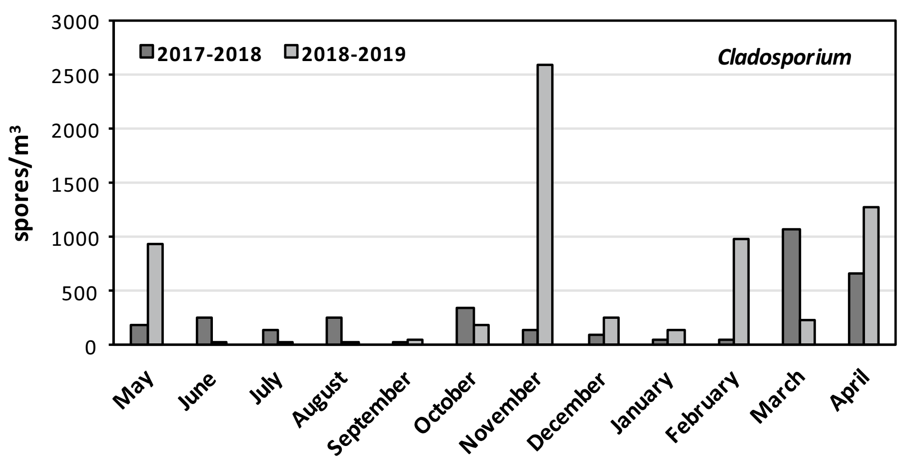
The presence of several peaks during the years studied made it practically impossible to establish the main spore season since the calculations led us to obtain long periods of multiple spore peaks that last almost the entire annum (Table 2).

3.3 Intradiurnal variation

The intradiurnal variations of *Cladosporium* and *Alternaria* spores showed a similar pattern, with the maximum peaks being detected mainly during the

Fig. 2 Monthly spore distribution of *Cladosporium* and *Alternaria* spores in the aerobiological station of Al Khor (May 2017 to May 2019)





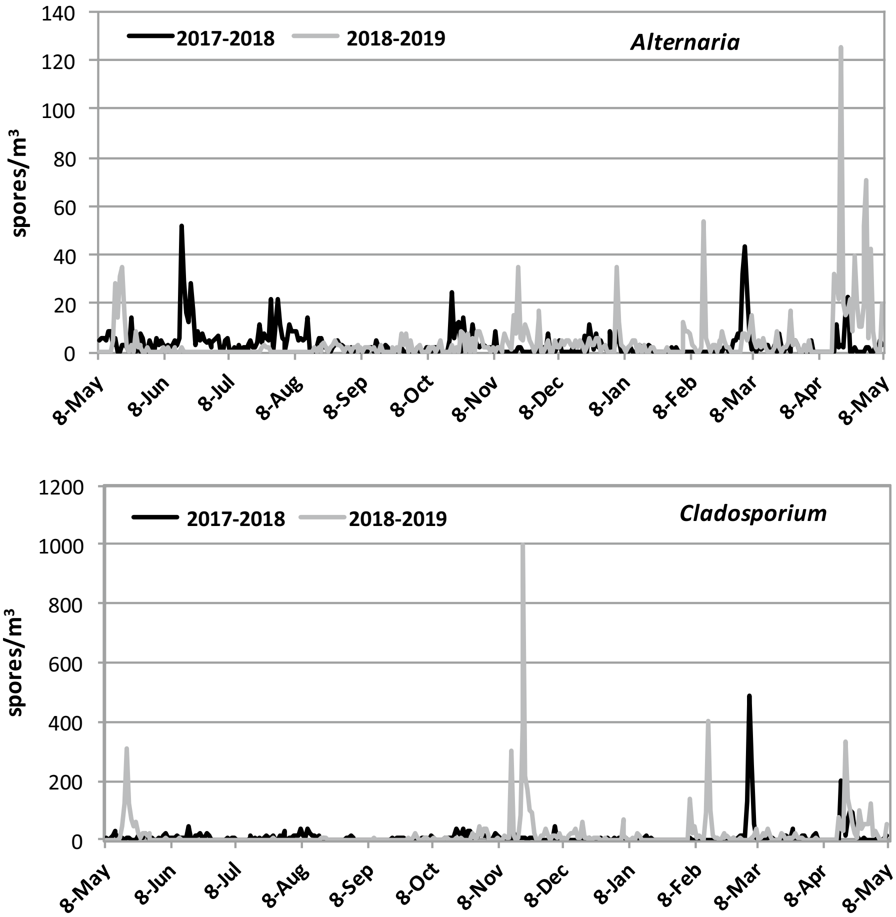


Fig. 3 Seasonal variation of *Cladosporium* and *Alternaria* airborne spores in Al Khor for the sampling years (May 2017 to May 2019)

Table 2 Main spore season (MSS) parameters for *Alternaria* and *Cladosporium* registered in Al Khor during the period May 2017–May 2019

Year	2017–2018		2018–2019	
Fungal type	*Alternaria*	*Cladosporium*	*Alternaria*	*Cladosporium*
Total MSS (90%)	1056	3035	1418	6323
Start MSS	19/05/2017	25/05/2017	18/05/2018	18/05/2018
End MSS	17/04/2018	19/04/2018	01/05/2019	28/04/2019
Duration (days)	333	329	348	345
Peak date	15/06/2017	03/03/2017	18/04/2019	19/11/2018
Peak value (spores/m^3)	52	485	125	1003
Annual total	1172	3334	1538	6796

morning from 8:00 to 12:00 h. The concentrations remained between 6 and 12% of the daily total until midnight, decreasing later and reaching the lowest concentrations between 04.00 and 06:00. The analysis of the intradiurnal distribution from 1 year to another, as well as the concentration peaks, presented scarce differences in the bi-hourly concentration behaviour. *Cladosporium* spores reached its highest level at 18:00–20:00 h during the first year, representing 13.10% of the total daily spore counts, and at 8:00–10:00 h in the second year, with 10.92% of the total daily spore counts and an IDI value of 0.07. A similar intradiurnal pattern was observed for *Alternaria* spores, with peaks (IDI values) of 15.78% (0.13) and 14.11% (0.11); however, the peaks of *Alternaria* spores occurred at different times of the day, 10:00–12:00 h in the year 2017–2018 and 08:00–10:00 in the year 2018–2019 (Fig. 4).

3.4 Correlation between fungal spores and meteorological parameters

To study the relationship between spore concentrations and meteorological parameters, correlation analysis was performed between the variables during the entire study period and the two separate annual periods. In all cases, the entire main spore season (MSS), as well as the pre-peak and post-peak periods, has been calculated separately.

Regarding temperatures (T_{min}, T_{max}, and T_{mean}), positive and statistically significant correlation has been found, both for *Cladosporium* and *Alternaria*, for the main pollination season, and the pre-peak period with $p \leq 0.01$ for most of the values. Moreover, for the entire study, the correlation coefficients were always negative between temperatures and the post-peak periods regardless of the degree of statistical significance.

Regarding rainfall, a significantly negative correlation was observed for *Cladosporium* with the pre-peak for the study year 2018–2019 ($p \leq 0.01$), and the post-peak for the study year 2018–2019 and the entire study period ($p \leq 0.05$). In contrast, *Alternaria* did not correlate significantly with the rainfall parameter. The number of rainy days and their distribution have also been examined. However, the low number of days with precipitation has not allowed correlations to be made.

When we analysed the correlation between *Cladosporium and Alternaria* spore concentrations and relative humidity, we observed a statistically significant negative correlation with the daily average spore concentrations for the 2018–2019 period for *Cladosporium* (MSS, pre- and post-peaks) and *Alternaria* (MSS, pre-peaks) with $p \leq 0.01$. Also, there was a negative correlation for the entire study period for *Cladosporium* and *Alternaria* (MSS and the pre-peak) with $p \leq 0.05$.

Finally, correlations were not statistically significant between spore concentrations and wind speed,

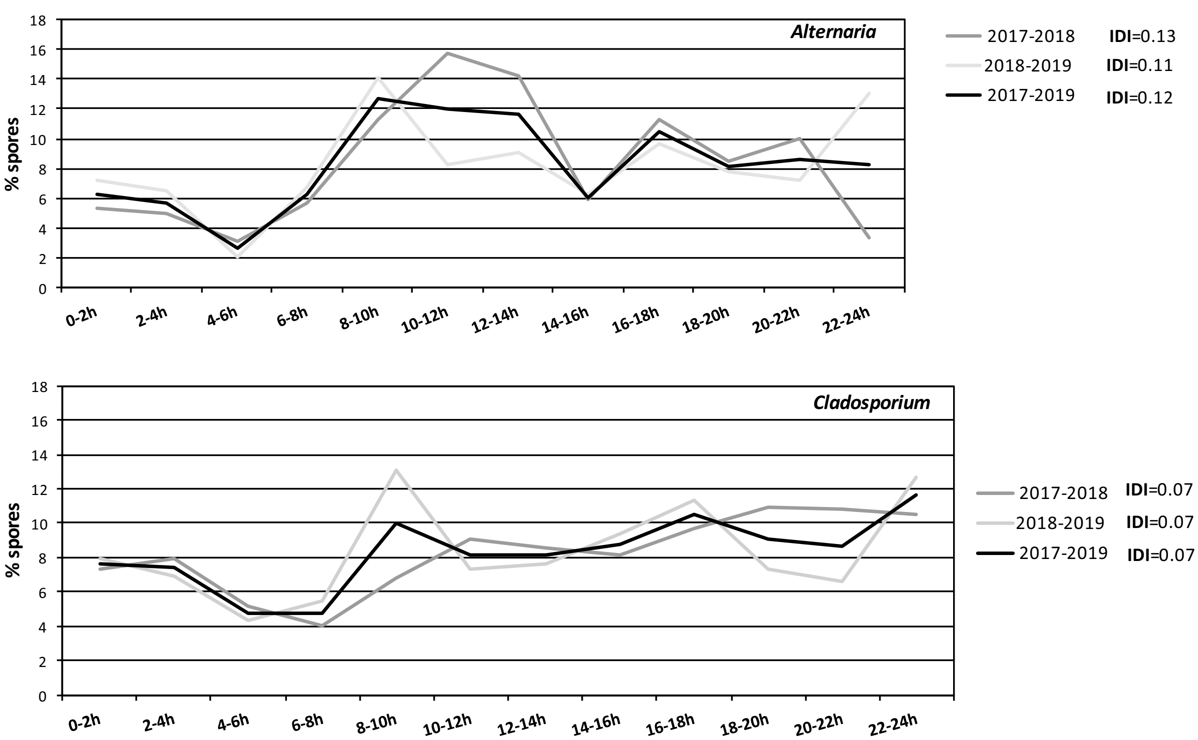


Fig. 4 Intradiurnal distribution pattern of *Cladosporium* and *Alternaria* concentration in Al Khor during the period of May 2017–May 2019. IDI: intradiurnal distribution index

with the sole exception of the *Alternaria* MSS during the study year 2018–2019, where there was a positive correlation between the two variables ($p \leq 0.05$). Regarding wind direction, by quadrants, 56.06% of total spores in the case of *Alternaria* and 65.64% in the case of *Cladosporium* were captured with wind blowing from the 4th quadrant (NW) (Fig. 5).

4 Discussion

Spores from *Cladosporium* and *Alternaria*, together with Aspergillaceae, are widely studied spore types from aerobiological and allergological perspectives owing to their abundance in the indoors and outdoors environment and their effects on human health (Burge & Rogers, 2000; Delfino et al., 1997). Its presence in the air has been detected practically throughout the world, such as in Europe (Grinn-Gofroń et al., 2019; Skjøth et al., 2016), Africa (Bardei et al., 2017; Berman & Hons, 2013), India (Reddy et al., 2015) America (Henríquez et al., 2001; Mallo et al., 2011; Martínez Blanco et al., 2016; Patel et al., 2018), or Australia (Mitakakis et al., 1997; Tham et al., 2019).

As reported in other countries of Middle East (Goronfolah, 2016; Hasnain et al., 2004, 2012; Ozdemir, 2015), *Cladosporium* and *Alternaria* were the most abundant spore types in the atmosphere of Al Khor city, being presented in the air throughout the year in different concentrations. Their constant presence in the atmosphere can be attributed to be very abundant fungi, with a high competitive capacity in the case of *Alternaria* and a high capacity of spore production in the case of *Cladosporium* what can be increased in high-temperatures conditions (Damialis et al., 2015). Additionally, some authors consider that the dark colour of *Alternaria* and *Cladosporium* conidia make them more resistant to solar radiation and physicochemical agents, and the spore survival exceeds those of the hyaline ones (Al-Subai, 2002). However, morphological features play another role. For *Cladosporium,* the small size, thin exine, and smooth wall of the spores would favour their dissemination and buoyancy (Asan et al., 2004; Shaheen, 1992). On the other hand, *Alternaria* conidia are a dry spore type and, besides having a dark colour, they have a thick wall that allows them to survive for a long time (Al-Subai, 2002).

In terms of seasonal distribution, several authors have reported two periods of high airborne spore concentration annually in different countries, such as Kuwait City, Kuwait (Halwagy, 1994); Ismailia, Egypt (Wahid et al., 1996); or Seville, Spain (Morales et al., 2006). In southern Spain, the occurrence of *Cladosporium* and *Alternaria* spores was registered in spring (April–June) and late summer to early autumn (September–October) (Recio et al., 2012; Aira et al., 2012). However, the highest concentrations for the same spore type were found from July to September in north-western Spain and Italy (De Linares et al., 2010; Rizzi-Longo et al., 2009) and in July and August in Central and Western Europe (Kasprzyk et al., 2004; Mikaliūnaité et al., 2009; Sadyś et al., 2016). This finding leads to the belief that there is no unique pattern for the seasonal presence of *Cladosporium* spores in the atmosphere, and it probably depends on the environmental conditions prevailing in the geographic area in question (Picornell et al., 2022). In Doha, Qatar, Al-Subai (2002) and Fayad (2016) detected two peaks for *Cladosporium* spores using a different methodology, the first one in April–May and, the second, in January–February, while for *Alternaria* the peak was detected in July, which was different from what we detected in Al Khor city for both spore types.

In Qatar, due to the fluctuations and the multiple peaks detected, it was difficult to define a clear

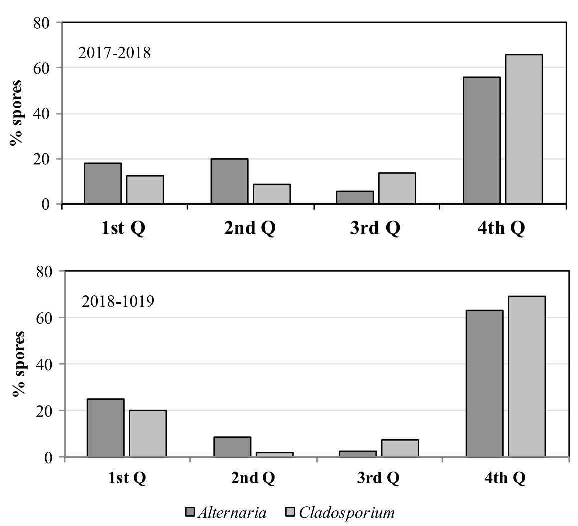


Fig. 5 Percentage of spores collected when winds flowing from the different quadrants. 1st Q (NE), 2nd Q (SE), 3rd Q (SW), 4th Q (NW)

pattern of seasonality for both *Alternaria* and *Cladosporium* airborne spores (Fig. 3). These fluctuations explain why trends in *Cladosporium* and *Alternaria* spore behaviour were not established in terms of MSS (start, end, and peak dates) or duration, as the spore season covers the whole year practically (Table 2). Additionally, the annual integrals were quite different, reaching higher values during the period 2018–2019 for both spore types, but especially for *Cladosporium* (Fig. 1). The interannual differences probably were related to meteorological conditions, which also affected plant growth, as airborne spores can be considered a contribution from the vegetation more than from the soil itself (Al-Subai, 2002).

Regarding meteorological parameters, significant associations were found for both fungal spore types between daily mean concentrations and air temperatures. The correlations were positive with the mean, maximum, and minimum temperatures during the pre-peak period, but negative during post-peak (Table 3). The reason for this observation is that during the pre-peak period, spore concentrations increase as temperatures rise, while during the post-peak, spore concentrations decrease as temperatures continue rising. The correlations for precipitation and relative humidity were, in general, negative or non-significant. We observed humidity has a negative correlation with spore concentrations in the period 2018–2019. The absence of significant correlations during the study period 2017–2018 was probably due to the scarcely registered precipitation, with a cumulative total of only 9.2 mm and 4 days of rainfall, that gave insufficient data to attain good correlations. In contrast, the period 2018–2019 was significantly rainier, with a total of 108.1 mm and 14 days with rainfalls (Table 1).

The previous studies suggested that temperatures and relative humidity were the meteorological parameters displaying strongest correlations with the spore concentrations of *Cladosporium* and *Alternaria*, i.e. being positively and negatively correlated with temperatures and relative humidity respectively, the last parameter not favouring particles buoyancy (Mitakakis et al., 1997; Oliveira et al., 2009; Recio et al., 2012; O'Connor et al., 2014; Sadyś et al., 2016; Ianovici, 2016; Almeida et al., 2018). Sanchez-Reyes et al. (2009) also found similar behaviour in the case of *Alternaria*. However, correlations were positive in

Table 3 Spearman's correlation coefficient between the daily average of Alternaria and Cladosporium airborne spore concentrations and meteorological parameters (maximum, minimum and average temperature; average relative humidity; rainfall, and average wind speed)

	2017–2018			2018–2019			2017–2019		
	MSS	Pre-peak	Post-peak	MSS	Pre-peak	Post-peak	MSS	Pre-peak	Post-peak
	Cladosporium								
T_{max}	0.212*	0.274**	−0.180	0.277**	0.400**	0.189	0.144*	0.227*	−0.119*
T_{min}	0.127	0.150*	−0.394**	0.317**	0.336**	0.179	0.275**	0.240*	−0.135*
T_{mean}	0.223*	0.275**	−0.127	0.296**	0.337**	0.179	0.133*	0.228*	0.113
PP	0.015	0.050	−0.096	0.021	−0.323**	−0.234*	−0.195*	0.099	−0.112
WS	−0.060	−0.042	−0.080	0.118	0.144	−0.027	−0.046	0.041	0.114
RH	−0.027	−0.103	−0.163	−0.334**	−0.430**	−0.434**	−0.183*	−0.169*	−0.130
	Alternaria								
T_{max}	0.292**	0.299**	0.079	0.275**	0.399**	0.201	0.243**	0.266**	−0.182*
T_{min}	0.269**	0.319**	0.176	0.326**	0.392**	0.161	0.232**	0.219*	−0.245**
T_{mean}	0.312**	0.320**	0.061	0.299**	0.388**	0.104	0.251**	0.279**	−0.208*
PP	0.015	0.017	0.020	−0.083	0.067	0.145	−0.049	0.079	0.141
WS	0.024	0.017	0.003	0.177*	0.138	−0.228	0.085	0.092	0.095
RH	−0.096	−0.073	−0.157	−0.326**	−0.391**	0.303	−0.168**	−0.215*	−0.085

*$p \leq 0.05$, **$p \leq 0.01$

T_{max}: maximum temperature, T_{min}: minimum temperature, T_{mean}: average temperature, *PP* rainfall, *WS* average wind speed, *RH* average relative humidity the case of rainfall and relative humidity for *Cladosporium*. Nevertheless, we are truly convinced that, in Al Kjor, probably due to its desert climate, what causes the spore concentrations to increase are the rains mainly. We have observed how rainfalls have a double effect on spore concentrations. Rainfalls produce atmospheric washout, forcing particles to precipitate. On the contrary, after a few days, the fallen rain favours the development of the mycelia and spore formation, increasing air concentrations. This effect can be observed if we pay attention to the months in which the annual peaks and rainfalls occur. These peaks took place after rainfall events recorded in Al Khor (Fig. 3). Even when precipitations were scarce (Table 1), they can be enough to moisten the soil and cause perennial halophytic vegetation growth, which is considered the main contributing substrates to the increased mould growth and, therefore, fungal spore concentration in the environment (Al-Subai, 2002; O'Brien et al., 2005). Obviously, other factors such as temperatures, humidity, and wind direction can also influence, despite the fact that the correlations often do not show this effect, due to the null or very low values, either in the rainfall itself or in the pollen concentrations.

Regarding wind speed, we practically did not find significant correlations, only a positive relationship in the case of the MSS of *Alternaria* during the period 2018–2019 ($p \leq 0.05$). On the other hand, there was inconsistency in the relationship between wind speed and spore concentrations. Wind speed is a controversial confounder in aerobiology since wind velocity can enhance microorganism dispersion in the atmosphere by detaching them from different surfaces (Jones and Harrison, 2004). Rather, wind speed can help to dilute fungal spore concentrations in the air (Sabariego et al., 2000; Stennett and Beggs, 2004). Probably, the combination of both effects, together with other environmental parameters, and the different sampling methods, determine its influence. In Doha, Qatar, wind speed was associated with higher fungal colony counts (Al-Subai, 2002; Fayad, 2016). However, it is difficult to study the influence of the different parameters on fungal spore concentrations, separately, because fungi respond to the combination of a series of environmental and physiological conditions. With respect to wind direction, the fact that most of the spores were collected when wind blowing from the fourth quadrant, is probably due to that it is from where the prevailing winds blow in Al Khor, having less influence, on the atmospheric spore content, those from the other quadrants (Windy Weather World, Inc., 2021).

Concerning intradiurnal distribution, both spore types, *Cladosporium* and *Alternaria,* showed similar patterns with hardly recognised differences between the 2 years of study. Our results were partially different from those identified in previous studies conducted in Doha, Qatar, where the highest concentrations were registered towards midday, and the lowest levels were at midnight (Al-Subai, 2002; Fayad, 2016). These differences could be due to the different capture methodology used by the authors: exposing Petri dishes with culture medium at intervals of 6 h on alternative days, which does not allow to stablish a very accuracy intradiurnal behaviour.

The maximum peaks detected in different countries have shown divergences in behaviour. For example, Rodríguez-Rajo et al. (2005) in the northwest of Spain recorded the highest spore concentrations in the afternoon, for both *Alternaria* and *Cladosporium*. Bardei et al. (2017) described a very stable intradiurnal behaviour for *Alternaria* spores in the atmosphere of Tetouan, Morocco, with maximum concentrations at midday while *Cladosporium* presented an almost flat curve with little peaks at different hours of the day, depending on the year. Grinn-Gofrom and Strzelczak (2009) detected the maximum abundance of *Cladosporium* in the air of Szczecin (Poland) between 12:00 and 17:00, while *Alternaria* did not show any diurnal pattern. The variations observed in the different localities may be due to the influence of meteorological parameters, as well as land use. So, Grinn-Gofroń et al. (2018) studied the influence of the meteorological parameters in the intradiurnal distribution, concluding that temperatures, relative humidity, wind speed and precipitations, in that order of importance, significantly influenced the composition of the atmospheric spores content in both hourly and daily periods of time. On the other hand, Sadyś et al. (2015) also studied the influence of the distance to the spore sources, wind speed, and trajectories, pointing out that for the *Alternaria* peaks detected in Worcester (England) between 03.00 and 08:00, probably, the real time of release took place before, between 10:00 and 16:00, being the result of horizontal transport. All these variables make difficult to explain the spore patterns. Sometimes peaks do not respond to the prevailing conditions in the sampling point but in that of the production sources.

The intradiurnal distribution index was not very high, indicating unremarkable concentration peaks along the day. However, the values of the IDI were slightly higher in *Alternaria,* which can be considered as a moderate value (Trigo et al., 1997).

The increased prevalence of allergic diseases caused by indoors and outdoors airborne spores of *Alternaria* and *Cladosporium* mandated numerous works throughout the world, including the Middle East, which results differ depending on the population and the geographical characteristics of the studied country (Goronfolah, 2016). In Qatar, a cohort involved 3283 children showed a prevalence of 30.5 and 19.8% for allergic rhinitis and asthma, respectively (Janahi et al., 2006). Also, among 569 patients with respiratory diseases and positive skin prick testing, response for *Cladosporium* was 2.3% and for *Alternaria* was 5.6% (Sattar et al., 2003).

The current study shows the different seasonal spore distribution observed between the two sampling periods, which can be attributed to the different meteorological conditions prevailing during the years of study, especially regarding rainfalls, and so prevent the consideration of a stable behaviour for the fungal spore types studied in Al Khor.

5 Conclusions

Cladosporium and *Alternaria* spores are present in the atmosphere of Al Khor practically throughout the year. However, they registered quite different values of the annual integrals, as well as rather irregular seasonal distribution in the 2 years of study, with peaks that occurred in different seasons of the year. It would be the periods of rain that determine the appearance of the maximum spore peaks a few days after the precipitations. Temperatures also correlate positively with increases in spore levels. The highest concentrations were reached in the morning and the evening, while the lowest levels were detected at dawn.

Longer study periods are necessary for establishing behaviour patterns and a better understanding of the fungal spore abundance and the associated factors, which can help in planning the management of fungal spore allergies by local inhabitants and physicians.

This study provided essential baseline data to fill the existing gap about one of the principal inhalant biological particles contributing to allergic respiratory diseases through understanding the seasonal and intradiurnal behaviour of fungal spore in the atmosphere of the Gulf region.

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Availability of data and materials The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Code availability (software application or custom code) Not applicable.

Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

Ethics approval and consent to participate The study was approved by the Ethical Committee of the Hamad Medical Corporation, Doha, Qatar (MRC#16150/16). All clinical investigations were conducted according to the principles expressed in the 1964 Declaration of Helsinki and its recent amendments.

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