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ABSTRACT

We conducted the first study of air pollen and fungal spores for Hermosillo, Sonora, where the human population is exposed to high temperatures and high levels of dust and suffers from diseases related to air quality. We sampled pollen and fungal spores daily in the air during 2016 using a volumetric spore trap Hirst-type sampler. We used simple linear correlation to investigate the association between pollen and spore counts and daily weather conditions. We found an Annual Pollen Integral of 16,243 pollen day/m^3 and an Annual Spore Integral higher 222,365 spore day/m^3. We identified 32 pollen taxa and 15 different spores. We found two periods of higher pollen and spore concentrations: March to May and August to October, the latter was the most severe. Spore and pollen concentrations in the air increased at higher temperature and higher relative humidity but decreased at higher precipitation. We detected negative impacts during summer and fall on population health, with 13,454 cases of people who presented diseases related to allergies. A peak in allergies is centered during October and correlates well with our peaks in pollen and spore concentrations; it seems that pollen of Poaceae is the one that generates most effects in allergic people.

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Allergenic pollen; fungal spores; Hermosillo Sonora; weather conditions

Introduction

More than 1.4 million people die every day worldwide because of bronco-respiratory diseases related to environment insalubrity (WHO, 2016). The OMS (2004) estimates that there are about 235 million people suffering from asthma, 64 million suffering from chronic obstructive pulmonary disease and many millions more suffering from allergic rhinitis. Allergenic diseases have increased in the last years due to global warming (Beggs 2004; Shea et al. 2008). These diseases affect around 30% of the world's population (Terán et al. 2009). Allergic and air pollution–related morbidity and mortality are associated to pollen and other allergenic particles. It has been hypothesized that climate change could alter the concentration, distribution, dispersion patterns and allergenicities of pollen and spores in the environment and further increase the prevalence of allergic diseases (EPA 2008). Anemophilous pollens (wind pollinated) dominate the pollen rain of any area, representing major seasonal carriers of allergens (Shahali et al. 2009). Overall, pollen carried on the wind can travel over very long distances and interact with numerous biological and chemical agents present in the atmosphere. Several studies also proved that pollutants attached to

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the pollen grains surface can modify the morphology of these antigen-carrying agents and alter their allergenic potential (Behrendt et al. 1997; Okuyama et al. 2007). The last, potency the effect of this pollen and spores allergenic on human health. In urban areas, people are exposed continuously to this kind of biological particles in the air; nevertheless, the degree of exposure depends on the concentration of this kind of allergenic particles. In this way, aerollargens studies in cities can help health agencies in the prevention and control of respiratory diseases caused by exposure to airborne allergens (Calderón-Ezquerro et al. 2015). In Mexico, there exist some aerobiological studies in highly populated cities including Mexico City (Ramírez-Oviedo and Rodríguez-Hernández 1961; Salazar-Coria 1995; Calderón-Ezquerro et al. 2015; Calderon-Ezquerro et al. 2018), Monterrey (Rocha-Estrada et al. 2009, 2013) and central Mexico (Cueva-Velázquez 1970). However, there are few studies about pollen and spores in the atmosphere of cities in the northern Mexico. Limited data for Mexicali (Ahumada-Valdez et al. 2006; Quintero et al. 2006; De la Fuente et al. 2013) and for Hermosillo (Moreno-Sarmiento et al. 2016) have been published. These studies mostly provide information about allergenic pollen in the air, but few provide information about fungal spores (Rosas et al. 1998; Rocha-Estrada et al. 2013; Moreno-Sarmiento et al. 2016). Fungi are the most abundant microorganisms in the air (Calderón et al. 1995, 1997; Rojas et al. 2007) because their spores originate from activities and environments related to human activity such as cattle raising, fermentation processes, industry, agriculture and waste management (Rosas et al. 1997; Hammed and Awad 2004).

In the particular case of Hermosillo, located into the Sonoran Desert, extreme temperatures and the aridity make this city the most vulnerable to climate change in Mexico. High levels of dust and particle matter suspended are frequently recorded at this region (Meza-Figueroa et al. 2007). Human population in Hermosillo suffers a higher incidence of respiratory problems, principally asthma and allergies (Castillo-Ramos 2010). We make an exhausts research about allergies in Sonora we only found journalistic notes with some general data. However, data provided by Health Secretary of Sonora State (Secretaría de Salud del Estado de Sonora, 2018, this study) show global statistics about the number of patients suffering from allergies for the state during 2016: 28,268 cases of conjunctivitis and of 9742 cases of pharyngitis were reported, of which 34% of conjunctivitis cases and 40% of pharyngitis cases occurred at Hermosillo (Secretaría de Salud, 2018).

For Hermosillo city, a recent study (López-Romero et al. 2017) of sensitization to allergens in patients between 2 and 18 years of age was conducted at Children's Hospital of the State of Sonora during 2016–2017. There were 125 patients, attended in consultation of pediatric allergology, who were referred with suspected allergic disease; the service of pediatrics recorded most of these patients (84%). The most common pathologies were asthma (68.8%), followed by allergic rhinitis (14.4%). Of the 125 skin tests performed, the presence of sensitization for at least 1 allergen is found in 59 patients (47.2%). Within 59 patients, 201 allergens were found positive: 40.7% showed greater sensitivity to grasses, followed by trees, 18.4%, and weeds, 16.4% (López-Romero et al. 2017). Among this group of airborne allergens, most important taxa were *Cynodon dactylon* (17.9%), followed by *Atriplex bracteosa* (12.9%), *Prosopis juliflora* (11.9%), *Lolium perene* (10.9%) and *Zea mays* (8.4%) (López-Romero et al. 2017). This study concluded that the prevalence of observed allergens cases related to pollen is above the national literature most probably due to the characteristics of our desert region, which expose our population to great amount of allergens (López-Romero et al. 2017). By the way, we observe that it is an important issue of health for Hermosillo city and there is insufficient information about air quality. Furthermore, there is no previous information about pollen and spores present in the atmosphere.

In this regard, this study is the first attempt to monitor this kind of allergenic particles focusing on both pollen and fungal spores, which we continuously monitored through 2016. This research aims to contribute to (1) create baseline information about biological air quality at Hermosillo city, (2) unveil correlations between the most important pollen and spore types and climatic variables and (3) infer the impacts of biological air quality on human health.

Methods

Study region and environmental settings

Hermosillo (29°05.02′N, 110°57.56′W) is located in the central Sonora. Hermosillo lies within the Sonoran Desert (Molina-Freaner and Van-Devender 2000), one of the great North American deserts, harboring a high biodiversity (Figure 1). Our aerobiological monitoring station is located in the northern part of the city, at Universidad Estatal de Sonora premises (Figure 1). Climate in Hermosillo is a transition of two climate types (García 1964): very dry and very warm BW(h′), and very dry and semi-warm (BW h). 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 (Gobierno Municipal de Hermosillo 2003). Dominant winds go SW–NE in the morning and in the opposite direction in the afternoon (Gobierno Municipal de Hermosillo 2003). Vegetation and land-use change types within the Municipality of Hermosillo are desert scrub (74.75%), agriculture (14.64%), forest (0.06%), grassland (3.03%) and others (7.52%) (INEGI 2014). Sonoran desert scrub communities are the principal source of pollen in the atmosphere in Hermosillo (Table 1). Dominant taxa are legume trees *Parkinsonia, Olneya, Acacia, Prosopis*, and cacti (Cactaceae) and grasses (Poaceae). Hermosillo is mostly in flat terrain flanked by a mountain range to the north and east. This mountain range determines the SW–NE wind direction and, consequently, the behaviour of airborne particles. There are two dominant winds, from SW and from NE. Dominant wind from SW has a means annual speed of 1.2 m/s, with mean annual calms of 83%.

Temporal variation patterns in meteorological variables

Dominant winds blow from the southwest with a mean annual speed of 1.2 m/s, with 82.8% of calm days (CONAGUA, 2016). The hottest months (June, July and August) had wind speed of 1.5 m/s, average direction from NE and west with 85% of calm days. The coolest months (December, January and February) had wind with mean speed of 1.5 m/s, average direction northeast and from east, and a 75% of calm days. The maximum annual speed equals ~1.8 m/s with southwest direction (CONAGUA, 2016). The highest values of maximum daily temperatures were recorded in June, July and August (Figure 2). Mean daily relative humidity was higher during summer (June, July and August) but highly variable during the year, with a small increase in December (Figure 2). Precipitation was restricted to summer period due to a monsoonal system (Figure 2). July, August and part of September recorded 80% of the 2016 annual precipitation. September recorded the rainiest days with daily rainfall values as high as 30 mm. In addition, wind and speed direction underwent important changes during 2016. For spring (March, April and May), the dominant wind direction was from southwest and west (Figure 3(A)), with mean speed of 8.04 m/s. During summer (June, July and August), wind direction becomes more important from the southeast and also west and southwest regions. Mean speed for these months is of 8.58 m/s (Figure 3(B)).

Sampling pollen and fungal spores

We applied a standard sampling method that proposed the Red Española de Aerobiología (Spanish Aerobiology Network, REA) (Galán et al. 2007) and was used by the Red Mexicana de

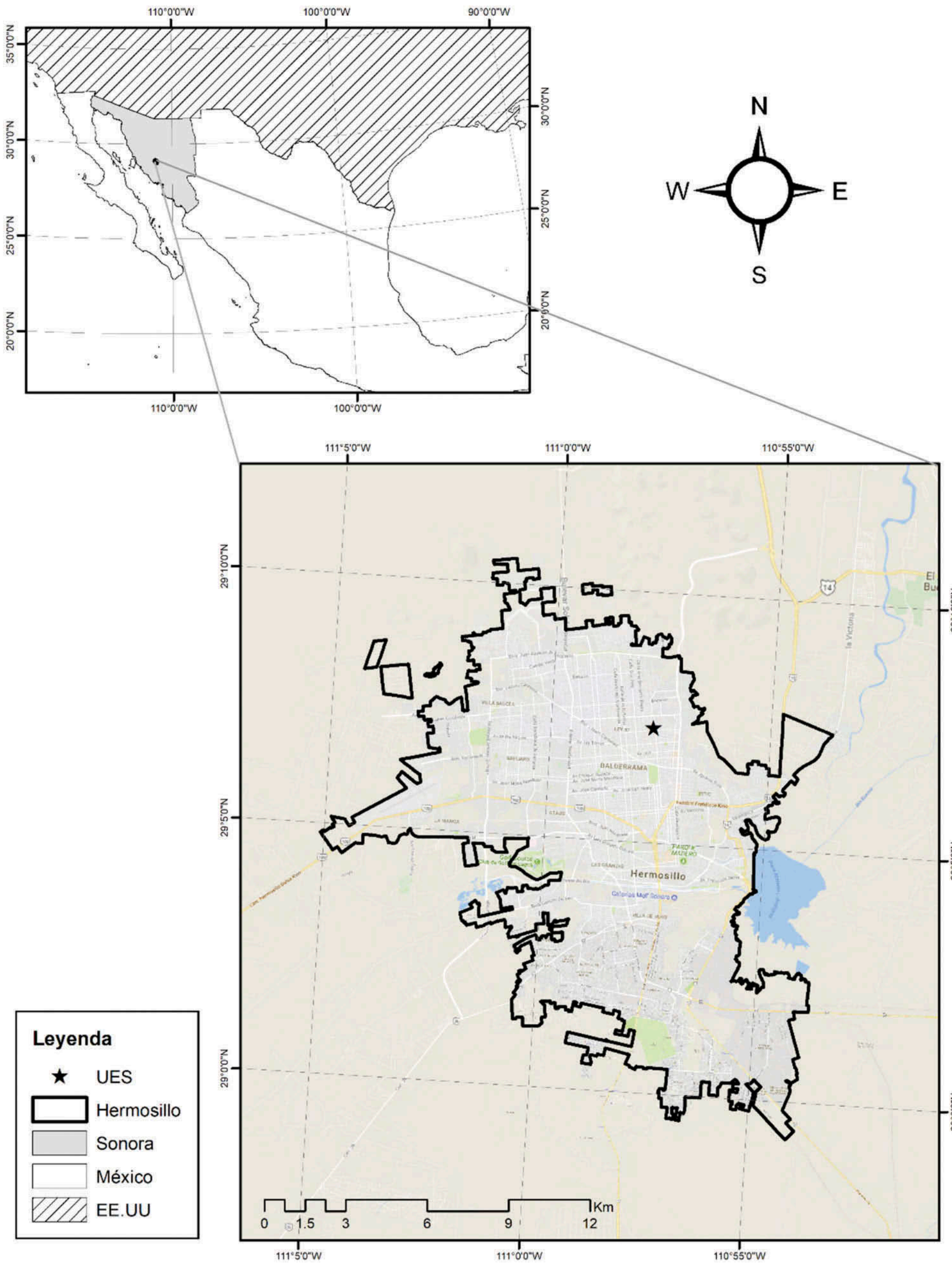

Figure 1. Localization map of study site in Northwestern Mexico. Star indicates the position of 'Burkard sampler' at Sonora State University (UES) in the northern side of Hermosillo city.

Aerobiología (REMA, Mexican Aerobiology Network). We sampled atmospheric pollen and spores daily from January to December of 2016 using 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 at Universidad Estatal de Sonora. We adjusted the Hirst spore-trap to aspirate 10 L air/min. Pollen and spores were trapped on a Melinex tape coated with adhesive (silicone fluid). We counted pollen and spores trapped on daily Melinex tape segments using an optical microscope with four longitudinal sweeps per slide and 400× magnification. Therefore, we provide daily concentrations of pollen and spores expressed as grains/m^3 (Galán et al. 2007).

Table 1. Vegetation types and species composition at Hermosillo city (INEGI 2014).

Vegetation type	Species composition	% cover in parks and gardens
Crasicaule scrub	*Opuntia spp., Carnegiea gigantea, Pachycereus pringlei, Stenocereus thurberi*	30%
Desert scrub	*Larrea tridentata, Ambrosia dumosa, A. deltoidea, Prosopis spp. Acacia sp., Jatropha sp., Bouteloua*	
Sarcocaule Scrub	*Parkinsonia microphyllum, Opuntia sp., y Carnegiea gigantea, Acacia, Prosopis, Larrea, Celtis, Encelia, Olneya, Ferocactus*	
Mezquital	*Prosopis velutina, Prosopis spp.*	
Introduced species	*Bucida buceras, Citrus aurantium, Eucalyptus spp., Azadirachta indica, Ficus benjamina, Phoenix dactylifera, Ehretia tinifolia, Ceiba pentandra, Olea europaea, Ficus nítida, Delonix regia, Leucaena sp. Tamarix sp.*	70%

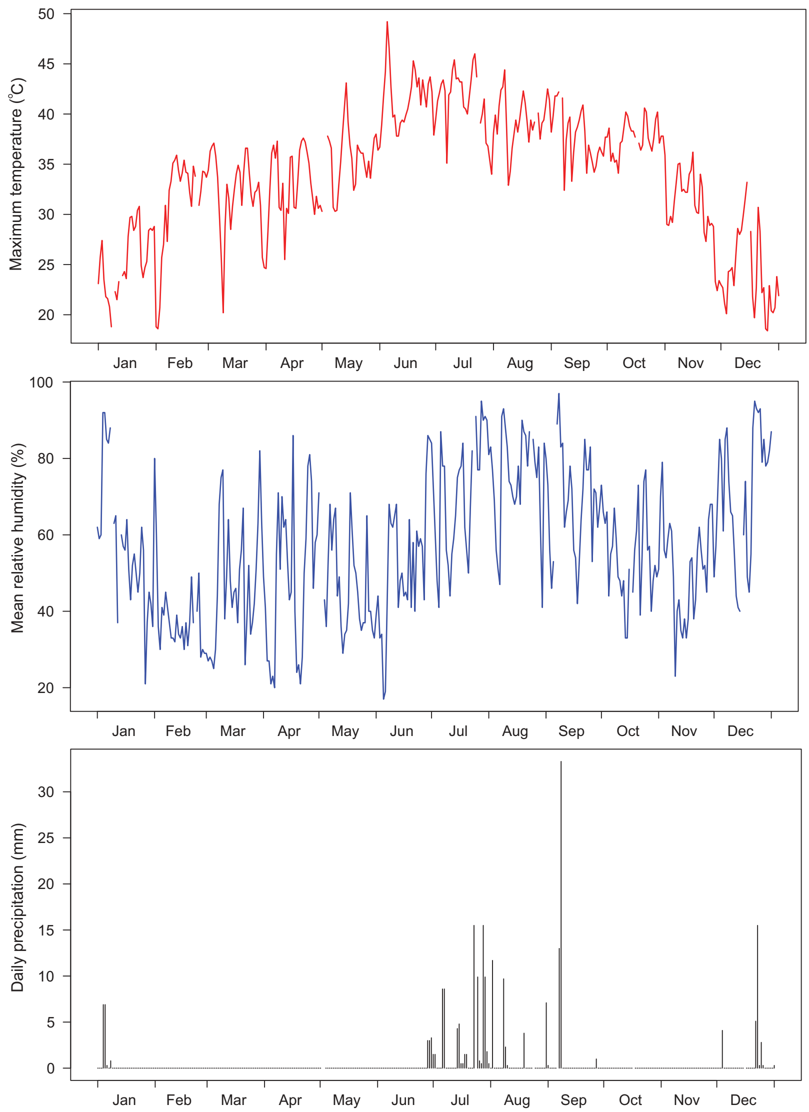

Figure 2. Daily variation in maximum temperature, relative humidity and precipitation (from top to bottom) in northern stations (Figure 1) through the urban area of Hermosillo, Mexico, in 2016.

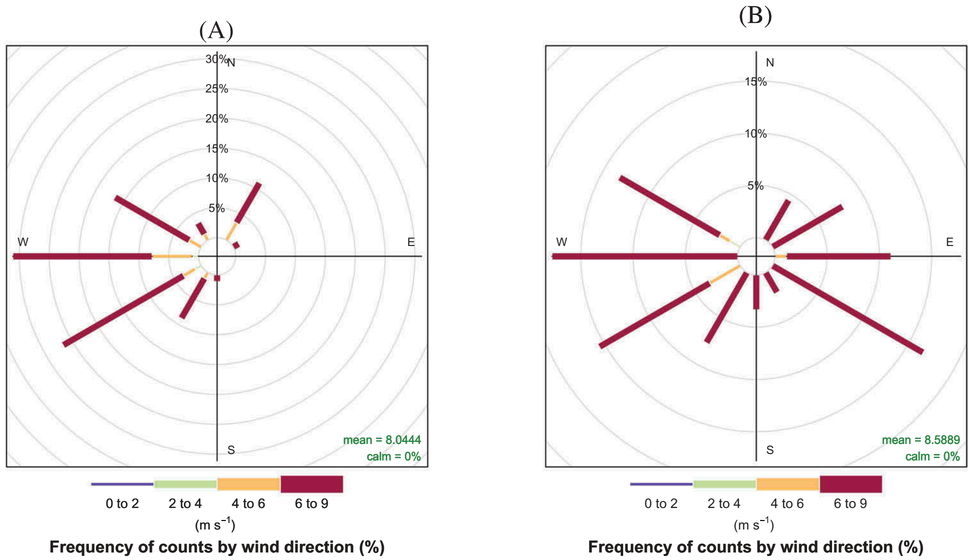

Figure 3. Wind rose for the urban area of Hermosillo, Mexico, in 2016 for (A) March, April and May and (B) June, July and August.

Meteorological data (mean, maximum and minimum temperatures, total rainfall, relative humidity, wind speed and wind direction) were provided by the Automatically Meteorological Station nearest to the sampling site (29.124–110.957, https://espanol.wunderground.com/personal-weather-station/widgets?ID = ISONORAH20).

Allergenic data from health secretary

Accumulated cases of patients attended in Sonora State related to allergies during 2016 were provided by the Health Secretary (Secretaría de Salud del Estado de Sonora, 2018). Data were provided by 'Cubos dinámicos' (The Service Provisioning Hub) which provides data for the construction of indicators of the different action programs that allow for their evaluation in the states, as well as contributing to health decision-making (http://www.dgis.salud.gob.mx/contenidos/basesdedatos/bdc_serviciossis.html). Monthly data for most important diseases related to allergies (conjunctivitis and pharyngitis) were arranged for Sonora State in three categories: municipalities, according to source of information (notifying medical unit) and age group. We filtered data only from Hermosillo municipality to compare with the results of pollen and spore concentrations. We compared monthly values of pollen and spore concentrations with the monthly cases of patients with allergic diseases reported (conjunctivitis and pharyngitis).

Statistical analyses

We drew 2D correspondence analysis biplots (Legendre and Legendre 1998) to visualize overall temporal patterns in pollen and spore concentrations using package ca (Nenadic and Greenacre 2007). Correspondence analysis biplots are frequently used to analyze community matrices and visualize patterns of the distribution of species (rows) across sampling units or sites (columns). In this regard, we performed this correspondence analysis on a data matrix of taxon counts (rows) per 10-day sampling periods (columns). We used the square root of the eigenvalues of ordination axis (λ), i.e. the linear correlation between taxon scores (species) and 10-day sampling period scores (sites), to judge the explanatory value of these correspondence analysis biplots.

We used simple linear correlation coefficients to investigate the association between pollen and spore counts and daily weather conditions. We used a *t*-test (Pearson et al. 1990) to determine the statistical significance of each correlation coefficient (H_0: $\rho = 0$ and H_a: $\rho \neq 0$, where ρ *is the population linear correlation coefficient*). We removed data from days with zero counts for ach taxa when computing simple linear correlation coefficients. Weather variables for the count model included daily maximum temperature, daily mean relative humidity, daily total precipitation, daily mean wind speed and daily mean wind direction [under transformation $\sin(\pi x/360)$]. We conducted all statistical tests under a significance level of $\alpha = 0.05$.

Results

Pollen and spore diversity at Hermosillo during 2016

We identified 32 pollen taxa and 15 different fungal spores in 2016 in Hermosillo (Table 2). Most important pollen taxa are Poaceae, accounting for 33% of the total annual pollen count, followed by Nyctaginaceae (15%), *Ambrosia* spp. (10%), Amaranthaceae (10%), Urticaceae (9%) and Fabaceae (3%). These pollen taxa differ in their degree of allergenicity. For fungal spores (Table 2), most important taxon is *Cladosporium*, with around 35% of total annual spore count, followed by the Smuts complex (31%), *Alternaria* (10%), Diatrypaceae (10%) and Ascospora (Ascomycetes, 7%).

Table 2. Aeroallergens diversity during 2016 at Hermosillo city.

Pollen	Concentration pollen/m^3 air	% of annual sum	Fungal spores	Concentration spores/m^3 air	% of annual sum
Poaceae	5357	32.98	*Cladosporium*	79,113	35.58
Nyctaginaceae	2369	14.58	*Smuts*	69,871	31.42
Ambrosia	1686	10.38	*Alternaria*	22,668	10.19
ChenoAma	1574	9.69	*Diatrypaceae*	21,855	9.83
Urticaceae	1524	9.38	*Ascospora*	17,162	7.72
Quercus	626	3.85	*Basidiospores*	4236	1.90
Cupressaceae	448	2.76	*Myxomycetes*	2950	1.33
Parkinsonia	447	2.75	*Bipolaris*	2091	0.94
Burseraceae	402	2.47	*Arthrinium*	1067	0.48
Scrophulariaceae	276	1.70	*Pithomyces*	444	0.20
Celtis	272	1.67	*Torula*	393	0.18
Asteraceae	225	1.39	*Leptosphaeria*	161	0.07
Rubiaceae	156	0.96	*Sporormiella*	145	0.07
Solanaceae	150	0.92	*Boerlagella*	141	0.06
Lobeliaceae	109	0.67	*Periconia*	33	0.01
Fabaceae	104	0.64	*Spegazzinia*	30	0.01
Euphorbiaceae	99	0.61	*Fuligo*	5	0.005
Zygophyllaceae	96	0.59			
Pinus	58	0.36			
Prosopis	55	0.34			
Myrthaceae	47	0.29			
Iridaceae	37	0.23			
Caesalpinia	30	0.18			
Betulaceae	27	0.17			
Alnus	19	0.12			
Myrica	19	0.12			
Salix	9	0.06			
Liliaceae	7	0.04			
Mimosaceae	6	0.04			
Acacia	4	0.02			
Polygonaceae	3	0.02			
Olneya	2	0.01			
Total annual	**16,243**			**222,365**	

Temporal variation patterns in pollen and spore counts

The Annual Pollen Integral (APIn), defined as the amount of recorded airborne pollen during a year (Sofiev and Bergmann 2013; Galan et al 2017), for Hermosillo was 16,243 pollen day/m^3, whereas the Annual Spore Integral (ASIn) was 222,365 spore day/m^3 (Table 2). Presence of pollen and spores at the atmosphere in Hermosillo was discontinuous through 2016. Seasonal patterns of their concentration vary considerably among taxa (Figure 4). For pollen, we documented two peaks: one from March–April, with concentrations around 500 pollen day/m^3, and from June to October, with higher concentrations ranging from 800 to 2450 pollen day/m^3.

The seasonal behaviour of fungal spores attained a single critical period (from June to August) of very high concentrations ranging from 19,000 to 33,000 spore day/m^3. It should be noted that these fungal spore concentrations far exceed those of pollen concentration. In winter (from October to December), fungal spore concentration levels also remained high, around 10,000 spore day/m^{3,} but not as high as those levels in the summer (Figure 4).

Major allergenic pollen taxa had different trends in concentration during 2016. Poaceae was present through the year, but concentration levels increased only during August, September and October, raising daily counts ~150–200 pollen day/m^3 (Figure 5). *Ambrosia* pollen was also present through the year, but flowering periods occurred from September to November and from February to mid-April, during which *Ambrosia* pollen daily concentration reached 50 pollen day/m^3. Urticaceae pollen was present from January to October, but concentration levels increase only from July to September, when daily concentration levels reached 150 pollen day/m^3. Nyctaginaceae, also present during all year, was more abundant from August to October, reaching daily concentration levels of 120 pollen day/m^3 (Figure 5). Amaranthaceae pollen is also very common at this desert city, being present during most of 2016 with higher concentration levels from August to October, reaching 50 pollen day/m^3. Amaranthaceae reached an extremely high concentration of 55 pollen day/m^3 in a day during June (Figure 5). Finally, Fabaceae pollen appeared at several periods of the year but became more important during summer (from June to August) with daily concentrations ~20 pollen day/m^3. Fabaceae also reached high concentrations (15 pollen day/m^3) in April (Figure 5).

Fungal spore taxa had a more homogeneous seasonal variation in concentration during 2016 than those of pollen taxa. *Cladosporium* was present during all the year with increased concentrations during July and August (4000 spore day/m^3) and during December (Figure 6). *Alternaria* was the second major fungal spore taxa with high concentrations all year but concentrations peaking in July, August, September and October reaching daily concentrations of 800 spore day/m^3. Ascospora was also present all year, with higher concentrations in July, August and September and daily concentrations around 600 spore day/m^3. Smuts were also present all the year with a small increase during summer, reaching daily concentrations of 2000 spore day/m^3. Basidiospores were important all the year but their concentrations were relatively low (100 spore day/m^3).

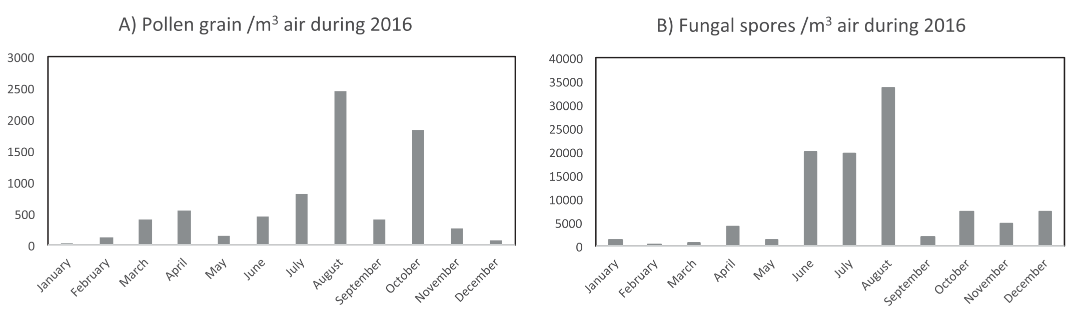

Figure 4. Monthly aeroallergens concentrations for pollen (A) and fungal spores (B) in the city of Hermosillo, Mexico, during 2016.

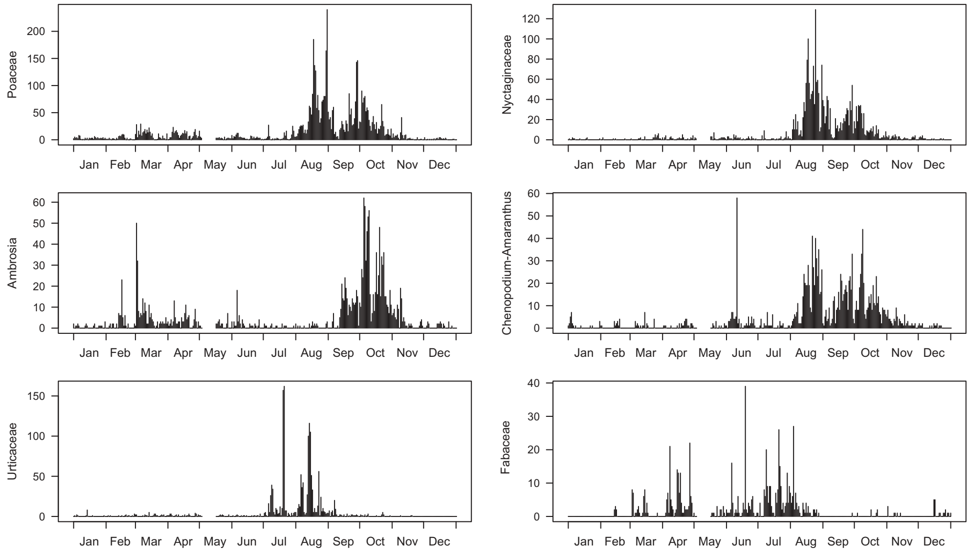

Figure 5. Daily pollen counts for the six most common taxa (Poaceae, Nyctaginaceae, Ambrosia spp., Chenopodium–Amaranthus, Urticaceae, Fabaceae spp.) in the city of Hermosillo, Mexico, during 2016.

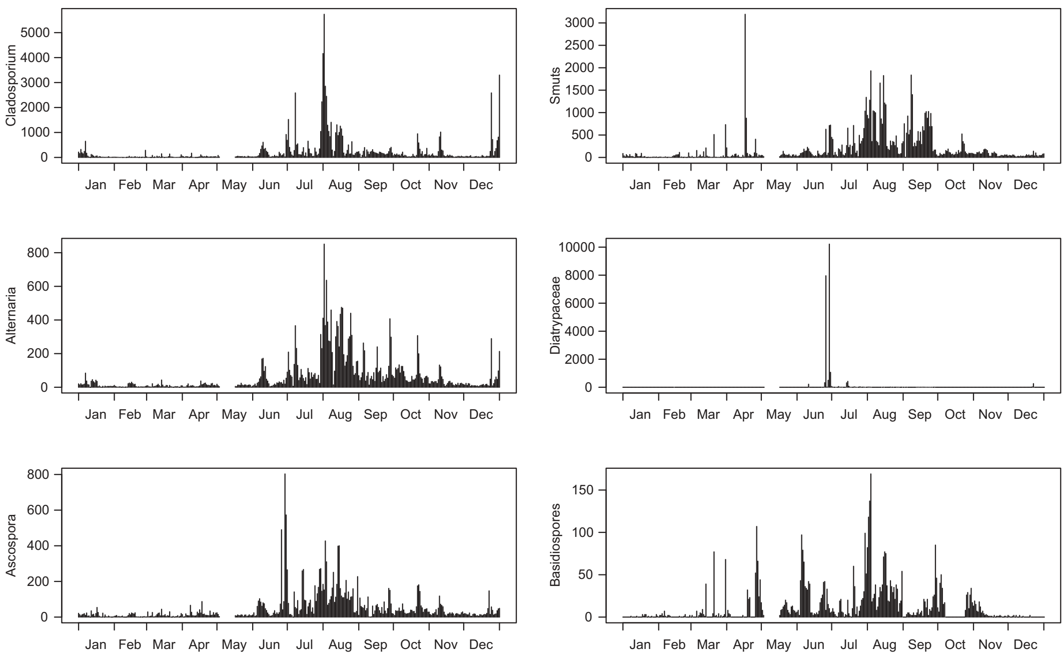

Figure 6. Daily in spore counts for the six most common taxa (Cladosporium spp., Smuts, Alternaria spp., Diatrypaceae, Ascospora and Basidiospores) in the city of Hermosillo, Mexico, during 2016.

Diatrypaceae spores were only present during June at high concentrations (8000 spore day/m^3) but they were absent during the rest of the year (Figure 6).

Pollen counts by taxon have an evident temporal pattern, as revealed by a correspondence analysis biplot (Figure 7). Square roots of the first and second eigenvalue of this analysis, $\sqrt{\lambda_1} = 0.6174$ and $\sqrt{\lambda_2} = 0.5924$, reveal a moderate relationship between pollen counts and timing

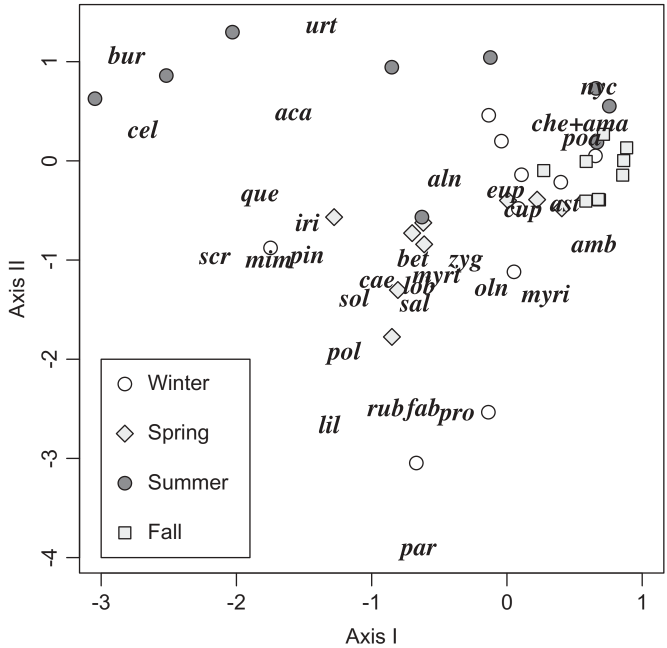

Figure 7. Temporal patterns of occurrence in pollen taxa as revealed by this correspondence analysis biplot from pollen data collected in the city of Hermosillo, Mexico, during 2016. Dots in the biplot are 10-day periods labeled by seasons. Pollen codes: Acacia (aca); Alnus (aln); Ambrosia (amb); Amaranthaceae (che + ama); Betulaceae (bet); Bursera (bur); Caesalpinia (cae); Celtis (cel); Euphorbiaceae (eup); Cupressaceae (cup); Fabaceae (fab); *Iridaceae* (iri); Liliaceae (lil); Mimosa (mim); Myrtaceae (myrt); Myricaceae (myri); Nyctaginaceae (nyc); Olneya (oln); Parietaria (par); Pinus (pin); Poaceae (poa); Prosopis (pro), *Polemoniaceae* (pol); Quercus (que), Rubiaceae (rub); Sapindaceae (sal); Scrophulariaceae (scr); Solanaceae (sol); Urticaceae (urt); *Zygophyllaceae* (zyg).

of sampling. Spring clearly separates from other seasons into a group with dominance of *Alnus*, Betulaceae, Caesalpinia, *Fabaceae*, Iridaceae, Lobeliaceae, Myrtaceae, *Olneya*, Pinus, *Polemoniaceae*, Scrophulariaceae, Solanaceae and Zygophyllaceae. In addition, summer clearly differs from other seasons by the prevalence of Bursera, Urticaceae, *Acacia* and *Celtis* pollen. Finally, fall and winter form a group in the biplot defined by the prevalence of *Ambrosia*, Asteraceae, Amaranthaceae, Cupressaceae, Euphorbiaceae, Nyctaginaceae and Poaceae principally.

Spore counts by taxon have also temporal pattern as revealed by a correspondence analysis biplot (Figure 8), although not as strong as that of pollen. Square roots of the first and second eigenvalue of this analysis, $\sqrt{\lambda_1} = 0.3030$ and for $\sqrt{\lambda_2} = 0.1773$, reveal a weak relationship between spore counts and timing of sampling for the presence of frequent outliers in spore counts. Nevertheless, we included this correspondence analysis biplot since temporal patterns for some taxon still arose. The temporal differences in fungal spore concentrations revealed by this correspondence analysis biplot (Figure 8) indicate for spring a group conformed by Basidiospores, *Leptosphaeria*, Myxomycetes and *Pithomyces*. Summer season has a more dispersed pattern with the dominance of Bipolaris, Diatrypaceae and Sporormiella. Fall and winter are grouped together (such as in pollen taxa biplot, Figure 7) with *Alternaria, Cladosporium*, Smut and *Torula*.

Correlation between airborne pollen and spore concentrations and weather conditions

There exists convincing evidence of correlation between meteorological variables and pollen and spore concentrations at Hermosillo (Tables 3 and 4). Results of simple linear correlation analyses show positive correlations between six principal pollen taxa (Table 3) (Poaceae, Nyctaginaceae,

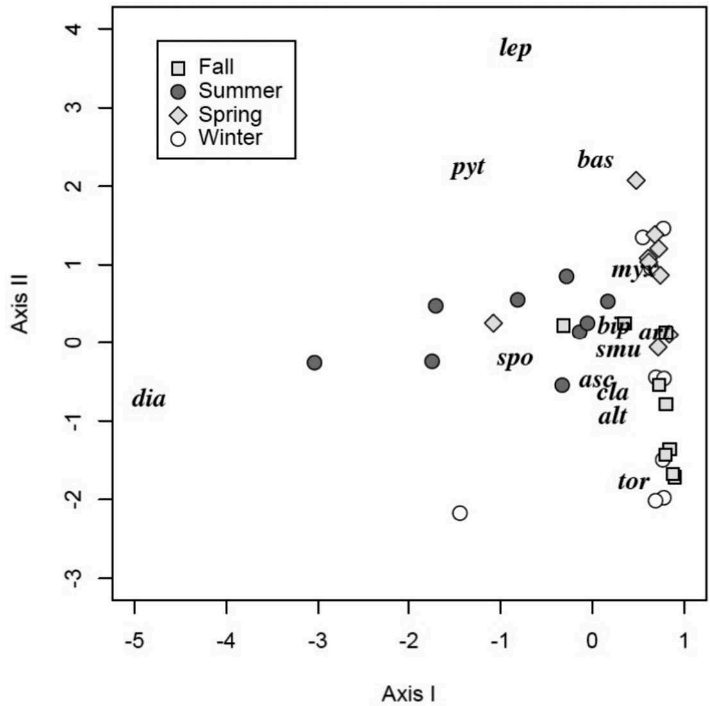

Figure 8. Temporal patterns of occurrence in fungal spore taxa as revealed by this correspondence analysis biplot from spores data collected in the city of Hermosillo, Mexico, during 2016. Dots in the biplot are 10-day periods labeled by seasons. Spore codes: Alternaria (alt); Arthrinium (art); Ascospores (asc); Basidiospores (bas); Bipolaris (bip); Cladosporium (cla); Diatrypaceae (dia); Leptonites (lep); Myxomycetes (mix); Phytomices (pyt); Sporormiella (spo); Smuts (smu); Torula (tor).

Ambrosia, Chenopodiaceae–Amaranthaceae, Urticaceae and Fabaceae) with mean daily relative humidity ($P < 0.001$ for t-test of H_0: $\rho = 0$ and H_a: $\rho \neq 0$). Poaceae, Nyctaginaceae and Chenopodiaceae–Amaranthaceae present positive correlation also with maximum daily temperature ($P < 0.001$ for t-test of H_0: $\rho = 0$ and H_a: $\rho \neq 0$). Furthermore, Poaceae, Chenopodiaceae–Amaranthaceae, Urticaceae and Fabaceae pollen correlate positively with wind speed ($P < 0.05$ for t-test of H_0: $\rho = 0$ and H_a: $\rho \neq 0$). The only taxon that correlates positively with precipitation is Nyctaginaceae nevertheless in less degree ($P < 0.05$ for t-test of H_0: $\rho = 0$ and H_a: $\rho \neq 0$).

Fungal spores also presented a robust correlation with some meteorological variables (Table 4). Results from simple linear correlation analyses show positive relationship between spore concentrations for the main six fungus taxa and meteorological variables (Table 4). All the spore taxa (*Cladosporium*, Smut, *Alternaria*, Diatrypaceae, Ascospora, Basidiospores) had positive correlation with maximum daily temperature and daily relative humidity, except *Diatrypaceae* for humidity ($P < 0.001$ for t-test of H_0: $\rho = 0$ and H_a: $\rho \neq 0$). *Cladosporium*, Smuts, *Alternaria* and Ascospores also correlated positively with precipitation ($P < 0.001$ for t-test of H_0: $\rho = 0$ and H_a: $\rho \neq 0$). All taxa except *Cladosporium* also correlate positively with wind speed ($P < 0.001$ for t-test of H_0: $\rho = 0$ and H_a: $\rho \neq 0$).

Impacts of airborne pollen and spore concentrations in human health

Data from the State Health Department (Secretaría de Salud del Estado de Sonora 2018) were provided for this research (Figure 9). We found in total 13,454 cases of people, who presented diseases related to allergies during 2016 for Hermosillo municipally, only data related to common diseases such as rhinoconjunctivitis and rhinopharyngitis were provided for this year. We are

Table 3. Simple linear correlation coefficients (R^2) between pollen counts and environmental variables for the main six pollen taxa and maximum daily temperature (*T*), mean daily relative humidity (*H*), total daily precipitation (*P*), mean wind speed (*V*) and mean wind direction (*D*).

Taxa	*n* Value	*T*	*H*	*P*	*V*	*D*
Poaceae	297	**0.26*** **	**0.21*** **	−0.03	**0.15** **	−0.13
Nyctaginaceae	213	**0.28*** **	**0.25*** **	**0.14***	−0.03	−0.15
Ambrosia spp.	224	**0.15** **	0.09	−0.10	−0.05	0.06
Chenopodiaceae + *Amaranthaceae*	223	**0.26*** **	**0.21*** **	−0.12	**0.13***	−0.07
Urticaceae	162	**0.20** **	0.11	−0.02	**0.15***	−0.20
Fabaceae spp.	142	**0.21** **	−0.06	0.02	**0.16***	−0.19

Number of data used for each taxa as shown (*n* value). Symbols ***, ** and *denote *P* values <0.001, <0.01 and <0.05, respectively, for the t-test of H_0: $\rho = 0$ and H_a: $\rho \neq 0$. Coefficients with statistical significance are shown in bold.

Table 4. Simple linear correlation coefficients (R^2) between fungal spore counts and environmental variables for the main six fungal spore taxa and maximum daily temperature (*T*), mean daily relative humidity (*H*), total daily precipitation (*P*), mean wind speed (*V*) and mean wind direction (*D*).

Taxa	*n* Value	*T*	*H*	*P*	*V*	*D*
Cladosporium spp.	331	**0.10***	**0.32*** **	**0.13***	0.05	−0.12
Smuts	335	**0.25*** **	**0.33*** **	**0.26*** **	**0.23*** **	−0.13
Alternaria spp.	339	**0.30*** **	**0.35*** **	**0.10***	**0.16*** **	−0.19
Diatrypaceae	164	**0.20***	−0.12	−0.10	**0.19***	0.10
Ascospora	329	**0.32*** **	**0.33*** **	**0.24*** **	**0.18*** **	−0.21
Basidiospores	230	**0.24*** **	**0.23*** **	0.05	**0.18** **	−0.90

Number of data used for each taxa as shown (*n* value). Symbols ***, ** and *denote *P* values <0.001, <0.01 and <0.05, respectively, for the *t*-test of H_0: $\rho = 0$ and H_a: $\rho \neq 0$. Coefficients with statistical significance are shown in bold.

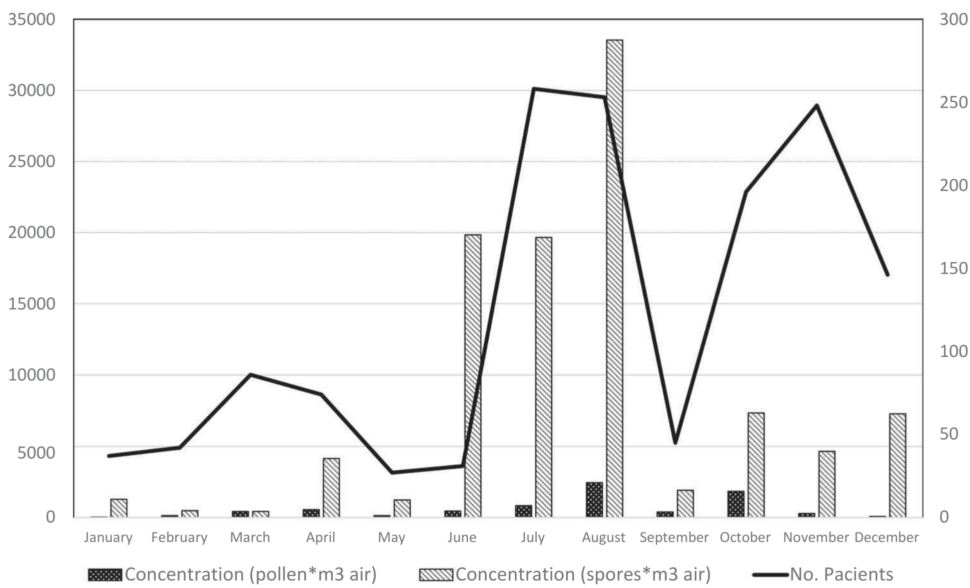

Figure 9. Monthly concentrations of spores and pollen in the city of Hermosillo, Mexico, during 2016 compared with the number of patients reported by the secretary of health who presented a common disease related to allergies (black line).

working to get more information about other diseases (e.g. asthma) related to allergies for the city. We observe clearly during summer and fall the highest number of patients attended, which correlates precisely with the highest pollen and spore concentration peaks during the year (Figure9). It seems that people respond quickly to the presence of this pollen and spores, principally grasses, in the atmosphere.

Discussion

This work represents the first aerobiological (pollen and fungal spores) study carried out in the arid urban environment of Hermosillo, and the second in Sonora (Moreno-Sarmiento et al. 2016), the latter reporting only fungal spores. Our results are very important because Hermosillo concentrates 40% of total population of Sonora. APIn estimated for this study (16,243 pollen day/m^3) was comparable with those of other northern cities in Mexico such as Monterrey (12,354 pollen day/m^3). However, we recorded a higher APIn than that of the city of Mexicali (Baja California) with a hotter climate, which records 1973 pollen grains/m^3. In more temperate regions, such as Mexico City, APIn ranges at higher levels from 25,062 to 113,253 pollen day/m^3 (Calderón-Ezquerro et al. 2015), which is expected because of the lower water limitation of temperate regions, whereas desert region plants are limited by precipitation events, and then pollen production is less important compared with those temperate regions (Ziska et al. 2008).

ASIn in Hermosillo (222,365 spore day/m^3) is much higher than that of Ciudad Obregón in southern Sonora (1690 spore day/m^3) as a consequence of differences in climatic conditions. For instance, ASIn reaches values around 11,000 spore day/m^3 in tropical zones (Adhikari et al. 2004); in arid zones, ASIn values range from 3500 to 34,000 spore day/m^3 (Rocha-Estrada et al. 2013). ASIn in Hermosillo is higher than ASIn reported for those studies, likely due to higher temperatures and higher humidity during the summer monsoon season leading to higher dispersal of fungal spores after this rainy period (Figure 5). Low concentration of fungal spores in Ciudad Obregón is linked to the removal of spores by winds (Moreno-Sarmiento et al. 2016) and to higher air humidity through the year.

We found that 40% and 60% pollen taxa (n = 32) corresponded to trees and to herbaceous plants and shrubs, respectively, reflecting the current composition of the plant community at the city with dominance of shrubs and herbs (Enciso-Miranda 2016). The main pollen taxa recorded in this study were Poaceae, Nyctaginaceae, *Ambrosia*, Amaranthaceae and Urticaceae. Our results are consistent with those from previous years suggesting low annual variation in pollen composition. Amaya-García (2015) and Amador-Rosas and Dominguez-Romo (2015) reported the same diversity of dominant pollen taxa for Hermosillo for 2013 and 2014, respectively. All these pollen taxa, except Nyctaginaceae, are well documented to have significant allergenic properties (Ahumada-Valdez et al. 2009; Rocha-Estrada et al. 2013; Calderon-Ezquerro et al. 2018).

The main spores out of the 18 different types were *Cladosporium*, Smuts. *Alternaria*, Diatrypaceae and Ascospora (Div. Ascomycota) accounting for the 94% of annual spore count. These data are consistent with those reported for Ciudad Obregon by Moreno-Sarmiento et al. (2016, except for Diatrypaceae) those reported for Hermosillo by Amaya-García (2015) and Amador-Rosas and Dominguez-Romo (2015). Our results on fungal spores are also similar to those found in central Mexico where *Cladosporium* and *Alternaria* are the most common airborne spores (Rosas et al. 1990) as well as Basidiospores (Calderón et al. 1995) in Mexico City. These fungal spores such as *Cladosporium* and *Alternaria* are common in urban and rural areas close to agricultural fields due to their presence in crops (Rocha-Estrada et al. 2013).

In spite of low annual variation in pollen and fungal spore taxa composition, we observed a significant annual variation at Hermosillo city, in pollen and spore concentrations. Pollen counts (in APIn units) for the second half of the year (June–December) were 2623 and 6292 for 2013 (Amaya-García 2015) and 2016 (this study), respectively. Similarly, spore counts (in ASIn units) for the same months were 21,430 and 94,195 for 2013 (Amaya-García 2015) and 2016 (this study), respectively. In addition, both APIn (2517) and ASIn (22,272) were two and three times lower from January to October in 2014 (Amador-Rosas and Dominguez-Romo 2015) than in 2016. This increase in pollen and spore concentrations during 2016 is likely related to abnormalities in the seasonal precipitation pattern of Hermosillo in 2016 (Martínez-Ramírez 2018). Historical data for Hermosillo (Gutiérrez-Ruacho et al. 2018) for a period of 53 years show a mean annual precipitation values for this site of around 365.3 mm. Although annual rainfall in 2016 (328 mm) was only 10% lower than the annual rainfall average, the distribution of precipitation was unusual with September as the rainiest month and a bimodal distribution of summer rains (Martínez-Ramírez 2018), whereas the historical data (Gutiérrez-Ruacho et al. 2010) clearly show that most important precipitation events for this city occurred during July. It is well known that summer precipitation drives the reproductive cycles of herbaceous plants in the Sonoran desert (Molina-Freaner and Van-Devender 2000). Consequently, pollen production and dispersal are favored by increasing temperatures and reduced by precipitation events (Calderón-Ezquerro et al. 2015).

Seasonal variation of pollen and spore concentrations in Hermosillo is evident as changes in pollen and spore concentrations must be directly related to weather conditions as was stated for other regional works (Rocha-Estrada et al. 2013; Moreno-Sarmiento et al. 2016). During the winter rains (November–February, Figure 4), we found the lowest concentrations of pollen and spores in the year (500 pollen day/m^3 and 13,683 spore day/m^3), being even than those of the dry season from March to June (1535 pollen day/$m^3$and fungal spores for 25,930 spore day/m^3). The highest concentrations of allergens (5494 pollen day/m^3 and 62,426 spore day/m^3), recorded during the summer rainy period (July–October), were directly influenced by a monsoonal system. It is well documented that higher temperatures and wetter conditions stimulated the production and release of spores (Calderón et al. 1995, 1997). Our pollen and spore data correlate well with the other studies in the region (such as Moreno-Sarmiento et al. 2016). For instance, the highest concentrations of pollen occur in the spring and the summer in Sonora, whereas the highest pollen concentrations are reported during winter and spring for Monterrey (Rocha-Estrada et al. 2013). Furthermore, we found a strong positive correlation between pollen and spore concentrations with humidity and temperature but negative correlation of pollen with precipitation (Tables 3 and 4). Allergic risk then immediately increases after precipitation events as temperature increases and the concentrations of pollen and spores increase, as supported by other studies (Méndez et al. 2000; Rodríguez-Rajo et al. 2002; Stevenson et al. 2007; Calderón-Ezquerro et al. 2015). In the city of Monterrey, airborne pollen also decreases with precipitation, although a lagging effect was observed when heavy rainfall events during winter were followed by the highest pollen concentrations in March (Rocha-Estrada et al. 2013). In Ciudad Obregón, Moreno-Sarmiento et al. (2016) also found that spores correlate with both relative humidity and temperatures for the rainy season. In the city of Mexicali, pollen also correlates with relative humidity (Ahumada-Valdez et al. 2006). In a regional context, all these studies corroborate that the highest concentration of pollen and spores occurs during the warmest and most humid part of the year. However, although relative humidity increases the presence of fungi, humidity does not necessary increase spore production (Calderon-Ezquerro et al. 2015, 2018). Therefore, the release of fungal spores apparently depends more on the increase temperatures and less on the increase relative humidity (Calderon et al. 2017). Some pollen taxa such as Poaceae, Chenopodiaceae–Amaranthaceae, Urticaceae and Fabaceae were influenced by wind speed (positive correlation, Table 3), this higher presence in the atmosphere occurs in summer. It means that this taxon is more abundant at the city when wind comes from S and W. Dominant wind directions come from W and SW principally during the dry season, whereas wind converge from different directions, SE, SW and W, during summer period (when pollen concentrations are higher). This effect is also related to monsoon system that is strong during July–August and September (Higgins et al. 2003) which bring more strong winds in northwestern Mexico. Therefore, higher concentrations of pollen and spores during summer also are likely linked to the convergence of winds into the city allowing the entry of these airborne particles from different places nearby and their permanence in the city's environment. Principal sources of pollen in Hermosillo are local urban vegetation and surrounding native vegetation, whereas fungal spore sources are more related to the agricultural lands close to the city. Our results agree with those of Calderón-Ezquerro et al. (2015) for Mexico City where wind direction affects the type and concentration of pollen and spores within the city.

According to the international aerobiological networks such as Spanish Aerobiological Network and Mexican Aerobiological Network (REA 2007; REMA 2016), the biological air quality of one city or region is stablished according to daily allergenic-pollen concentrations and due to the possible simultaneous presence, of one or more pollen types with allergenic capacity. There exist four categories to establish the biological quality of air in an area: (1) Good: when the pollen types present in the air are maintained at low pollen concentration levels; (2) acceptable, if the concentrations of pollen grains are low for most pollen types but some of them have a greater allergenic, (3) regular: if the concentrations of pollen grains of types with greater allergenic potential are within moderate categories, but two pollen types or more of high allergenic potential that are present at the same time; (4) bad: provided that one of the types with the highest allergenic potential is present in high concentrations, or when there are moderate concentrations of two pollen types of high allergenic potential simultaneously (REA 2007). In this sense, the biological air quality of Hermosillo is then critical during two seasons. The first and most important peak in pollen and spore concentrations occurs in summer, yielding a 'bad' air quality because Poaceae and Chenopodiaceae has a high allergenic potential and occurs together at this season (Figure 4). Summer is precisely when symptoms and occurrence of diseases related to allergies increase in Hermosillo (García-Arellano 2018) and its coincidence with peak allergen concentrations deserves special atention. The second peak in pollen and spores concentration for Hermosillo occurs during October (Figures 4 and 5) when Ambrosia, Chenopodiaceae and Poaceae are together in higher concentrations leading to also a 'bad' biological air quality (Galan et al., 2007; REA 2007). The two peaks of pollen and spore concentrations in the city may be related to the period attaining the highest temperatures (Calderon et al. 2015; 2018). In the particular case of pollen, its release to the atmosphere depends on the flowering period of plants that in turn depends on weather and physiological processes. Our results indicate that the increase of airborne pollen concentrations depends on higher temperatures and relative humidity (Figure 2), conditions that appear at this desert city after rainy days. When precipitation occurs (mostly in the summer), all particle matters of the atmosphere are washed away and precipitated on several surfaces (Meza-Figueroa et al. 2007). But in desert regions, all dust deposited on surfaces is quickly resuspended to the atmosphere after rainy days, explaining pollen concentration increases after rain events. Plants depend on precipitation to produce pollen, but the release of pollen needs additional conditions as mentioned above. In this regard, Martínez-Ramírez (2018) reported atypical distribution of rains during 2016 related to a weak 'La Niña' event, where the most intense precipitation event of the year occurred in September (unusual for this region) and pollen and spore concentrations considerably decreased at that time. This finding is consistent with most of the data reported for Mexico City (Torres-Valdos 2006; Calderón-Ezquerro et al. 2015) followed by an abrupt increase of pollen, principally by herbs (Poaceae, *Ambrosia* and Chenopodiaceae–Amaranthaceae), during October in response to an increased relative humidity after rainy days. Herbaceous pollen, such as Poaceae's (with the highest concentrations in this study), is the principal cause of cutaneous sensibility (González-Galán et al. 1998; Rodríguez-Rajo et al. 2002). Actually, if daily concentrations are higher than 59 pollen day/m^3, Poaceae pollen can produce severe symptoms in allergic people (Davies and Smith 1973; Ong et al. 1997). In this study, Poaceae exceeded these threshold values during several days in August, September and October, precisely when more cases of allergic-related diseases were reported in Hermosillo during 2016 (Secretaria de Salud Pública Municipal comp. pers.). In Mexico, some aerobiological studies have reported the presence of Poaceae throughout the year as well (Salazar-Coria 1995; Torres-Valdos 2006; Calderón et al. 2015).

In particular for fungal spores, it is well known that high humidity and rain favor the production and release of fungal spores (Calderón et al. 2009). Our results show that the release of fungal spores to the atmosphere depends of high temperature and high relative humidity, in agreement with other studies in Mexico (Calderón et al. 2009; Moreno-Sarmiento et al. 2016).

The impacts of this airborne pollen and spores on population health at this desert city of Northwestern Mexico are clearly evidenced by the State Health Department. Data provided from Hermosillo city on a number of patients treated for respiratory diseases related to allergies

(Secretaria de Salud del Estado de Sonora 2018) indicate clearly a correspondence of the increasing of pollen and spores in the atmosphere and the amount of persons who presented one of the common diseases related to allergies (Figure 9). After September, many allergists from the city report highest cases of patients who attended more severe diseases (Espinoza-Vizcaino 2017), this peak in allergies is centered during October and correlates well with our peaks in pollen and fungal spores. We hypothesize that the increase of Poaceae pollen concentrations in October is causing severe effects in population health. A recent study developed by Children's Hospital (López-Romero et al. 2017) regarding the allergens sensitization of children's (2–18 years old) in Hermosillo denotes clearly a high frequency of patients suffering allergies related to pollen. One hundred and twenty-five patients were treated with asthma (68.8%) and allergic rhinitis (14.4%). Patients resulting positively to allergic-cutaneous test are more sensitive to grasses (40.7%), trees (18.4%) and herbs (16.4%). Most important taxa were *C. dactylon* (17.9%), *A. bracteosa* (12.9%), *P. juliflora* (11.9%), *L. perene* (10.9%) and *Z. mays* (8.4%) (López-Romero et al. 2017). In our study, we found other most common pollen taxa present at Hermosillo city such as Nyctaginaceae, *Ambrosia*, Chenopodiaceae, Urticaceae, *Quercus*, Cupressaceae, *Parkinsonia*, Burseraceae, Scrophulariaceae, *Celtis*, Asteraceae, Rubiaceae, Solanaceae, Lobeliaceae, Fabaceae, with higher concentration in the air during 2016 and all of them has a allergenic potential effect (Galan et al., 2007; REA 2007), we recommended to take allergic-cutaneous test over this taxon to explore the sensitization of Hermosillo population to these abundant airborne particles of Hermosillo. In the case of fungal spores, we recorded that the highest concentrations in Hermosillo during summer principal taxa which are *Alternaria, Cladosporium*, Smuts, Diatrypaceae, Ascospora, Basidiospores, Myxomycetes, Bipolaris, it seems that population of this city is not highly sensitive to fungal spores. López-Romero et al. (2017) tested also on children's population the sensitization of *Alternaria* and *Aspergillus* but the results show that only 1.4% of the tested population presented sensitization to this kind of fungal spores. We think that more specific teste of this fungal spore is needed to confirm the degree of population sensitization. This new information about the distribution and concentration of airborne pollen and spores is relevant for preventing impacts at human health (related to allergies) at this desert city. Preventive measures must be implemented and also environmental improvement for the control of this group of allergic diseases.

Conclusions

This work represents the first aerobiological study for Hermosillo, providing highly relevant results of great impact in public health. We detected important allergenic pollen and spore taxa and revealed their prevalence in Hermosillo's air at high concentrations. We also found a strong correlation between weather and pollen and spore concentrations that provide an excellent tool for air-quality contingency alerts. Temperature and humidity increase these biological particles in the atmosphere, whereas precipitation lowers pollen concentration. This information will allow health agencies to identify periods of higher vulnerability for people suffering from allergenic-related diseases. We also identified two critical periods when pollen and spore concentration increases due to the frequent occurrence of windsfrom SW and W: (1) June–October (also SE) and (2) March–May. Moreover, we proved that fungal spores, rather than pollen, are the most important allergenic agents for this desert city. Therefore, it is imperative to extend this study for at least 5 years and produce an allergenic calendar of pollen and spores that will greatly be able to help people to cope with their allergies.

Declaration of interest statement

The authors report no conflict of interest

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