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A six-Year Airborne Fungal Spore Calendar for a City in the Sonoran Desert, Mexico: Implications for Human Health

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Abstract: fungal spores' calendars for Mexico are inexistent. This research represents the first fungal spores' concentration data in the atmosphere of Hermosillo, Mexico, a city in the Sonoran Desert with high rates of allergies and public health problem. We used standardized sampling techniques frequently used by aerobiologists, including a Burkard spore trap to monitor airborne fungal spores daily for 2016-2019 and 2022-2023. Results are expressed as daily fungal spores' concentration in air (spores/m^3 air). The most common fungal outdoor spores corresponded to *Cladosporium* (44%), Ascospora (17%), Smut (14%), *Alternaria* (12%) and Diatrypaceae (7%) of the total 6 years data. High minimum temperatures produce an increasing of most important spores in air (*Cladosporium* and *Alternaria*), whereas precipitation increase Ascospores concentrations. The most important peak of Fungal spores' concentration in air is recorded during summer-fall in all cases. Airborne fungal spores at Hermosillo had a greater impact on human health. This data will be of great help for prevention diagnostic and treatment of seasonally allergies in population and for agricultural sector that have problems with some pathogens of their crops caused by fungus.

Keywords: fungal spores; allergies; spores calendar; Sonora; climate change; human health

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1. Introduction

Aerobiological studies around the world are focused on airborne pollen concentration [1–3]. Few studies explore fungal spores in the air due to difficult identification and the higher count effort given their extremely high concentrations compared to pollen [4]. Nevertheless, in the last two decades, the incidence of fungal diseases in humans has rapidly increased worldwide, [5]. In this regard, airborne fungal spores are now considered one of the leading causes of respiratory allergies around the world, as their concentration currently exceeds pollen concentration in the atmosphere by 2–3 orders of magnitude [6].

The prevalence of respiratory allergy due to fungi is not fully known. However, this allergy type is estimated to affect 20–30% of sensitive subjects (Immunoglobulin E-specific antigens (allergens) on airborne fungal spores induce type I hypersensitivity (allergic) respiratory reactions in sensitized atopic subjects, causing rhinitis and/or asthma). Fungal spores are reproductive structures produced and dispersed in large amounts and are a major contributor to the spectrum of airborne allergens [7]. Fungal sensitization is associated with increased asthma severity symptoms, morbidity, and decreased pulmonary function. Severe asthma with fungal sensitization has been described as a specific phenotype in patients with severe asthma [9]. Aerobiological studies estimate that 3–10% of the world's population has some sensitivity to airborne fungal spores [10]. The World Health Organization (WHO) indicates that asthma affected 262 million people and caused 461 thousand dead worldwide in 2019 [11].

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Cladosporium and *Alternaria* are the most common outdoor fungal spores, which show seasonal variation, peaking during the rainy seasons [1,6,7]. The outdoor concentration of fungal species from these genera has been associated with the exacerbation of asthma epidemics [5]. In Mexico, there is no published fungal-pollen calendar, although some research includes fungal spores' sensitization for Mexico City [8]. For northern Mexico, some information about airborne fungal spores have been published [1,3,12]. In northern Mexico most common airborne fungal spores belong to taxa *Cladosporium*, *Alternaria, Aspergillus* and Basidiospores, all positive associated to precipitation and relative humidity. For central Mexico, a sensitization test performed on children from 2-18 years old [8] revealed that 7565 out of the 8794 patients displayed sensitization to ≥1 fungus taxon, being *Aspergillus*, with a rate of 16.8%, the most common taxon.

The study of fungal spore phenology has further implications in human health for subtropical arid lands, where high temperatures and high humidity, favourable conditions for fungal spread, occur during the summer. For instance, Sonora, clinical records from a public hospital at Hermosillo reported that 36 out of 279 people tested for aeroallergens tested positive to fungal spores (Basidiospores 19%; Smuts 16%, *Alternaria* 9%; Ascomycetes 9%) [1].

Airborne spores are also relevant for agriculture as they cause epiphytotic events [13]. In this regard, a fungal spore calendar is a convenient tool for both public health officials and farmers, providing summarized information on taxonomic composition and daily concentrations of airborne fungal spores, as well as their seasonal variation. The effects of weather conditions on fungal spore concentrations are also topic of interest. The estimation of weather effects helps in the construction of prediction models of the spore concentrations in the atmosphere [14]. Moreover, climate change will increase fungal spore production and their release to the atmosphere, accelerating the expansion of invasive plants along with their fungal parasites. This facilitated expansion of may be associated with introduction of new aeroallergens to these territories [6].

Few countries have fungal spore calendars to assess air quality [7,13,14]. We report here the six-years (2016-2017-2018-2019-2022-2023) fungal spores' concentration to build the first fungal spore calendar for a urban area in the Sonoran Desert, where human population has a high sensibilization and high rates of asthma and allergy incidence due to fungal spores. This calendar will assist the prevention, diagnostic and treatment of both seasonal allergies in human population and epiphytotic events in crops.

2. Materials and Methods

2.1. Study Region

This research was developed in Hermosillo, capital city of the Mexican state of Sonora, at the center of the Sonoran Desert (29°05.02′N, 110°57.56′W) (Figure 1). The geomorphology of this area consists in valleys, hills and mountains aligned in NNW-SSE direction, with elevations <700 m. The Sonoran Desert harbours a high biodiversity [15]. Our aerobiological monitoring station is in the northern part of the city, at the roof top of a three-story building at the Sonora State University (Figure 1). Climate in Hermosillo is a transition of two types [16]: very dry and very warm BW(h'), and very dry and semi-warm (BWh) (*sensu* CITA A KÖPPEN). Mean annual temperature equals 25.1°C. December is the coldest month (mean monthly temperature 16.8°C), and July is the warmest month (mean monthly temperature 32.6°C). Mean annual precipitation is 393 mm, with a summer rains regime due to the North American monsoon system. Vegetation and land-use types in the Municipality of Hermosillo are desert scrub (74.75%), agriculture (14.64 %), forest (0.06%), grassland (3.03%) and others (7.52%) [16]. Hermosillo is mostly in flat terrain flanked by a mountain range to the north and east (Figure 1 left). This mountain range wind direction and, consequently, the behaviour of airborne particles. In this regard, there are two dominant winds, north-eastward from the Sonora coast (SW) and westward from the Sierra Madre Occidental (W). Dominant winds from SW have an average annual speed of 1.2 m s^{-1}, with mean annual calms of 83%.

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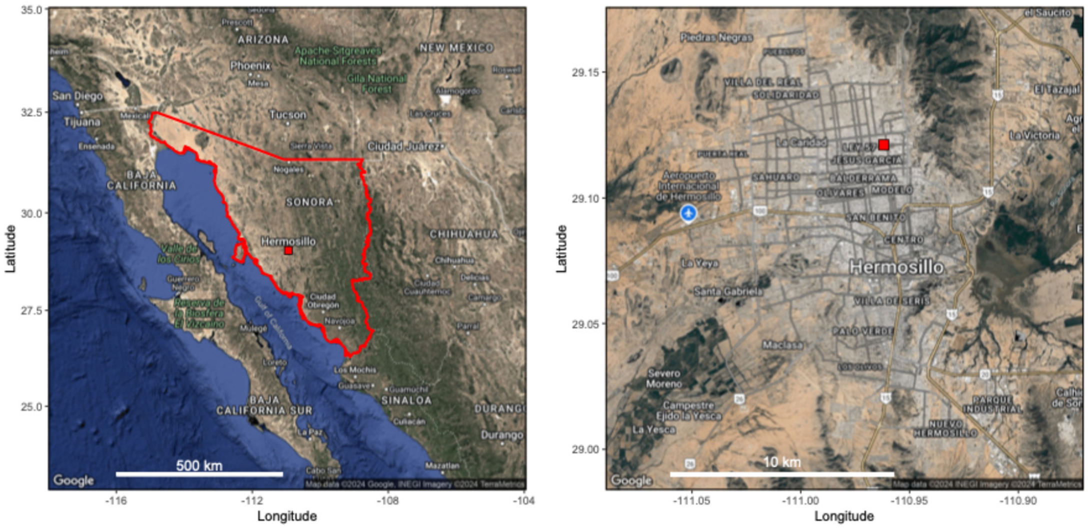

Figure 1. Location of airborne spore sampling site in the city of Hermosillo (right), state of Sonora, in NW Mexico (left).

2.2. Sampling Airborne Fungal Spores

We applied a standard sampling method proposed by the Red Española de Aerobiología (Spanish Aerobiology Network, REA) [17], and used by the Red Mexicana de Aerobiología (REMA, Mexican Aerobiology Network). We sampled atmospheric spores daily from January to December during six years (20016 to 2019; 2022-2023), using a Hirst (1952) type volumetric spore-trap (Burkard; http://www.burkard. co.uk). This Hirst spore-trap was located ~20 m above ground level on an exposed flat roof top at Sonora State University (Figure 2). We adjusted the Hirst spore-trap to aspirate 10 L air min^{-1}. Fungal spores were trapped on a Melinex tape coated with an adhesive (silicone fluid). We counted fungal spores trapped on daily Melinex tape segments using an optical microscope with four longitudinal sweeps per slide and 400× magnification. Therefore, we obtained daily concentrations of spores expressed as sporesm^{-3} air [18]. Also, we calculated the Annual Spore Integral (ASIn), which is defined as the amount of recorded airborne fungal spores during a year [18].

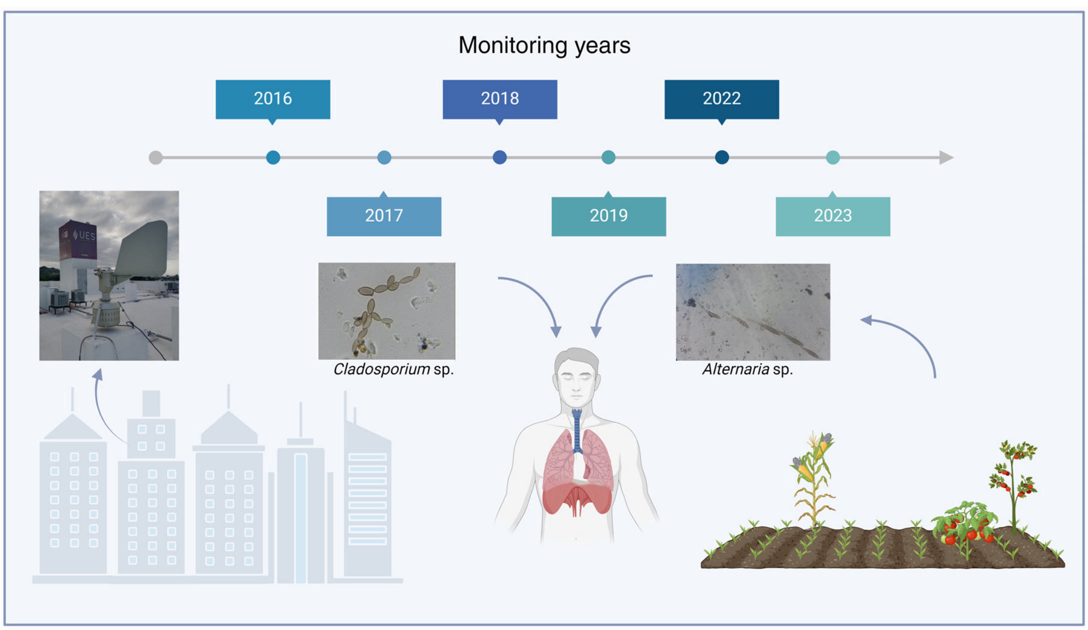

Figure 2. Fungal spores monitoring at Hermosillo city and potential sources of spores.

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2.3. Fungal Spore Calendar Construction

We summarized daily fungal spore concentrations into a fungal spore calendar. Our fungal spore calendar was created in accordance with well-established methodology [19]. Average daily fungal spore concentrations were averaged across periods of 10 days and then each 10-day period were averaged across the 6 years of our study period. Fungal spore levels were presented as averaged concentrations on a log_2 scale. In this way, all interactions between external factors and fungal spore concentrations were leveled out, thus enabling us to compare different fungal spore species concentrations throughout the year. Individual fungal spore taxon appears in the spore calendar in a chronological order based on scores of the first axis from a correspondence analysis of the data matrix taxon vs. 10-days period.

2.3. Climatic Variables

Meteorological data (mean, maximum and minimum temperatures, total rainfall,) were provided by the nearest Comisión Nacional del Agua Station to the sampling site (Figure 1). Data is shown in Supplementary Figure 1 (SF1).

2.4. Statistical Analysis

We determined whether daily meteorological conditions influenced spore concentration, accounting for the effect of date and annual variation. For each of the four taxa (*Cladosporium*, *Ascospora*, Smut, and *Alternaria*) that comprised >85% of the total spore concentration, we used a generalized linear model with response variable *daily spore concentration* (log-transformed) having a gamma distribution and linear predictor *daily minimum temperature* + *daily maximum temperature* + *daily precipitation* + *YEAR*. Meteorological variables are intrinsically related to date of year. Therefore, we included a five-order sine series on ordinal date ($\sum_{n=1}^{5} \boldsymbol{\beta_n} \mathbf{sin}\,(\mathbf{2\pi n}(\boldsymbol{date})/\mathbf{365})$) in the linear predictor above to unveil the effect of meteorological variables on spore concentration. We also included factor *YEAR* (levels: 2015, 2016, … , 2022, 2023) to account for annual variation. The gamma distribution is suitable for random variables with highly skewed distribution. In this case, daily spore counts frequently show extreme high values. To account for lagged effects of meteorological variables on spore concentration, we also run the model described above with daily minimum temperature, daily maximum temperature and daily precipitation lagged by 1 and/or 2 days. We evaluated the adequacy of these four models (with lags 0 days, 1 day, 2 days, and 0+1+2 days) using the Akaike's Information Criterion (AIC) (Burnham and Anderson, 2002). We also included a null model (without meteorological variables) in the set of models to rank by the AIC. We kept the model with the lowest AIC value (i.e., the best model) for inferences. We used Wald's tests [20], 2013) to determine the existence of effects of the predictor variables on daily spore concentration. We used program R [21] for all statistical analysis and visualization.

3. Results

3.1. Airborne Fungal Spores' Diversity

Twenty-one airborne fungal spore taxa were recorded in Hermosillo during our 6-year study period (Table 1), with 14 taxa were in present in < 1% ASIn. Fungal spore taxa with highest concentration were: *Cladosporium* (43.70 % ASIn), Ascospora (16.93%), Smut (14.05%), *Alternaria* (11.78%), Diatrypaceae (7.22%), Basidiospores (1.77%) and *Bipolaris* (1.29%), those taxa accounting for 96% of 6-year of Annual Spores Index (ASIn) (Supplementary Figure 2, SF2). The average 6-year fungal spores index was ASIn= 133,218, with the highest value (ASIn = 191,448) recorded during 2016 with an (Table 2).

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Table 1. Mean Airborne fungal spore types collected in Hermosillo Sonora over 6 years. Averaged percentages during the study time are reported.

Taxa	Total spores	Percentages (%)
Cladosporium	298,357	43.70
Ascospora	115,629	16.93
Smut	95,903	14.05
Alternaria	80,451	11.78
Diatrypaceae	49,279	7.22
Basidiospores	12,093	1.77
Bipolaris	8,820	1.29
Myxomicetes	5,639	0.83
Pithomyces	5,046	0.74
Agaricus	4,954	0.73
Arthrinium	2,562	0.38
Curvularia	1,856	0.27
Torula	862	0.13
Periconia	500	0.07
Sporidesmium	310	0.05
Boerlagella	291	0.04
Spegazzinia	117	0.02
Leptosphaeria	116	0.02
Peronospora	6	0.00
Beltrania	1	0.00
Fuligo	1	0.00
ASIn	**682,793** [1]	**100%**

[1] Annual Spore Integral (ASIn) for the total years of monitoring.

Fungal spore concentrations showed a high seasonal variability (Figure 3). Critical spore concentration consistently occurred during summer through the study period, with 14%, 19% and 28% of the ASIn for June, July, and August, respectively. We also documented annual variable interannual changes in spore concentration (Tabla 2): the highest monthly concentration occurred during in August 2015 (33% ASIn) and August 2016 (33%), whereas the highest concentration occurred in July for 2017 (22%) and in September for 2018 (20%) and 2019 (30%).

Table 2. Fungal spore total year-concentrations (spores/m^3 air) of most important taxa during the study period. Annual Fungal Spores Index (ASIn) is also reported.

Taxa	2016	2017	2018	2019	2023	Average
Cladosporium	73,205	44,876	55,439	36,455	80,510 [1]	58,097
Ascospora	15,837	13,265	7,520	5,633	6,8241	22,099
Smut	50,601	24,662	10,661	9,161	0	19,017
Alternaria	20,252	18,279	12,905	9,716	17,487	15,728
Diatrypaceae	22,021	11,990	5,183	2,758	7,296	9,850
Basidiospores	96	2,410	1,583	1,439	6,121	2,330
Bipolaris	1,249	856	1,367	1,304	3,663	1,688
Myxomicetes	2,481	1,420	854	764	0	1,104
Pithomyces	322	115	104	73	4,431	1,009
Agaricus	3,817	1,133	0	0	0	990
Arthrinium	855	845	409	414	0	505
Curvularia	1	0	0	0	1,851	370
Torula	356	224	169	101	0	170
Periconia	8	102	186	186	0	96
Sporidesmium	93	86	69	56	0	61

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Boerlagella	116	79	48	45	0	58
Spegazzinia	21	47	27	19	0	23
Leptosphaeria	116	0	0	0	0	23
Peronospora	0	0	0	6	0	1
Beltrania	0	1	0	0	0	0
Fuligo	1	0	0	0	0	0
ASIn	**191,448**	**120,390**	**96,524**	**68,130**	**189,600**	**133,218**

[1] *Cladoporium* has the highest concentration in air in 2023 compared to the entire monitoring period.

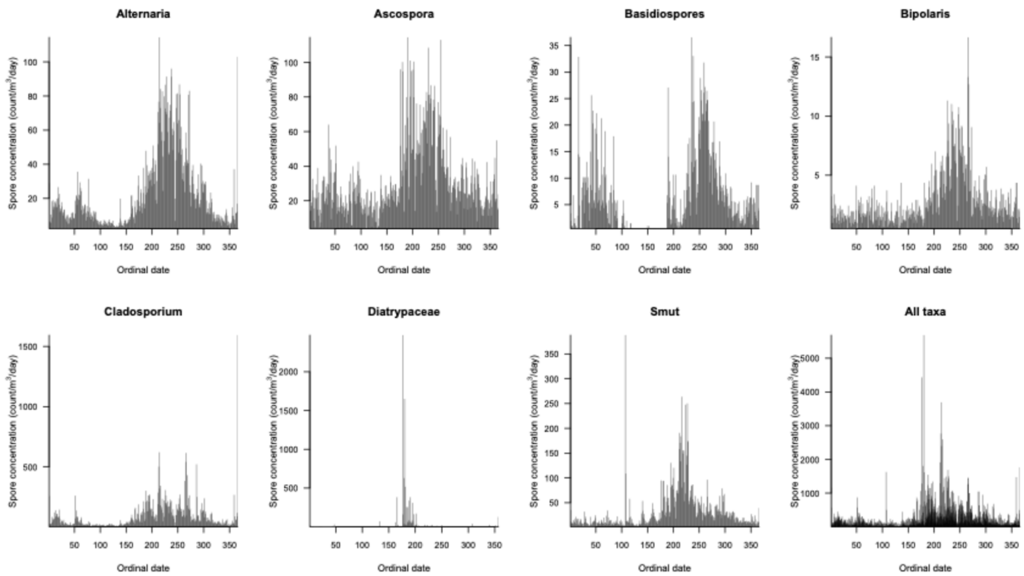

Figure 3. Average daily fungal spore concentration (spores/m^3 air) in the atmosphere of Hermosillo across 2016-2029 and 2022-2023.

3.2. Fungal Spore Calendar

Fungal spores' calendar for Hermosillo is shown in Figure 4. This represents the first atmospheric fungal spores' six-year calendar for not only for Hermosillo but for northern Mexico. Only taxa reaching a 10-day mean > 1 % of total concentration were included. This criterion left only 7 fungal spore types on the calendar.

The highest diversity of fungal spores we detected between June to December including principally Dyatrypaceae, Smut, *Cladosporium*, Ascospora and *Alternaria*. Airborne fungal spores, remaining at lower concentrations during spring (Figure 4). We describe now annual and seasonal variability in spore concentration for each fungal taxon.

Diatrypaceae

Fungal spores of Diatrypaceae appear early in January and last two weeks of February, but the highest concentrations occur in summer from June-August reaching mean daily values of 600 spores/m^3 air during summer (Figure 3). There is a a slight increase during November-December. This fungal spore is recognized as a pathogenic species for wood in angiosperms. During 2016 we recorded the highest concentrations with values doubling the five-years averages (Table 2)

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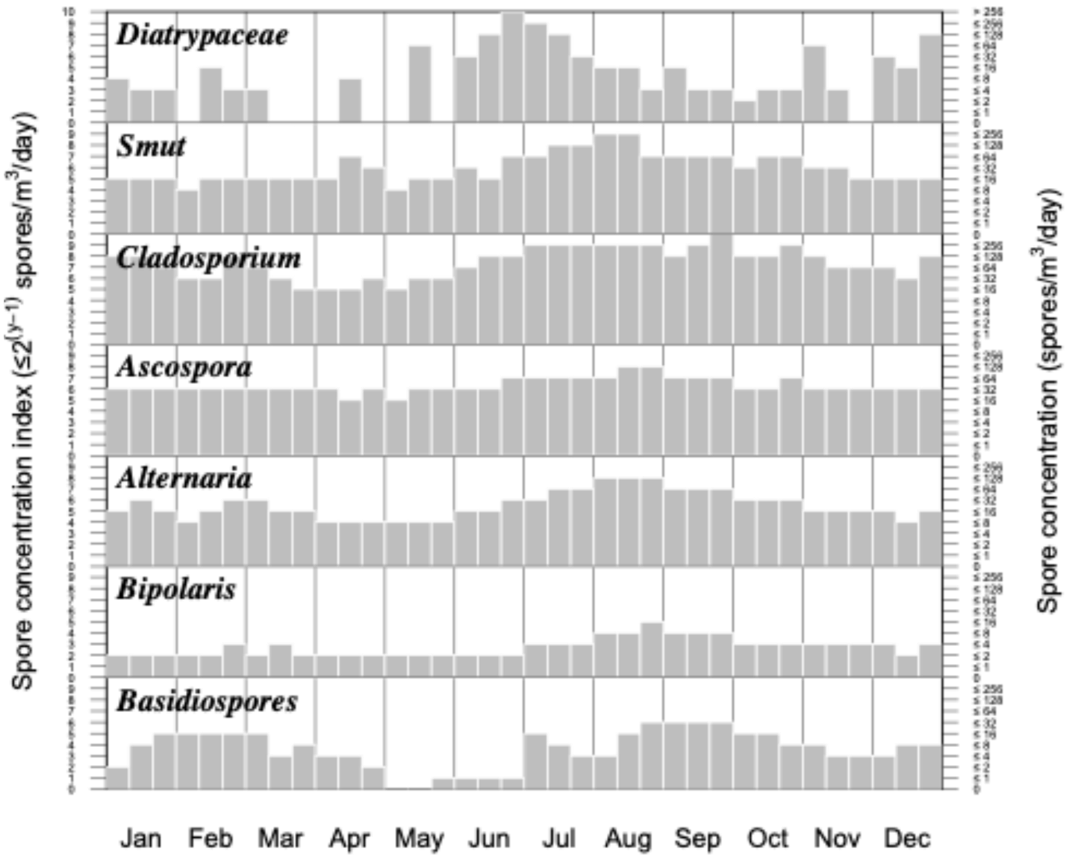

Figure 4. Six-year fungal spores' calendar 2016-2019, 2023) in the atmosphere of Hermosillo, Mexico.

Smut

Smut spores appear all the year although concentrations increase during summer from June to September, reaching mean daily values of 130 spores/ m^3 air (Figure 2). This fungal spore group includes Ustilaginomycetes, Microbotryales, Urediniomycetes and Basidiomycota, which are parasites of plants especially herbs belonging to Poaceae and Cyperaceae, both of economic importance. We recorded the highest concentrations of Smuts spores in 2016, with values doubling the 5-year averages (Table 2).

Cladosporium sp.

Cladosporium fungal spores are one of the most abundant airborne allergens worldwide. This taxon is present all the year in Hermosillo at high concentrations too, peaking from June until October (Figure 2) and reaching mean daily concentrations of 300 spores/m^3 air. During 2016 and 2023 we recorded the highest concentrations with values considerably higher than the 5-year average (Table 2).

Ascospora

Ascospora spores are present year around at low concentrations. The highest peak concentration also occurs in summer, from June-September, reaching mean daily values around 60 spores/m^3 air (Figure 3). During 2023 we recorded the highest concentrations with values three times higher than 5-year averages (Table 2). [es 6-year y no 6-years porque, creo, los adjetivos nunca son en plural en ingles]

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Alternaria sp.

Alternaria, which commonly grows as a parasite on vegetation, is the major environmental allergen associated with asthma worldwide. *Alternaria* is present all year in Hermosillo. The period with the highest concentrations peaks also occurs in the summer from June-October, reaching mean daily values around 60 spores/m^3 air (Figure 3). During 2016, we recorded the highest concentrations values, 1.5 times higher than five-year average (Table 2)

Bipolaris sp.

Bipolaris spores are present all year at low concentrations (< 4 spores/m^3 air) although its concentration increases during summer from June-September, with mean daily concentrations of 8 spores/m^3 air (Figure 3). During 2023, we recorded the highest concentrations with values 2 times higher than five-year average (Table 2)

Basidiospores

Fungal spores of Basidiospores are present during two periods of the year from January- April and from July-December. The highest concentrations are recorded during summer-fall from June-October, reaching mean daily concentrations of 15 spores/m^3 air (Figure 3). During 2023, we recorded the highest concentrations with values 3 times higher than five-year average (Table 2).

3.2. Climate and Spores' Concentration in Air

We found strong evidence that daily spore concentration is related to daily meteorological conditions after accounting for seasonal and annual variation. We also found lagged effects of meteorological variables on spore concentration (Table 3). High daily minimum temperatures promoted higher spore concentrations. Daily minimum temperature had a strong positive effect on daily spore concentration for *Cladosporium* and *Alternaria.* This strong positive effect of daily minimum temperature on spore concentration lagged two days for *Cladosporium* (Table 3).

Table 3. Effects of meteorological variables on spore concentration in Hermosillo, Mexico. Symbols + and— denote gamma regression coefficients $\beta > 0$ and $\beta < 0$, respectively. Single, double, and triple symbols denote *P* values <0.01, <0.01, and <0.001 for the Wald's test ($\beta = 0$). Symbol 0 (no effect) denotes gamma regression coefficients whose Wald's test had *P* values > 0.05. All models include and intercept term, variable *date* and factor *YEAR* (levels: 2015, 2016, …, 2023), all omitted in this table. Gamma regression model for each taxon was the best of five models (see text) by the means of the Aikaike's Information Criterion.

Parameter (lag in days)	*Cladosporium*	*Ascospora*	Smut	*Alternaria*
Min. Temp. (0)	+ + +	+	+ + +	+ + +
Min. Temp. (1)	0	+	0	0
Min. Temp. (2)	+ +	+ + +	+ +	+ +
Max. Temp. (0)	− − −	0	0	0
Max. Temp. (1)	0	0	0	0
Max. Temp. (2)	− −	− − −	− − −	− − −
Precipitation (0)	0	+ + +	0	0
Precipitation (1)	0	+ + +	0	0
Precipitation (2)	0	0	0	0

[1] The daily maximum temperature inhibits spore concentration in all cases after 2 days.

High maximum temperatures inhibited spore production. Daily maximum temperature had a strong negative effect on daily spore concentration for *Cladosporium.* This strong negative effect of daily minimum temperature on spore concentration lagged 2 days for *Alternaria*, *Ascospora*, and Smut (Table 3).

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Finally, high daily precipitation promoted spore production only for *Ascospora* and showed no effect for *Alternaria, Cladosporium, and Smut.* Daily precipitation from both the current day and the day before had a strong positive effect on current daily spore concentration for *Cladosporium* (Table 3).

4. Discussion

Fungal spores' calendar is a powerful tool for agricultural, public health, and aerobiological research. In agriculture, the monitoring of fungal spores is highly relevant to the study of life cycles of parasites and to develop plant protection plans. For human health, detection of above-threshold airborne concentrations events for allergenic taxa (e.g., *Alternaria* and *Cladosporium*) helps in the diagnosis and treatment of inhaled allergens.

Allergenic fungal spores recorded in Hermosillo are usually present throughout the year (Figure 3 and 4), but high concentrations occur at the onset of the summer and fall seasons (Figure 3). The most important airborne fungal spores in the six-year average were *Cladosporium,* Ascospora, Smut and *Alternaria.* This composition correlates well with numerous studies that report that *Cladosporium* and *Alternaria* are the most dominant spore type in most monitoring stations around the world [5,7,8,14,22]. As in other studies of fungal spores in Sonora [12], *Alternaria* and *Cladosporium* together with *Aspergillus* were the dominant taxa during 2011 at Ciudad Obregon in southern Sonora. Our ASIn indicates a high interannual variation on fungal spores in air during the years of monitoring. The 6-year average ASIn was **133,218**, which exceeds those reported for Obregon in 2008 (917 spores) and 2011 (1,690 spores) [12]. An ASIn of 11,000 has been reported for the tropics [23], whereas an ASIn of 3,500-54,595 has been reported for dry climates in urban evironments [24], both much lower than ours. We recorded the lowest ASIn (68,130 spores/m^3) air during 2019 and the highest ASIn in 2016 (191,448) and 2023 (189600). Those values are higher than those reported in other cities of Mexico but are lower than those of other cities of Europe such as Szczecin, Poland (595199), [14] and, Bratislava, Slovackia (83641) [7]). In North America, several studies found higher concentrations of fungal spores in desert cities including Las Vegas, (USA) [22]. Although ASIn is not reported for Las Vegas, the total fungal spores' concentration in air was 6393 spores/m^3 in May of 2015, comparable to the concentration that we recorded in Hermosillo during the highest peak during in May of 2023 with 8445 spores/m^3. Other study in New Orleans (USA) showed lower values on fungal spores' concentrations than those recorded in Hermosillo, ranging from 33,179-66,167 spores/m$^{3.}$ [25].

Sonora not only has a higher rate of ASIn than those documented for regions in Mexico, but also we document an increase in total annual amount of spores in air, showing an important inter annual variation (Table 2). In 2016 and 2023 we recorded the highest ASIn with 191448 and 189600 spores/m^3 air. These peaks coincidentally occurred during El Niño years [27] .El Niño causes above-average winter precipitation in Sonora. As suggested by our statistical analysis Ascospores is positively influenced by precipitation and could explain the higher concentration reached during 2016 (ASIn = 15,837 spores/m^3 air) and 2023 (ASIn = 68,241 spores/m^3 air). Both genera were present with higher concentrations in those years (Table 2). Further research about the influence of ENSO in airborne fungal spores is mandatory in light of this research.

Regarding most important airborne fungal spores that we recorded, *Cladosporium* spores are present all year, but its spore concentrations increase from June-October, correlating well with previous works at Sonora [1], and correlating with a fungal record from a similar desert city of United States [22] were *Cladosporium* was present through summer and fall months. High daily minimum temperature increase may favor the production and release *Cladosporium* spores in air, whereas daily maximum temperature inhibits spores' concentration at 0 and 2 delay days (Table 3).

Ascospore spores, the second with higher concentrations on air, was present more consistently all year but concentrations increased from June-September in summer months related to the monsoon season, supporting the findings of previous work in Hermosillo [1]. Our statistical analysis shows that these fungal spores are positively correlated with precipitation at 0- and 2-day lags (Table 3).

Smuts spores was the third spores' group with highest concentration in air, present in lowest concentrations through spring but increasing considerably during summer-fall, as previously reported [1]. Minimum temperature increases also triggers an increase of Smut spores in air (Table 3) with 0- and 2- day lag. Also, the daily maximum temperature inhibits spore concentration with a 2-day lag.

Alternaria spores were the fourth dominant spore in the air, being present all year but whose concentrations increase from June-November, these results are similar to those documented by previous research in Sonora [1] and at other desert city of United States [22]. A daily minimum temperature increase favors the production and release these spores in air with 0- and 2-day lags. In contrast, daily maximum temperature inhibits spores' concentration with a 2-day lag (Table 3).

Alternaria and *Cladosporium* genera are the most important outdoor allergens. Sensitization and exposure to those spore types is related to the development of asthma and rhinitis. Epidemics of asthma may exacerbate into life-threatening forms of asthma [5]. In this regard, the Sonora State Health Secretary reports that 13,454 people in Hermosillo presented diseases related to allergies in 2016 [1]. This agency also reports that the highest number of patients attended occurred during summer and fall, associated with the highest peaks of fungal spores in the atmosphere (Figures 3 and 4). A study of sensitization to fungus spores from skin tests taken between 2004 and 2015 in patients between 2-18 years old in Mexico City [8], who presented some type of allergic condition, indicated that 7,565 out of the 8794 patients displayed sensitization to at least one fungus. A remarkable prevalence was observed for *Alternaria* (36%), followed by *Aspergillus* (27%), *Cladosporium* (18%) and Penicillium (13%) [8]. Data provided from the Hospital General Zona Sur del IMSS in Hermosillo for 2018 indicates 90% of patients arriving with allergies symptoms (151 people for 2018) tested positive to allergy to fungal spores. Most important fungal spores were Zygomycetes (23%), *Alternaria* (21%) Ascomycetes (20%), *Cladosporium* (19%) and Smuts (18%). Overall, the period when people presented more symptoms correlates well with the higher concentrations of fungal spores in air recorded at this work (Figure 5) from June- November (in summer-fall).

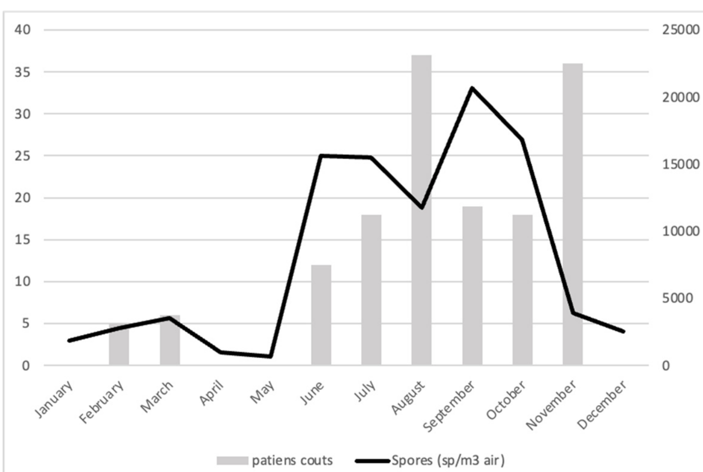

Figure 5. Monthly count of patient's positive sensitization to fungal spores at a public hospital and airborne fungal spore concentration in Hermosillo during 2018.

5. Conclusions

Extremely high concentrations of airborne fungal spores are recorded at the desert city of Hermosillo, Sonora, which requires explicit attention from public health agencies. Most important taxa are *Cladosporium*, *Alternaria*, Ascospores and Smuts. Fungal spore concentrations show high annual and interannual variability. The period with the highest peak in airborne fungal spores' concentrations in centered about the summer-fall, after the monsoon season. Our fungal spore calendar is first for Mexico, which will be of great application for public health. Fungal spores in the air that can trigger adverse effects on the human immune system and lead to respiratory diseases, such as asthma and allergies. This calendar will also find applications in agriculture to control fungi that can cause epiphytotic event in crops. For grape which is a major crop in the municipality of Hermosillo, *Cladosporium* sp. produce berry rot, while *Alternaria* sp. causes spots on the leaves of grape crops in both cases those fungi produce a loss in grape (*Vitis vinifera*) production in the region.

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org, Figure S1: Images of most common fungal spores at microscopy; Figure S2: Meteorological variables during the study period.

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References

1. Ortega Rosas, C.I.; Calderón-Ezquerro, M.D.C.; Gutiérrez-Ruacho, O.G. Fungal spores and pollen are correlated with meteorological variables: effects in human health at Hermosillo, Sonora, Mexico. *International journal of environmental health research* **2020**, *30*, 677-695, doi:https://doi.org/10.1080/09603123.2019.1625031.
2. Sofiev, M.; Bergmann, K.-C. Allergenic pollen: a review of the production, release, distribution and health impacts. **2012**.
3. Ortega-Rosas, C.; Meza-Figueroa, D.; Vidal-Solano, J.; González-Grijalva, B.; Schiavo, B. Association of airborne particulate matter with pollen, fungal spores, and allergic symptoms in an arid urbanized area. *Environmental Geochemistry and Health* **2021**, *43*, 1761-1782, doi:https://doi.org/10.1007/s10653-020-00752-7.
4. Gioulekas, D.; Damialis, A.; Papakosta, D.; Spieksma, F.; Giouleka, P.; Patakas, D. Allergenic fungi spore records (15 years) and sensitization in patients with respiratory allergy in Thessaloniki-Greece. *Journal of Investigational Allergology and Clinical Immunology* **2004**, *14*, 225-231.
5. Fukutomi, Y.; Taniguchi, M. Sensitization to fungal allergens: resolved and unresolved issues. *Allergology International* **2015**, *64*, 321-331, doi: https://doi.org/10.1016/j.alit.2015.05.007.
6. Sztandera-Tymoczek, M.; Szuster-Ciesielska, A. Fungal Aeroallergens—The Impact of Climate Change. *Journal of Fungi* **2023**, *9*, 544, doi:https://doi.org/10.3390/jof9050544.
7. Ščevková, J.; Kováč, J. First fungal spore calendar for the atmosphere of Bratislava, Slovakia. *Aerobiologia* **2019**, *35*, 343-356, doi:https://doi.org/10.1007/s10453-019-09564-4.
8. Fernández-Soto, R.; Navarrete-Rodríguez, E.; Del-Rio-Navarro, B.E.; Sienra-Monge, J.L.; Meneses-Sánchez, N.; Saucedo-Ramírez, O. Fungal Allergy: Pattern of sensitization over the past 11 years. *Allergologia et immunopathologia* **2018**, *46*, 557-564, doi:https://doi.org/10.1016/j.aller.2018.01.005.
9. Zureik, M.; Neukirch, C.; Leynaert, B.; Liard, R.; Bousquet, J.; Neukirch, F. Sensitisation to airborne moulds and severity of asthma: cross sectional study from European Community respiratory health survey. *Bmj* **2002**, *325*, 411, doi: https://doi.org/10.1136/bmj.325.7361.411.

10. Twaroch, T.E.; Curin, M.; Valenta, R.; Swoboda, I. Mold allergens in respiratory allergy: from structure to therapy. *Allergy, asthma & immunology research* **2015**, *7*, 205-220, doi:http://dx.doi.org/10.4168/aair.2015.7.3.205.
11. WHO. Asthma Available online: https://www.who.int/news-room/fact-sheets/detail/asthma/?gad_source=1&gclid=CjwKCAjwmaO4BhAhEiwA5p4YLyseQOE2Dfp9Fn_p5eo9iU-ZLTIRzB8LUqQDTiWQotcqfOVY9JsM7xoCtgIQAvD_BwE (accessed on 6 may 2024).
12. Moreno-Sarmiento, M.; Peñalba, M.C.; Belmonte, J.; Rosas-Pérez, I.; Lizarraga-Celaya, C.; Ortega-Nieblas, M.M.; Villa-Ibarra, M.; Lares-Villa, F.; Pizano-Nazara, L.J. Airborne fungal spores from an urban locality in southern Sonora, Mexico. *Revista mexicana de micología* **2016**, *44*, 11-20.
13. Sánchez-Reyes, E.; Rodríguez de la Cruz, D.; Sánchez-Sánchez, J. First fungal spore calendar of the middle-west of the Iberian Peninsula. *Aerobiologia* **2016**, *32*, 529-539, doi:https://doi.org/10.1007/s10453-016-9430-x.
14. Bednarz, A.; Pawlowska, S. A fungal spore calendar for the atmosphere of Szczecin, Poland. *Acta agrobotanica* **2016**, *69*, doi:DOI: 10.5586/aa.1669.
15. Molina Freaner, F.E., Van Devender, T. R. . DIVERSIDAD BIOLÓGICA DE SONORA
16. INEGI. Conociendo Sonora. **2013**.
17. Galán Soldevilla, C.; Cariñanos González, P.; Alcázar Teno, P.; Domínguez Vilches, E. Spanish Aerobiology Network (REA): management and quality manual. *Servicio de publicaciones de la Universidad de Córdoba* **2007**, *184*, 1-300.
18. Galán, C.; Ariatti, A.; Bonini, M.; Clot, B.; Crouzy, B.; Dahl, A.; Fernandez-González, D.; Frenguelli, G.; Gehrig, R.; Isard, S. Recommended terminology for aerobiological studies. *Aerobiologia* **2017**, *33*, 293-295, doi:https://doi.org/10.1007/s10453-017-9496-0.
19. Spieksama, F.T.M. Regional European pollen calendars.[In:] G. D'Amato, F. Th. M. Spieksma, S. Bonini (eds). Allergenic pollen and pollinosis in Europe. **1991**.
20. Fahrmeir, L.; Kneib, T.; Lang, S.; Marx, B.; Fahrmeir, L.; Kneib, T.; Lang, S.; Marx, B. *Regression models*; Springer: 2013.
21. Team, R.C. *A language and environment for statistical computing*, 2021.
22. Patel, T.Y.; Buttner, M.; Rivas, D.; Cross, C.; Bazylinski, D.A.; Seggev, J. Variation in airborne fungal spore concentrations among five monitoring locations in a desert urban environment. *Environmental monitoring and assessment* **2018**, *190*, 1-10, doi:https://doi.org/10.1007/s10661-018-7008-5.
23. Adhikari, A.; Sen, M.M.; Gupta-Bhattacharya, S.; Chanda, S. Airborne viable, non-viable, and allergenic fungi in a rural agricultural area of India: a 2-year study at five outdoor sampling stations. *Science of the Total Environment* **2004**, *326*, 123-141, doi:https://doi.org/10.1016/j.scitotenv.2003.12.007.
24. ROCHA ESTRADA, A.; ALVARADO VÁZQUEZ, M.A.; GUTIÉRREZ REYES, R.; SALCEDO MARTÍNEZ, S.M.; MORENO LIMÓN, S. Variación temporal de esporas de Alternaria, Cladosporium, Coprinus, Curvularia y Venturia en el aire del área metropolitana de Monterrey, Nuevo León, México. *Revista internacional de contaminación ambiental* **2013**, *29*, 155-165.
25. Solomon, G.M.; Hjelmroos-Koski, M.; Rotkin-Ellman, M.; Hammond, S.K. Airborne mold and endotoxin concentrations in New Orleans, Louisiana, after flooding, October through November 2005. *Environmental Health Perspectives* **2006**, *114*, 1381-1386, doi:https://doi.org/10.1289/ehp.9198.
26. Grinn-Gofroń, A.; Strzelczak, A. Hourly predictive artificial neural network and multivariate regression tree models of Alternaria and Cladosporium spore concentrations in Szczecin (Poland). *International Journal of Biometeorology* **2009**, *53*, 555-562, doi:https://doi.org/10.1007/s00484-009-0243-2.
27. NOAA. National Oceanic and Atmospheric Administration. Available online: https://www.noaa.gov/ (accessed on May 2024).