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Pollen in the atmosphere of Mexico City and its impact on the health of the pediatric population

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A R T I C L E I N F O

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A B S T R A C T

Over a period of eight years, were assessed the main types of airborne pollen in Mexico City (a tropical region). We established the airborne pollen calendar and we evaluated the associations between aeroallergens and allergic diseases in children treated at hospitals. A Hirst-type volumetric spore trap was placed in an open area within the Chapultepec Forest, and pollen records were obtained during the flowering period of the plants. A total of 502 patients between 1 and 17 years old were evaluated. The patients were diagnosed by skin testing with extracts of tree pollen, grass and weeds. During the monitoring period, the airborne pollen grains were dominated by trees (*Fraxinus*, Cupressaceae, *Alnus*, *Quercus*) followed by Poaceae, with the highest average values detected between January and February. Children with positive reactions to pollen aeroallergens were diagnosed with allergic diseases. The predominant airborne allergens were determined. An airborne pollen calendar was established. A close association was found between the most frequent and abundant pollen types and the responses of children produced by exposure to pollen grains. Children with positive reactions to pollen were diagnosed with allergic conjunctivitis, allergic rhinitis, asthma and keratoconjunctivitis.

1. Introduction

The health status of an ecosystem can be determined by the quantity and quality of its atmospheric load and the load generated by more distant areas. For this reason, it is important identify the biological particles to which we are exposed that can cause damage to the health of both, the population and the environment. Some studies have determined that airborne pollutants can increase the frequency and intensity of symptoms in allergic individuals, as well as promote sensitization to airborne allergens in the respiratory tracts of predisposed subjects (D'Amato, 2002). Allergic diseases (ADs) are considered to be a global public health problem, and have been classified by the WHO among the six most common chronic diseases worldwide. ADs are the most frequent pathology in childhood, among the chronic diseases that may occur at this stage (Park et al., 2012; Zubeldia et al., 2012).

Among the main bioaerosols are pollen grains, which are naturally produced because they are part of the reproductive process of gymnosperms and angiosperms (De Weerd et al., 2002). Pollen is one of the main sources of allergens in the air and is one of the most common triggers of allergic diseases (Kiotseridis et al., 2013a). For example, allergic rhinoconjunctivitis (ARC), hay fever and allergic asthma affect almost 10% of the world's population, increasing to more than 25% of the population in industrialized or heavily contaminated cities; its incidence has doubled in the last three decades (Diethart et al., 2007).

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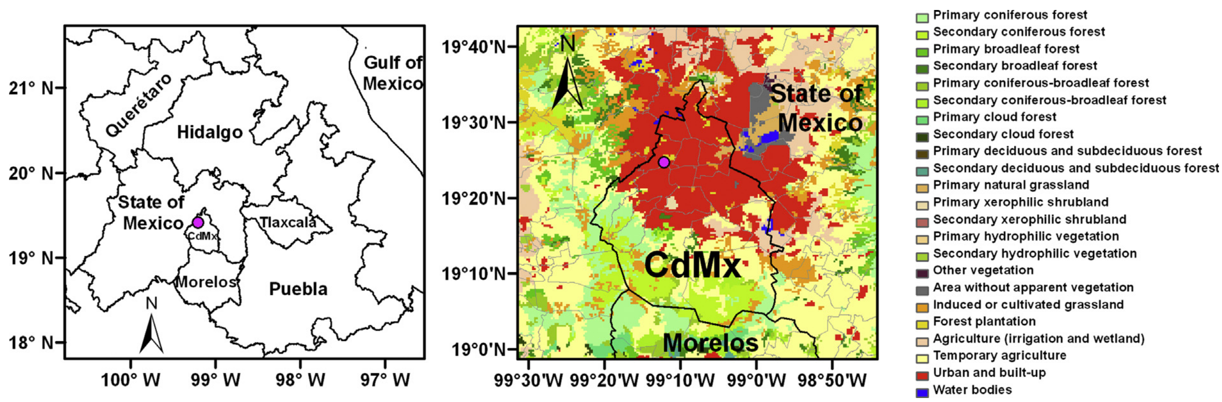


Fig. 1. Location of the pollen grain monitoring station northwest of Mexico City and the distribution of vegetation cover and land use for the city and metropolitan areas.

Vignola et al. (1998) reported that 30% of children with rhinitis have asthma and more than 80% of children with asthma have symptoms of rhinitis. These diseases, along with other afflictions, are responsible for a worldwide mortality rate of approximately 250,000 people/year. Airborne pollen, in addition to affecting pediatric health, alters many aspects of patients' daily lives, including physical and emotional aspects (Pawankar et al., 2011).

Today, there are few countries in Latin America (mostly Argentina and Mexico) and some countries in less developed continents where aerobiological studies are performed, but usually without a continuous sampling on bioaerosols. In Mexico, different studies have focused on pollen detection since 1940, but we have no continuous databases (González-Macías et al., 1993; Bronillet-Tarragó, 1992, 1996; Salazar-Coria, 1995; Rosas et al., 1998; González-Lozano et al., 1999; Torres-Valdos, 2006; Cid-Martínez, 2007). Due to the above, the international scientific community, in the frame of the 8th International Congress on Aerobiology 2006, transmitted to the aerobiologists in Latin American the urgency to carry out studies on airborne pollen to determine their impacts on health. In addition, they noted that there are few studies on this subject in subtropical and tropical regions, such as Mexico, since most research on airborne pollen and their effects on health have been carried out in developed regions such as Canada, the United States of America and Europe, among others.

Pollen allergens trigger inflammatory responses (Kiotseridis et al., 2013a). Some papers have shown positive correlations between airborne pollen and allergic symptomatology (Sack et al., 1942; D'Amato and Lobefalo, 1989; Kiotseridis et al., 2013a; Weger et al., 2013; Grewling et al., 2016; Kmenta et al., 2016; Cebrino et al., 2017). For this reason, pollen calendars offer important tools for both allergologists and patients, as doctors can plan the most appropriate treatments and the allergic subjects will be able to plan their work and recreational activities (Martínez-Bracero et al., 2015) (https://www.uco.es/rea/; http://rema.atmosfera.unam.mx/rema/). This information has been a determinant in epidemiological studies of some related respiratory diseases.

In Mexico, several clinical studies have investigated the effects of allergens from microorganisms or biological particles, such as mites, fungal spores and pollen, among others, on human health (Salazar-Mallén, 1949; Cueva-Velázquez, 1970; Montes and Cisneros, 1982; Bronillet-Tarragó, 1996; Enríquez-Palomec et al., 1997; Rosas et al., 1998). A relationship has been observed between different pollen types and allergic diseases, such as conjunctivitis, rhinitis and asthma (Salazar-Mallén, 1949; Cueva-Velázquez, 1970; Montes and Cisneros, 1982; Ontiveros-Castro et al., 1995; González-Lozano et al., 1999; Larenas-Linnemann et al., 2009, 2011; Rocha et al., 2009; Calderón-Ezquerro et al., 2016). On the other hand, it is important to point out that pollen in densely populated urban areas, such as Beijing, Delhi and Mexico City, may carry aeroparticles of organic and inorganic origin in their exines that serve as coadjuvants and increase the allergenicity of the pollen, thereby increasing the health risk in sensitive exposed populations (Cao et al., 2014; Ribeiro et al., 2014).

Due to the serious effects caused by the exposure of sensitive populations to pollen, the Mexican Aerobiology Network (Red Mexicana de Aerobiología, REMA) was created in 2008 to perform continuous monitoring of airborne biological particles in various areas of the country (Calderón-Ezquerro et al., 2015, 2016). This network has published pollen calendars for some municipalities or delegations, presenting the main pollen types to which the population of the city is exposed. Calderón-Ezquerro et al. (2016) published the first pollen calendar in the south of Mexico City. In this study, tree species such as *Fraxinus, Alnus,* Cupressaceae and *Quercus* were reported as the most abundant and allergenic, followed by pollen from the Poaceae family and other herbaceous plants.

The main goals of this study were to present a pollen calendar for northwestern Mexico City and to assess the relationship between airborne pollen and allergic diseases in children.

2. Material and methods

2.1. Studied area

Mexico City is located in the south-central region of the country and lies within the basin of the Valley of Mexico at the coordinates 99°12′07″ W and 19°24′38″ N and an altitude of 2292 meters above sea level (m.a.s.l.). The city is surrounded by mountains except for the north. Forty-five percent of the city is urbanized (north and center), whereas 55% is located in rural areas to the south and east, where the land is used for ecological reserves, forestry and agriculture (INEGI, 2010) (Fig. 1).

The sampling station is located in the Miguel Hidalgo Delegation, within the Chapultepec Forest (Miguel Hidalgo Delegation), the largest urban green area in the country (Meza-Aguilar and Moncada-Maya, 2010) and also in Latin America, with an area of 686.01 hectares (Casasola, 2006; GDF, 2006a) located at an altitude between 2250 and 2300 m m.a.s.l. in the upper part of the third section (Molina, 1979), 166,818 trees according to the inventory conducted by the National Institute of Forestry, Agriculture and Livestock Research (INIFAP-DBCh, 2009). This area contains 105 species, particularly: *Ligustrum lucidum* (thunder), *Fraxinus uhdei* (ash), *Cupressus benthamii* (white cedar), *Taxodium mucronatum* (Ahuehuete) and *Lusitanian Cupressus* (white cedar), as well as some herbaceous families: Asteraceae, Amaranthaceae, Poligonaceae, Solanaceae, Commenilaceae, Cyperaceae and Lilaceae (Guerrero, 1997; GDF, 2006b).

This area is characterized by a dry season from November to April and a rainy season from May to October.

2.2. Pollen monitoring and analysis

Pollen sampling was performed using a Hirst-type volumetric spore trap (Hirst, 1952), from September 21, 2008, to September 12, 2016. The sampler was located on the roof of the Museum of Natural History in Chapultepec Park, 15 m above ground level. Data analysis and management were carried out following the protocol published by the Spanish Aerobiology Network (REA) Management and Quality Manual (Galán et al., 2007) and the minimum recommendations of the European Aeroallergen Network (EAN) (Galán et al., 2017). The pollen concentration is expressed as the daily average of pollen grains/m^3 of air. The main pollen season (MPS) was defined according to Andersen (1991), considering 95% of the annual pollen. Pollen season starts on the first day with a cumulative daily pollen concentration of 2.5% and finishes at 97.5%. The annual pollen integral (APIn) was used to present inter-annual variations.

2.3. Determination of the pollination period

To determine the days of beginning and end of the period of pollination, and therefore of flowering, the cumulative method was used at 95%. It was considered "Beginning of the flowering period: date of the first day on which an accumulated pollen concentration equal to or greater than 2.5% is obtained. End of flowering period: date of the last day on which the accumulated concentration of pollen is equal to or lower than 97.5%. Duration of the flowering period: number of days that pass from the start date to the end date of the flowering period "(Nilsson and Persson, 1981; Aguilera et al., 2013).

2.4. Pollen calendar

The pollen calendar was constructed following Spieksma's model (Spieksma and Wahl, 1991), which transformed 10-day mean pollen grains concentrations (pollen grain/m^3 of air) into a series of classes according to Stix and Ferretti (1974), representing series in a pictogram as an average of the eight studied years. Each month was divided into three parts (Fig. 2). This pictogram only present pollen types with a minimum 10-day average equal to or higher than 1 pollen grain/m^3 of air. The pollen calendar was built with Surfer Version 11 software (Golden Software Inc.).

2.5. Selection of patients

A clinical history from 2003 to 2005, related to allergic rhinitis or asthma, was obtained from 502 pediatric patients between 3 and 17 years old who came for the first time to the allergy and clinical immunology services of hospitals located in Mexico City as the Institute of Ophthalmology Count of Valenciana (IOCV, N = 285), 21st Century National Medical Center (CMN, N = 106), National Institute of Pediatrics (INP, N = 22), the Children's Hospital of Mexico (HIM, N = 55) and private hospitals (PHs, N = 34).

For the selection of children, the guidelines for the management and prevention of asthma (Global Initiative for Asthma, 2017) and the guidelines for allergic rhinitis and its impact on asthma (Larenas-Linnemann et al., 2014) were taken as clinical parameters. Patients who met the above criteria for one year were subjected to specific allergen skin tests for sensitivity to tree and herbaceous, house dust mite, epithelia, cockroach and some other allergens. The allergen extracts were obtained from the following manufacturers and used at the standardized concentrations according to the manufacturer: ALK-Abelló, Madrid, Spain; Allerquim, Mexico City, Mexico; IPI-ASAC, Madrid, Spain and ALK-Abelló, Rockville, MD, USA.

Due to the lack of information in some clinical records, we did not perform an association analysis between the positive responses to various allergenic pollen extracts and their seasonal presence. The information obtained from the private hospitals did not present a complete record and, therefore, they were not included in the seasonal analysis.

2.6. Statistical analysis

The clinical results were analyzed using descriptive statistics with IBM SPSS Ver. 22.

3. Results

3.1. Pollen load in Mexico

The APIn (Galán et al., 2017) for different pollen types at the Miguel Hidalgo Delegation station (in Chapultepec Park) of Mexico City is presented in Table 1. The highest APIn was registered during 2009–2010 with a concentration of 101,352 pollen*day/m^3, while the lowest concentration was recorded in 2014–2015, with 42,531 pollen*day/m$^{3.}$

The eight-year monitoring averages (2008–2016) (Table 2) showed the highest percentages of pollen from trees (95%), including *Fraxinus* spp. (40.2%), Cupressaceae (*Cupressus, Thuja* and *Juniperus*: 29.9%), *Alnus* spp. (5.4%), *Pinus* (4.3%) and *Quercus* (3.8%), among others. Pollen from herbaceous plants only represent the 5% of the total, with higher pollen concentrations from Poaceae (2.5%), but also from Urticaceae (1.4%), Amaranthaceae (0.6%) and Asteraceae (0.6%), among others.

Table 3 presents the eight-year monitoring averages monthly values, with the highest pollen concentrations during January of 2009, 2010, 2011, 2013, 2015 and 2016 and February of 2012, 2014 and 2016. The lowest concentrations were registered during the rainy season from June to September.

The most important pollen types based on abundance and allergenicity were *Fraxinus* (trees), Cupressaceae and Poaceae (herbaceous). The concentration of the *Fraxinus* pollen type showed a similar inter-annual pattern, but with some differences on the MPS depending on the flowering intensity. The MPS length during periods with higher pollen concentrations tended to be shorter, i.e. 2009–2010 with 103 days, 2010–2011 with 197 days and 2015–2016 with 112 days, compared to years with lower concentrations, i.e. 2011–2012 with 247 days (Table 4).

In the case of Cupressaceae pollen type, the highest concentrations were obtained during the periods 2009–10 (35,431 pollen*day/m^3), 2010–11 (24,473 pollen*day/m^3) and 2011–12 (39,304 pollen*day/m^3), also representing a shorter MPS; the periods with concentrations lower than 16,086 pollen*day/m^3 coincided with longer MPS (Table 4).

Poaceae pollen type did not show marked inter-annual differences, with annual concentrations between 1263 pollen*day/m^3 (representing 1.59 of total APIn) and 2375 pollen*day/m^3 (5.3% of total APIn). Additionally, the highest daily pollen concentration varied between 19 and 77 pollen grains/m^3. The MPS during the studied period was similar, between 339 and 361 days.

The pollen calendar shows the seasonal variation of the main pollen types collected from the air during the period from 2008 to 2016 (Fig. 2), considering the most abundant taxa (Calderón-Ezquerro et al., 2016). The herbaceous group includes pollen from Poaceae and Urticaceae, whereas the tree pollen include *Ligustrum, Alnus, Fraxinus, Cupressaceae, Myrtaceae, Pinus* and *Quercus*, among others.

3.2. Pollen and allergic children

Regarding the frequency of pediatric patients with allergic diseases by age and gender (Fig. 3), the higher frequency age of treated children varied depending on the hospital, i.e. higher frequency in patients of 10 years old (12.9%) evaluated at the Institute of Ophthalmology Conde de Valenciana (IOCV); or the highest frequency in children of 17 years old (49.0%) treated at the other hospitals. At IOCV, similar to the rest of the

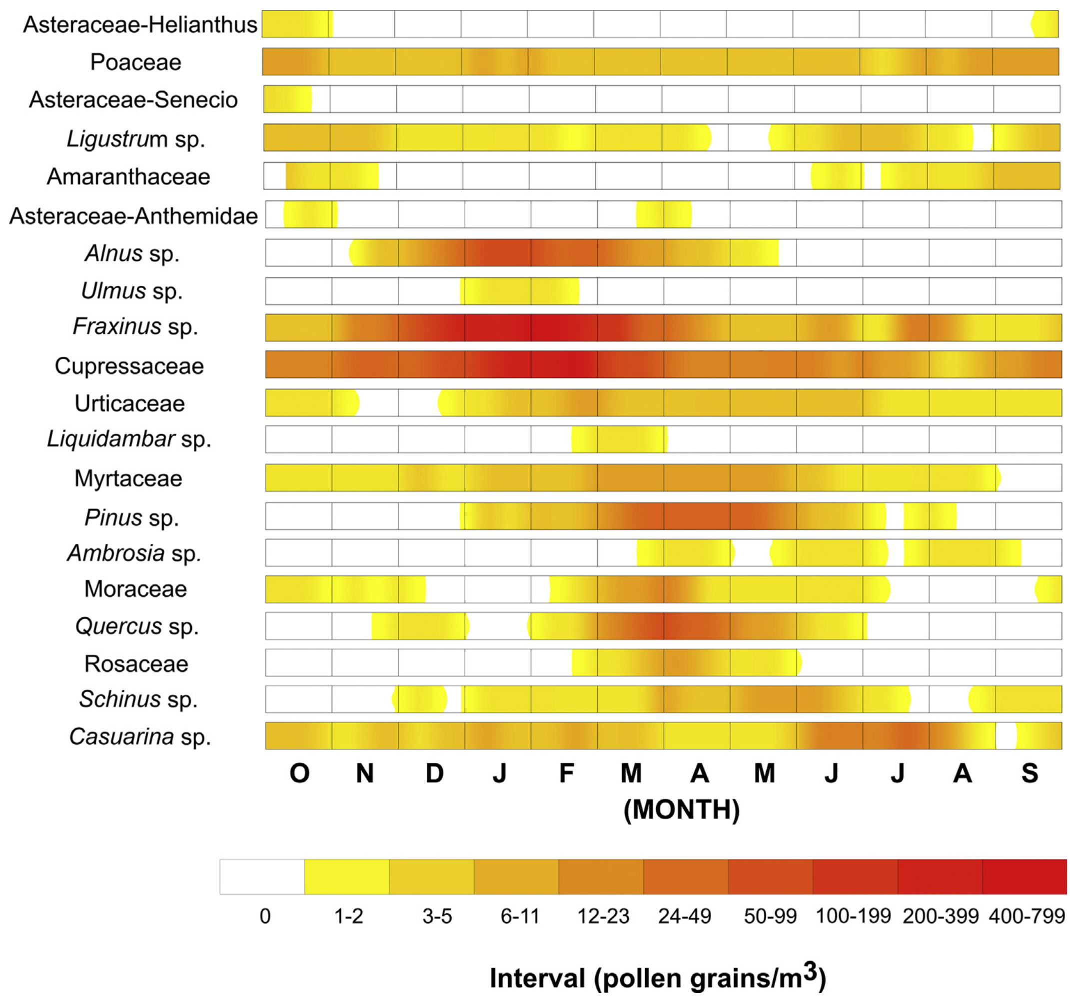


Fig. 2. Pollen calendar of the Miguel Hidalgo delegation (in Chapultepec park), Mexico city, from 2008 to 2016.

Table 1
The Annual Pollen Integral (APIn) recorded at the station of the Miguel Hidal Delegation, Mexico City.

Monitoring station Miguel Hidalgo	Start of sampling year							
	2008	2009	2010	2011	2012	2013	2014	2015
Pollen concentration	41065	101352	84562	86708	45006	42717	42531	62418

hospitals, most patients were male, with 285 patients (56.8%) at IOCV and 217 patients (43.2%) at the other hospitals. Furthermore, 47.6% of the patients treated at IOCV came mainly from the State of Mexico, followed by Mexico City with 41.3%; 11.1% were from other states in Mexico. The children treated at the other hospitals were mainly residents of Mexico City (92.7%) and the State of Mexico (5.7%).

Regarding the skin test results (Fig. 4), the positive response of the children evaluated at IOCV, who presented with mostly allergic conjunctivitis, corresponded to extracts of herbaceous pollen types. A total of 60% of these extracts corresponded to the family Poaceae, followed by pollen from different trees, such as *Olea, Quercus*, Cupressaceae and *Fraxinus*, among others; the positive responses ranged from 22% to 17%. At the other hospitals, the positive responses were to Poaceae (41.5%), *Fraxinus* (27.6%) and *Quercus* (23.5%).

Fig. 5 shows the percentages (and the confidence intervals) of the total number of patients treated at hospitals and who responded positively to pollen extracts throughout the different seasons of the year. The analysis of pediatric patients who responded positively to the pollen extracts showed that 60% of the 285 patients, mainly during the rainy months at IOCV, responded to grass pollen and other herbaceous species, such as Amaranthaceae and Asteraceae (32.6% and 24.2%, respectively). Regarding the trees, responses were observed to *Quercus*, *Olea*, Cupressaceae *Fraxinus* and *Alnus*. Likewise, the lowest number of patients was recorded during the month of July, at 7%. The highest percentages of patients at the other hospitals were during September to February and responded positively to Poaceae allergenic pollen (41.5%) and to trees such as *Fraxinus* (27.6%) and *Quercus* (23.5%), among others. Fig. 6 shows the percentages of pediatric patients diagnosed with allergic and respiratory type diseases associated with pollinosis at the different hospitals.

Regarding the diagnosis in the 285 patients treated at IOCV, 85.5% had allergic conjunctivitis, followed by 40.9% with allergic rhinitis, 11.2% with keratoconjunctivitis and 8.4% with atopic dermatitis; only 3.1% of the patients were diagnosed with asthma. Of the 257 patients evaluated at the other hospitals, 53.3% of the children presented with allergic rhinitis, 18.4% with asthma, 4.6% with atypical dermatitis and 0.9% with allergic conjunctivitis.

Table 2
Classification of the main types of airborne pollen collected in Miguel Hidalgo Delegation (Chapultepec Park) over an eight-year period.

Taxon	Σ APIn (8 years)	%	95% CI
Fraxinus	222741	40.22	40.09–40.35
Cupressaceae	166016	29.98	29.86–30.10
Alnus	30062	5.42	5.36–5.48
Pinus	23643	4.27	4.21–4.32
Quercus	20798	3.75	3.70–3.80
Casuarina	14975	2.70	2.66–2.74
Poaceae	13800	2.49	2.45–2.53
Myrtaceae	10080	1.82	1.78–1.85
Urticaceae	7510	1.35	1.32–1.38
Schinus	6431	1.16	1.13–1.18
Ligustrum	6038	1.09	1.06–1.11
Moraceae	5697	1.02	1.05–1.10
Amaranthaceae	3405	0.61	0.59–0.63
Rosaceae	3228	0.58	0.56–0.60
Asteraceae	3118	0.56	0.54–0.58
Ambrosia	2055	0.37	0.35–0.38
Ulmus	1225	0.22	0.20–0.23
Salix	1135	0.20	0.19–0.21
Populus	1083	0.19	0.18–0.20
Rumex	1069	0.19	0.18–0.20
Corylus	997	0.18	0.16–0.19
Ricinus	984	0.17	0.16–0.18
Liquidambar	734	0.13	0.12–0.14
Buddleia	662	0.12	0.11–0.12
Palmae	569	0.10	0.09–0.11
Citrus	501	0.09	0.08–0.09
Plantago	413	0.075	0.06–0.08
Indeterminate	392	0.071	0.06–0.07
Fagus	382	0.069	0.06–0.07
Artemisia	362	0.065	0.05–0.07
Celtis	350	0.063	0.05–0.07
Brassicaceae	310	0.056	0.049–0.062
Tilia	289	0.052	0.046–0.058
Carya	266	0.048	0.042–0.054
Platanus	249	0.045	0.039–0.050
Olea	246	0.044	0.039–0.050
Mimosa	217	0.039	0.034–0.044
Ginkgo biloba	215	0.039	0.033–0.044
Acer	210	0.038	0.032–0.043
Thypaceae	201	0.036	0.031–0.041
Tamarix	175	0.032	0.027–0.036
Juglans	131	0.024	0.019–0.028
Solanaceae	94	0.017	0.013–0.020
Jacaranda	89	0.016	0.012–0.019
Oreopanax	85	0.015	0.012–0.018
Lamiaceae	56	0.010	0.007–0.013
Acacia	48	0.009	0.006–0.011
Cyperaceae	38	0.007	0.004–0.009
Castanea	33	0.006	0.004–0.008
Grevillea robusta	25	0.005	0.002–0.006
Apiaceae	23	0.004	0.002–0.006
Liliaceae	23	0.004	0.002–0.006
Onagraceae	22	0.004	0.002–0.006
Reseda	20	0.004	0.002–0.005
Ficus	19	0.003	0.002–0.005
Cannabaceae	15	0.003	0.001–0.004
Prosopis	8	0.001	0.0006–0.0028
Begoniaceae	5	0.001	0.0002–0.0021
Cassia	5	0.001	0.0002–0.0021
Ericaceae	4	0.001	0.0001–0.0018
Alyssum	2	0.0006	0.00004–0.0013
Total	553717	100	

4. Discussion

This study is the first performed in Mexico to associate the main pollen types associated with allergic diseases of pediatric patients (1–17 years old) attended at various hospitals in the city. Most of the patients came from the State of Mexico and Mexico City. This study presents information on the different pollen seasons and annual data, relevant

Table 3
Monthly values and annual percentages of Annual Pollen Integral (APIn) pollen from 2008 to 2016.

Month	2008–2009		2009–2010		2010–2011		2011–2012		2012–2013		2013–2014		2014–2015		2015–2016	
	Σ month	% annual	Σ month	% annual	Σ month	% annual	Σ month	% annual	Σ month	% annual	Σ month	% annual	Σ month	% annual	Σ month	% annual
Sep	110	0.3	748	0.7	1103	1.3	1103	1.3	845	1.9	483	1.1	1695	4.0	1352	2.2
Oct	1324	3.2	1379	1.4	1070	1.3	1976	2.3	835	1.9	1162	2.7	1568	3.7	1236	2.0
Nov	1507	3.7	3194	3.2	2402	2.8	2789	3.2	975	2.2	1329	3.1	1893	4.5	2011	3.2
Dec	7120	17.3	11210	11.1	11366	13.4	11030	12.7	3282	7.3	2156	5.0	3891	9.1	3736	6.0
Jan	15802	38.5	32207	31.8	31509	37.3	17408	20.1	18277	40.6	7156	16.8	14230	33.5	20981	33.6
Feb	7260	17.7	27728	27.4	24733	29.2	31846	36.7	8610	19.1	13533	31.7	10386	24.4	21187	33.9
Mar	2503	6.1	12702	12.5	4276	5.1	10172	11.7	4033	9.0	9280	21.7	2502	5.9	4849	7.8
Apr	1450	3.5	5463	5.4	1917	2.3	4386	5.1	2579	5.7	3578	8.4	2982	7.0	3067	4.9
May	1447	3.5	2259	2.2	1944	2.3	1876	2.2	1312	2.9	1117	2.6	1006	2.4	2633	4.2
Jun	1087	2.6	1186	1.2	834	1.0	785	0.9	2226	4.9	1938	4.5	1236	2.9	866	1.4
Jul	1126	2.7	2083	2.1	2374	2.8	2771	3.2	1483	3.3	433	1.0	656	1.5	171	0.3
Aug	329	0.8	1193	1.2	1034	1.2	566	0.7	549	1.2	552	1.3	486	1.1	329	0.5
APIn (pollen*day/m3)	41065	100.0	101352	100	84562	100.0	86708	100.0	45006	100.0	42717	100.0	42531	100.0	62418	100.0

Table 4
Characteristics of the Main Pollen Season (MPS) for the most important taxa (*Fraxinus,* Cupressaceae and herbaceous Poaceae) in the atmosphere of Miguel Hidalgo Delegation.

Pollen type	Period	APIn	APIn/Type pollen	percentage	Start of pollination MPS	End of pollination of MPS	Maximum	Date of the maximum	Duration of the period (days)
Fraxinus	2008–2009	41065	16233	39.5	13/12/2008	14/07/2009	790	05/01/2009	213
	2009–2010	101352	38825	38.3	06/12/2009	19/03/2010	2710	10/02/2010	103
	2010–2011	84562	44740	52.9	29/11/2010	14/06/2011	1734	08/01/2011	197
	2011–2012	86708	27216	31.4	16/11/2011	20/07/2012	1078	24/01/2012	247
	2012–2013	45006	26265	58.4	02/12/2012	02/06/2013	1011	13/01/2013	182
	2013–2014	42717	18608	43.6	17/11/2013	26/05/2014	632	03/02/2014	190
	2014–2015	42531	14242	33.5	17/11/2014	04/04/2015	1125	15/01/2015	138
	2015–2016	62418	36748	58.9	03/12/2015	24/03/2016	2839	26/01/2016	112
Cupressaceae	2008–2009	41065	11832	28.8	14/10/2008	26/08/2009	902	27/01/2009	316
	2009–2010	101352	35431	35.0	09/11/2009	26/04/2010	2940	21/01/2010	168
	2010–2011	84562	24473	28.9	26/11/2010	16/07/2011	795	17/02/2011	232
	2011–2012	86708	39304	45.3	21/10/2011	08/05/2012	8746	17/02/2012	200
	2012–2013	45006	10683	23.7	05/10/2012	28/07/2013	272	27/03/2013	296
	2013–2014	42717	12994	30.4	05/10/2013	16/09/2014	287	10/01/2014	346
	2014–2015	42531	16086	37.8	09/10/2014	10/09/2015	989	08/01/2015	336
	2015–2016	62418	15613	25.0	28/09/2015	24/03/2016	1427	26/01/2016	178
Poaceae	2008–2009	41065	2209	5.4	02/10/2008	06/09/2009	58	06/01/2009	339
	2009–2010	101352	2375	2.3	02/10/2009	13/09/2010	77	12/02/2010	346
	2010–2011	84562	1568	1.9	26/09/2010	16/09/2011	19	09/10/2011	355
	2011–2012	86708	1263	1.5	27/09/2011	18/09/2012	26	19/09/2012	357
	2012–2013	45006	1805	4.0	24/09/2012	01/09/2013	22	21/09/2012	342
	2013–2014	42717	2049	4.8	29/09/2013	17/09/2014	35	07/09/2014	353
	2014–2015	42531	1617	3.8	23/09/2014	15/09/2015	22	26/09/2014	357
	2015–2016	62418	1465	2.3	22/09/2015	17/09/2016	24	22/09/2015	361

Columns:
Period: Annual sampling period.
APIn: Annual Pollen Integral.
APIn/Type pollen: Concentration for each type of pollen.
Percentage of: Type of pollen with respect to APIn.
Start ofpollination MPS: Pollination start of the main pollen season.
End of pollination of MPS: End of pollination of the main pollen season.
Maximum: Maximum concentration (pollen grain/m^3) of air within the MPS period.
Date of the maximum: Date of the maximum concentration within the MPS period.
Duration of the period: Days.

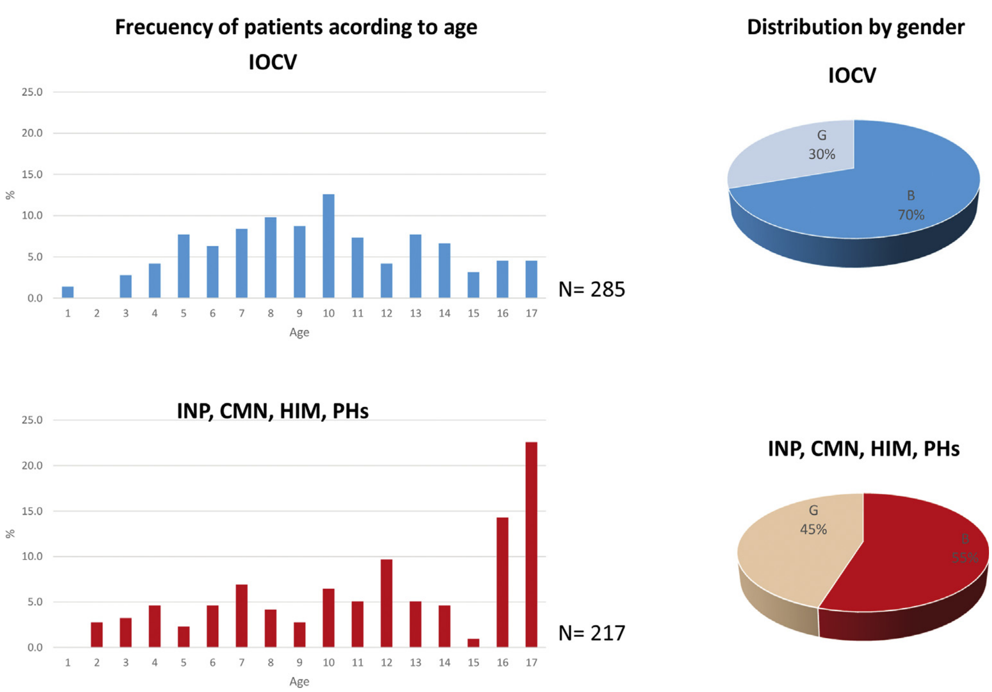


Fig. 3. Frequency of pediatric patients (B = boys and G = girls) with conjunctivitis, rhinitis, and other respiratory allergies stratified by age and gender. The children were treated at the following hospitals: top panel: Institute of Ophthalmology Conde de Valenciana (IOCV); bottom panel: National Institute of Pediatrics (INP), National Medical Center 21st Century (CMN), Children's Hospital of Mexico (HIM) and private hospitals (PHs).

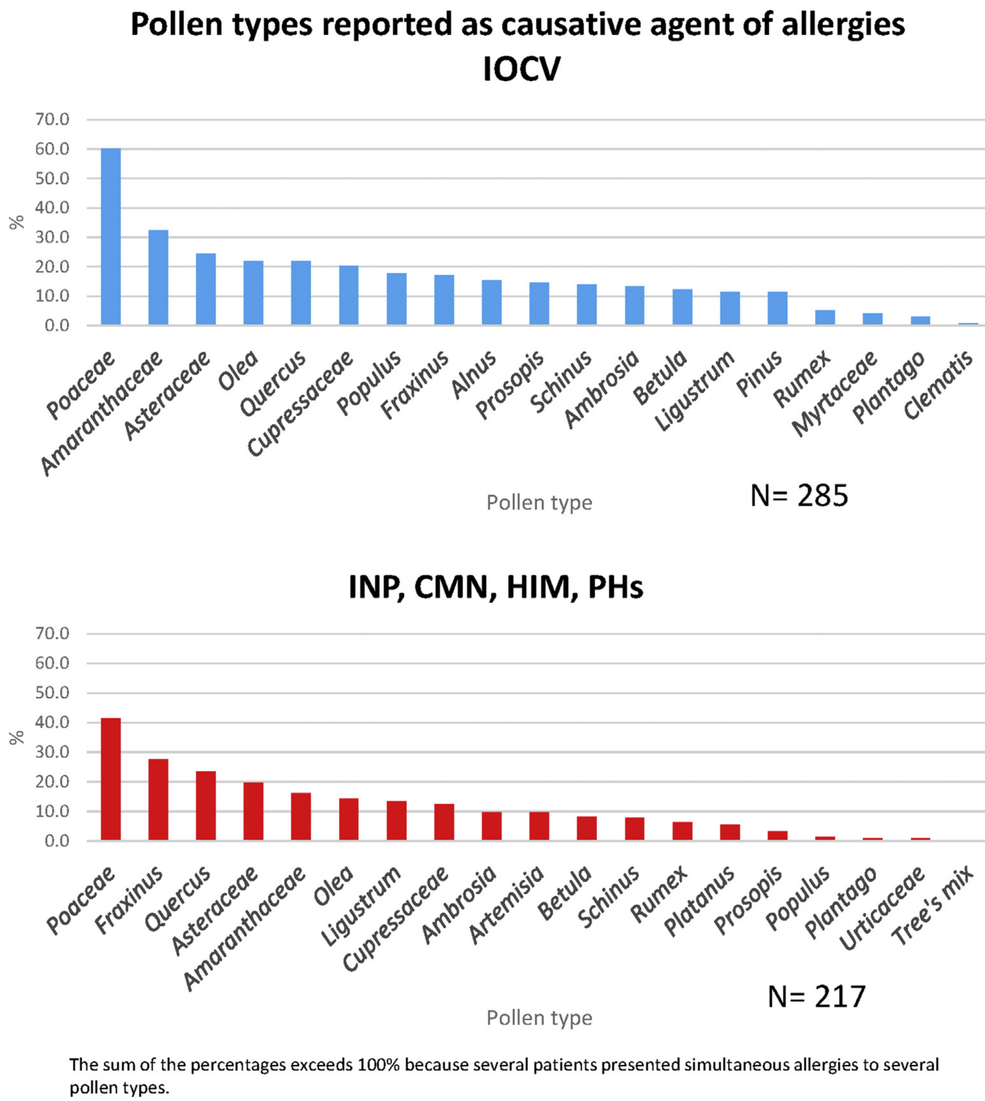


Fig. 4. Types of allergenic pollen sensitization in skin prick tests in patients treated at IOCV, INP, CMN, HIM and PHs.

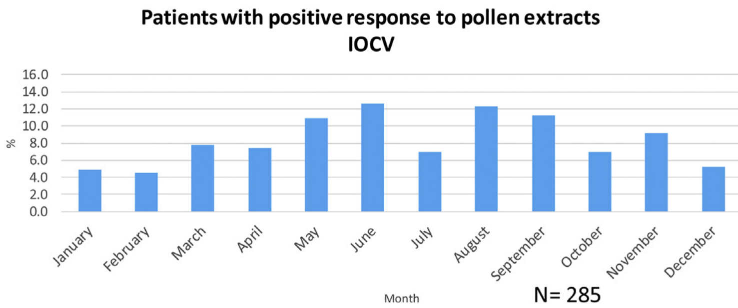
information for people suffering from allergies and for allergists in terms of planning the treatment.

The interannual variations in airborne pollen found in this study allowed us to determine changes in the phenology of the flowering, which probably depends on environmental conditions, vegetation or changes in the use of soil, among other factors. The above results coincide with those reported by Calderón-Ezquerro et al. (2016).

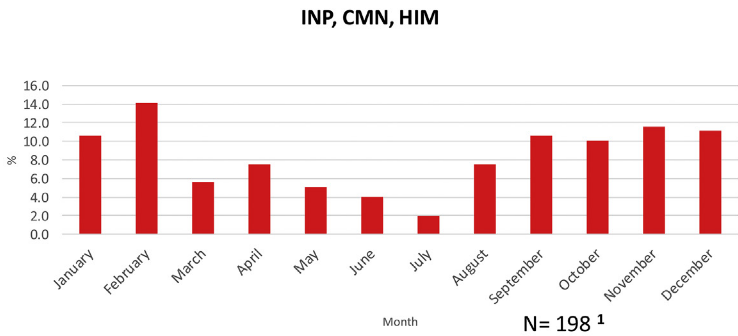
Our study also agrees with other studies performed in Mexico, mainly in the 1990s, and recent papers that used volumetric sampling methods, with more pollen detection from tress (Bronillet-Tarragó, 1992, 1996; González-Macías et al., 1993; Rosas et al., 1998; González-Lozano et al., 1999, Torres-Valdos, 2006; Cid-Martínez, 2007; Gaspar-López et al., 2014): *Fraxinus,* Cupressaceae (*Cupressus, Thuja* and *Juniperus*), *Alnus*, *Pinus* and *Quercus*. Higher airborne pollen concentrations were detected during the winter and early spring, with different flowering length periods, depending on the flowering intensity. The most abundant and allergenic pollen type was *Fraxinus*, which starts its flowering period during the fall, and is associated with the first symptoms of allergy in patients sensitive to this pollen (Larenas-Linnemann D., personal communication). Pollen from herbaceous plants was recorded in low concentrations in both rainy and dry seasons, however, several species of these have been reported as highly allergenic (Sofiev and Bergmann, 2013).

The results also show the great diversity of herbaceous plants that produce pollen grains, most of them identified as allergens, that are present in the air during both the dry and rainy seasons. Although their concentration is lower in the air than pollen from trees, they are present during longer periods during the year, depending on the different species involved. Most are in the botanical family, sometimes with a high number of species.

The children sensitive to pollen showed positive responses even when low concentrations, especially to grasses, with a high percentage of sensitization in skin tests performed at IOCV (60.4%) and at the other hospitals (41.5%). In the case tree pollen exposure, a large number of the evaluated children showed positive responses during the main pollen season of different trees, especially to *Fraxinus, Quercus, Olea*, Cupressaceae and *Alnus*, among others, probably due to cross-reactions with pollen from species belonging to the same family, such as *Fraxinus* and *Olea* (Vara et al., 2016), or from different families, i.e. *Quercus, Alnus* and *Casuarina* (Bucholtz et al., 1987; Garcia et al., 1997). Positive responses were also observed when pollen concentrations were low or null. For example, *Ligustrum* and *Olea* airborne pollen with low percentages (1.0% and 0.04%, respectively), which belong to the same family of *Fraxinus* (Oleaceae) with high pollen concentrations, produced a positive response due to cross-reactions; this is attributed to Fra e 1, which is a homolog of Ole e 1, the major olive pollen allergen (Pajarort et al., 1997; Sofiev and Bergmann, 2013). A similar situation was observed between *Betula* and *Alnus* pollen, both belonging to the



Pollen	% people with positive response[2]	95% CI
Poaceae	60.4	54.41-66.07
Amaranthaceae	32.6	27.21-38.41
Asteraceae	24.2	19.67-29.98
Quercus	22.1	17.42-27.37
Olea	22.1	17.42-27.37
Cupressaceae	20.4	15.83-25.49
Populus	17.9	13.62-22.84
Fraxinus	17.2	12.99-22.08
Alnus	15.4	11.44-20.16
Prosopis	14.7	10.83-19.39
Schinus	14.0	10.21-18.61
Ambrosia	13.3	9.61-17.83
Betula	12.3	8.70-16.66
Ligustrum	11.6	8.10-15.87
Pinus	11.6	8.10-15.87
Rumex	5.3	2.97-8.53
Myrtaceae	4.2	2.19-7.23
Plantago	3.2	1.45-5.90
Clematis	0.7	0.08-2.51



Pollen	% people with positive response[2]	95% CI
Poaceae	41.5	34.40-47.87
Fraxinus	27.6	21.81-34.11
Quercus	23.5	18.02-29.71
Asteraceae	19.8	14.72-25.74
Amaranthaceae	16.1	11.49-21.71
Olea	14.3	9.91-19.66
Ligustrum	13.4	9.13-18.62
Cupressaceae	12.4	8.74-18.10
Ambrosia	9.7	6.09-14.41
Artemisia	9.7	6.09-14.41
Betula	8.3	4.99-12.79
Schinus	7.8	4.62-12.24
Rumex	6.5	3.57-10.58
Platanus	5.5	2.88-9.46
Prosopis	3.2	1.30-6.53
Populus	1.4	0.28-3.98
Plantago	0.9	0.11-3.28
Urticaceae	0.9	0.11-3.28
Tree's mix	0.5	0.01-2.54

[1]The total of 217 was not reached because several patients had no recorded date of consultation.
[2]The value of positive cases exceeds the sample value because most patients are allergic to several allergens simultaneously

Fig. 5. Percentages of patients seen at IOCV and INP, CMN, HIM, and PHs who responded positively to the testing of extracts of various pollen types throughout the year.

Betulaceae family; *Betula* pollen grains were not registered in the air of Mexico City, but the children responded positively to their extracts in the skin tests, both at IOCV (12.3%) and at the other hospitals (8.3%). *Fraxinus* also presents a cross-reaction with pollen from some grasses (Lombardero et al., 2002; Niederberger et al., 2002; Popescu, 2015).

During the year, pediatric patients responded positively to extracts of both tree and herbaceous pollen, especially to grasses present in Mexico City (Sánchez-Ken et al., 2012), such as *Lolium perenne, Cynodon dactylon, Dactylis glomerata, Phleum pratense* and weeds, such as *Ambrosia*, Amaranthaceae, *Artemisia, Atriplex* and *Rumex* among others, ensuring the prevalence of responses to pollen aeroallergens at any time of the year (Larenas-Linnemann et al., 2011; Larenas-Linnemann D, personal communication, Gaspar-López et al., 2014; Calderón-Ezquerro et al., 2016). It has been documented that cross-reactivity can occur when patients react to different pollen species or mixtures of them (D'Amato et al., 2007; Burbach et al., 2009). In this study, a large number of children who were treated for ocular diseases, asthma and other allergic diseases responded positively to various pollen types.

Strong positive responses in patients with allergies were observed during the dry season (November to April), coinciding with the *Fraxinus, Quercus, Olea, Ligustrum*, Cupressaceae and *Alnus* flowering season, among others; large amounts of these allergens are suspended in the air, thereby increasing exposure and the responses of allergic subjects.

Children with positive reactions to pollen were diagnosed mainly with conjunctivitis, rhinitis, allergic asthma and keratoconjunctivitis. Allergic rhinitis is also associated with an increased risk of obstructive sleep apnea (OSA) in children and adults, the latter with a high risk of cerebrovascular disease (Weger et al., 2013).

Numerous studies have shown an association between pollen exposure and allergy (Brunekreef et al., 2000; D'Amato et al., 2007; Annesi-Maesano et al., 2012; Kiotseridis et al., 2013b); some of them have reported that exposure to low grass pollen concentrations can cause reactions in the eyes and nose (D'Amato et al., 2007), whereas exposure to more than 50 pollen grains/m^3 leads to pulmonary symptoms. In this study, the maximum exposure to grass pollen fluctuated between 19 and 77 pollen grains/m^3 of air, which can cause conjunctivitis, keratoconjunctivitis, rhinitis and asthma in sensitive children. This agrees with what has been reported in some studies that demonstrated a strong association between the amount of grass pollen and severe asthma attacks or emergency visits to hospitals (Oh et al., 2006; Jeon et al., 2010; Annesi-Maesano et al., 2012).

The presence and high concentrations of allergenic tree pollen grains had an important contribution and were associated with allergic diseases in the children who visited various hospitals in the city. The increase in pollen concentrations during the flowering periods increases the risk of their effects on health. This result is consistent with a study conducted in Mexico that included a total of 4169 skin tests with positive allergic reactions from different parts of the country. Mite allergens were associated with the greatest number of sensitized patients with rhinoconjunctivitis (and asthma), followed by pollen allergens mainly from tropical grass pollen (*Cynodon dactylon*), *Fraxinus* and *Quercus* (Larenas-Linnemann et al., 2011). Global studies have shown similar results and have reported that the substantial increase in the concentrations of airborne allergenic pollen, such as olive (*Olea*, from the same family as *Fraxinus*), is one of the leading causes of respiratory allergies in Europe (D'Amato and Lobefalo, 1989; Docampo et al., 2007). Additionally, a study associated the concentrations of pollen from different species with visits to the emergency department for asthma and wheezing in the city of Atlanta, with an increase in 2%–3% patients suffering allergy risk when *Quercus* and Poaceae pollen increase. The associations for different species of *Quercus* were strongest for children between the ages of 5 and 17 years (Darrow et al., 2012).

The positive responses of children allergic to pollen from the Asteraceae family are consistent with those reported in other studies, demonstrating that exposure to allergens in this family is the cause of respiratory diseases in children and increases the number of patients suffering from seasonal allergic rhinitis and allergic conjunctivitis (Jeon et al., 2010). Likewise, Park et al. (2012) found a significant association between pollen concentrations and the occurrence of allergic diseases

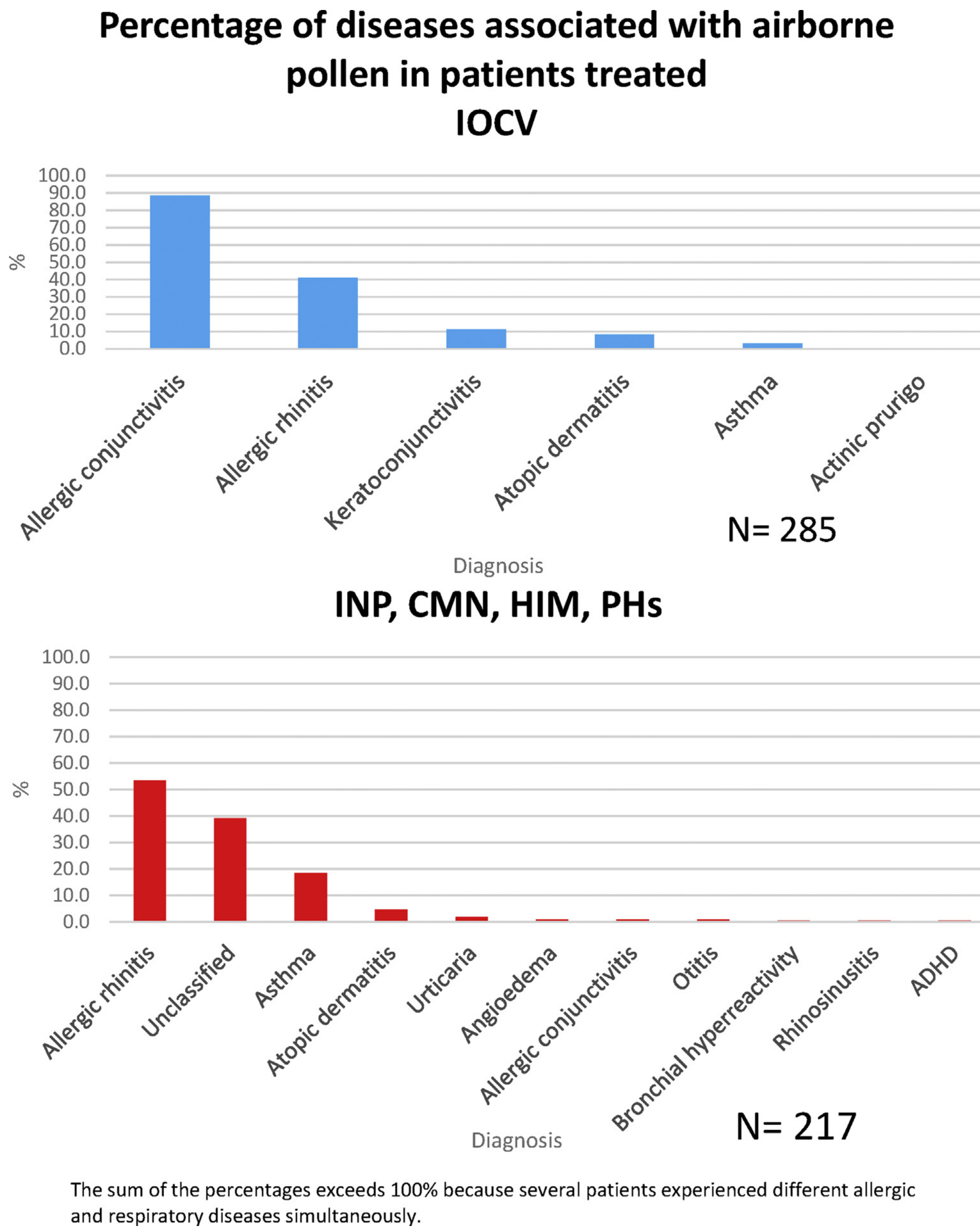


Fig. 6. Percentages of pediatric patients diagnosed with allergic and respiratory type diseases associated with airborne pollen at the IOCV hospital and at INP, CMN, HIM and PHs in Mexico City.

in children.

When presenting the role of airborne pollen in sensitized patients, it is also important to note variations in allergen potency (amount of allergen per pollen), sometimes reaching twenty-fold between different geographical areas and years (Buters et al., 2015; Buters, 2016; Galán et al., 2013). Organic and inorganic particles and gases in polluted cities, such as Mexico City, and their possible long or medium distance transport also play a role (Calderón-Ezquerro et al., 2016; Celada-Murillo et al., 2013). Previous studies in Mexico City detected *Fraxinus* pollen proteins adhered to dust, with the presence of a 21.5 kDa protein observed by Western blotting, suggesting that *Fraxinus* proteins can be suspended in the air attached to aeroparticles (Robledo-Retana et al., 2015). Therefore, it is important to note that pollen allergens can be associated with particles present in the atmosphere. Because these particles are much smaller than pollen grains, they can penetrate the lower respiratory tract and induce allergic responses and asthma (Kiotseridis et al., 2013a).

Therefore, knowledge of airborne pollen in Mexico City is very important for pollen calendars, which offer information about the main local pollen types in the atmosphere, their timing and intensity. This information is very important for both allergologists and allergy sufferers in cities with high levels of environmental pollution. In addition, this study responds to the demands of academics in the international scientific community in the frame of the 8th International Congress on Aerobiology, 2006.

5. Conclusion

This study showed a close association between the allergenic pollen types present in the air of Mexico City and exposure in children. Sensitized children responded positively to allergens as soon as they came into contact with them.

The pollen calendar offers important information for both the health sector (allergists, immunologists and pneumologists) and the sensitive population (mainly children). This knowledge will allow for measures of prevention and control, mainly in the seasonal periods with higher concentration of these pollen grains in the air.

The continuous monitoring of pollen in the air of Mexico City is necessary due to changes in climate that are modifying the flowering periods of the plants, as well as the extensive changes in land use that are occurring in the city. In addition, high levels of environmental pollution that occur mainly during the cold dry season (November to March), which coincides with the flowering of trees with allergenic pollen grains such as *Fraxinus, Alnus*, Cupressaceae and compromises the health of the population.

It is also important to perform further studies on the risk of reaction of atopic individuals after exposure to pollen aeroallergens, both in healthy people who may be sensitized by exposure to pollen aeroallergens, as well as in subjects exposed to pollen allergens and contaminants.

This study responds to the demands of academics of the international scientific community who are experts in this subject.

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