

Increased sensitization rates to tree pollens in allergic children and adolescents and a change in the pollen season in metropolitan Seoul, Korea

Running title : Tree pollen sensitization and pollen season

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Abstract

Introduction: Children with allergies are at greater risk of becoming sensitized to allergenic pollens in response to environmental changes. This study investigated the relationship between changes in pollination associated with meteorological changes and the sensitization rates of children to tree-pollen allergens in the metropolitan area of Seoul, Korea.

Methods: The study population consisted of 8,295 children who visited the pediatric allergy clinics at Hanyang University Seoul and Guri Hospital for allergy symptoms between January 1, 1998 and December 31, 2019. Pollen was collected at the two hospitals during the study using a Burkard 7-day sampler. Meteorological data were obtained from the National Weather Service.

Results: Among the major tree pollens, the largest increase in allergic sensitization was to oak, hazel, and alder pollens (0.28% annually). The pollen-sensitization rates increased annually within younger age groups. The duration of the pollen season was 98 days in 1998 and 140 days in 2019. Positive correlations were determined between the duration of the pollen season and the rates of sensitization to tree pollens as well as between the pollen-sensitization rates and increasing temperature.

Conclusions: This study demonstrated the correlation between weather changes and the resulting changes in the pollen season with sensitization rates to allergenic pollens in children living in the Seoul metropolitan area. An annual increase in sensitization rates in younger children was determined. This pattern is expected to continue due to continuing climate change.

Key words: Climate change, Pollen, Pollen allergy, Children

Key Message

The sensitization rates to tree pollens in children with allergic diseases have increased with a changes in the pollen season pollen season following to weather change. And the age of sensitization to tree pollens was also extended to younger children. These findings indicate that climate change may be related to the pollen season and sensitivity to tree pollens in children.

Introduction

Sensitization to pollen plays a crucial role in the development of allergic disorders¹ and thus in the development of more serious allergic symptoms and an increased risk of asthma.^{2,3}

An interaction between pollen exposure and sensitization to pollen allergens has been described, but the effect is less pronounced in individuals sensitized to only one type of pollen than in those sensitized to many types of pollen. Since different pollen types are released at different periods of the pollen season, atopic individuals sensitized to more than one type of pollen have a longer period of exposure, with potentially greater effects on airway hyperreactivity and reduced lung function.⁴

Weather variables, mainly air temperature, sunshine, and rainfall, together with the CO₂ level are among the main factors affecting plant phenology and thus pollen production. The weather directly determines the start and end of pollination, which defines the duration of the pollen season, but with the additional influence of environmental factors such as greenhouse gases and other air pollutants. Thus, the weather may influence the occurrence of allergic diseases such as asthma and allergic rhinitis. A consequence of climate change may therefore be an increase in the number of people developing pollen allergies.⁵

Because pollen is produced and emitted by mature flowers, the pollen season is related to the flowering season. However, the duration of the pollen season, reflected in the levels of airborne pollen, is also influenced by factors affecting pollen dispersal and may therefore not coincide exactly with flower maturation. A longer pollen season and larger amounts of atmospheric pollen may enhance human exposure to allergenic pollens, potentially leading to an increase in allergic sensitization. In fact, increases in pollen sensitization in children have recently been reported. The effective management of pollen allergy should therefore include a survey of the pollens in the area of exposure.⁶⁻⁸

A number of studies on the impact of climate change on allergenic pollen distribution have focused on pollen counts and their regression relationships with local meteorological factors. Ongoing climate change has increased both the concentration of atmospheric CO₂ and the average temperature, thereby altering the duration of seasons and increasing the atmospheric loads of many pollens.⁸ In an experimental study, warming and increases in the CO₂ level were shown to increase pollen production.^{9,10} Other studies similarly reported that an elevated CO₂ concentration resulted in both early pollen production by trees and greater seasonal pollen production.^{11,12} In addition, weather patterns influence the movement and dispersion of aeroallergens in the atmosphere through the action of wind and rainfall, and

depending on the atmospheric stability.

This study investigated the relationship between changes in the pollen season associated with meteorological changes and the rates of sensitization to pollen allergens in children living in the Seoul metropolitan area, Korea. The results of the analysis can be used to predict trends in pollination start dates. They also provide insights into phenology as an indicator of weather changes and the recent rise in pollen allergies in children in Korea.

Methods and Materials

1. Pollen identification, counting, and definition of pollen season

Pollen grains have been identified and counted at Hanyang University Seoul and Guri hospitals for over 22 years (1998–2019). Pollen samples are obtained at both sites using a Burkard 7-day sampler (Hertfordshire, UK) positioned on exposed rooftops. Cumulative pollen concentrations and a preset percentage threshold level are used to define the start and end of the pollen season. The present study applied a 5% threshold, as it had the smallest standard deviation in the start dates.¹³

2. Patient selection and measurement of sensitization to allergenic tree pollen

This study included pediatric patients (< 18 years of age) who underwent allergic tests for asthma, allergic rhinitis, atopic dermatitis, and other diseases at two referral hospitals in Korea: Hanyang University Hospital Seoul and Guri Hospital. Patients without allergic tests or whose test results were missing from the medical records were excluded. Data on allergenic pollen-sensitization rates were selected based on the results of the skin prick test and the quantitative serum test for allergen-specific IgE. The standard panels of allergens used in each institute were the same during the study period. Sensitization to the allergenic pollen was defined as > 3 class levels of a pollen allergen-specific serum IgE as determined in a multiple antigen simultaneous test (MAST) or a wheal greater than ≥ 3 mm in diameter on a skin prick test^{7,14} of birch, alder, oak, hazel, pine, and willow pollen. The allergenic pollen-sensitization rates were calculated as the number of patients sensitized to the tested allergenic pollens as a percentage of the overall allergy-tested population. Sensitization was classified according to the following age groups: (3–5, 6–9, 10–12, 13–15, and 16–18 years of age).

3. Meteorological data

Daily records of climate variables, including mean temperature, rainfall, cumulative temperature, and 7-day hours of sunshine, were obtained from the Korea Meteorological Administration and used to represent the daily weather conditions close to the pollen monitoring sites. The weather station nearest to each pollen sampling site was selected to provide the meteorological data. The cumulative temperature was defined as the sum of the temperature from 1 January until the starting day of pollination, as this was determined to be the most important meteorological variable with respect to pollination.

4. Statistical analyses

Long-term pollen data were analyzed to determine the potential relationship to sensitization rates during the pollen-collection period. R version 4.0.2 (The R foundation, <https://www.r-project.org>) was used in the statistical analyses. Changes in the rates of pollen sensitization were assessed using a linear regression and time series analyses. A standardized regression coefficient using the least squares method to minimize the sum of squared residuals was estimated, and the independent variables that significantly influenced the dependent variables were determined.¹⁵

The correlation between the starting date and duration of the pollen season and pollen-sensitization rates was assessed in a correlation analysis. Prediction of the long-term variation in the pollen season was assessed in an autoregressive integrated moving average (ARIMA) - 11 analysis. Time-series data were seasonally adjusted. The ARIMA-11 analysis can back-cast from the previous year's data from the starting point of the data, predict the year data from the end point of the data, and solve missing value problems by moving the average of the expanded data.¹⁶

5. Ethics statement

This study was approved by the institutional review board of the Hanyang University Guri Hospital (IRB No. HYI-10-45). The requirement for informed consent from patients was waived, as the study was a retrospective analysis.

Results

1. Study population

The 8,295 children (males: 4,032, females: 4,263; age: 3–18 years) enrolled in the study had visited one of two pediatric allergy clinics for allergy symptoms between 1998 and 2019. Table 1 shows their diagnoses. Despite differences from year to year, allergic rhinitis was the most common diagnosis ($n = 2,295$; 27.7%), followed by atopic dermatitis ($n = 2,259$; 27.2%), others ($n = 2,005$; 24.2%), and asthma ($n = 1,736$; 20.9%).

2. Allergenic pollen-sensitization rates

Sensitization rates to tree pollens increased from year to year. With earlier first-pollen detection, the duration of the season for the different pollens increased. Sensitization to tree pollens gradually increased over the last 22 years (Table 2), with the largest increases in sensitization being to oak, hazel, and alder pollens (0.28% annually), followed by sensitization to birch, willow, and pine pollens (0.25%, 0.25%, and 0.23%, respectively) (Table 2). The age distribution in the pollen-sensitization rates also increased over the last 22 years, with a larger proportion of sensitized children < 10 years of age (Fig. 1).

3. Duration of the pollen season and meteorological changes

The start and end dates of the pollen season in 1998 were March 5 and June 7, respectively, and the duration of the pollen season was 94 days. In 2019, the start and end dates were February 15 and July 5, respectively, and the duration of the pollen season was 140 days (Fig. 2). Both the total and the peak pollen concentrations increased gradually during this period (Fig. 3). These data were used in an ARIMA-11 analysis to predict the future start and end dates of the pollen season in the Seoul metropolitan area. By 2027, the start date will be February 9 and the end date June 24 (Table 3). The cumulative temperature correlated strongly with pollination. In this study, the mean cumulative temperature at the pollination start date was $182.14 \pm 52.02^{\circ}\text{C}$ (Table 2). Over the course of the study, the start date of pollination in the Seoul metropolitan area became earlier and the end date later.

4. Relationship of pollen-sensitization rates to pollen season duration and meteorological parameters.

A simple linear regression could be fitted between the pollen-sensitization rate (dependent variable) for each tree species and the given year (independent variable). This showed an annual increase in sensitization to oak, hazel, pine, birch, alder, and willow pollen among
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children during the last 22 years: 0.28%, 0.28%, 0.23%, 0.25%, 0.28%, and 0.25%, respectively. According to the regression analysis, the duration of the oak, hazel, pine, birch, alder, and willow pollen seasons correlated positively with the sensitization rate ($R^2 = 0.79, 0.81, 0.85, 0.79, 0.80, \text{ and } 0.70$, respectively). A correlation analysis measuring the strength of the linear association between the accumulated temperature and the pollen-sensitization rate for each tree species yielded the following correlation coefficients: 0.71 for oak 0.71, 0.66 for hazel, 0.53 for pine, 0.69 for birch, 0.53 for alder, and 0.64 for willow (Table 2).

None of the other meteorological parameters was significantly related to the increasing sensitization rate resulting from the increasing duration of the pollen season.

Discussion

In contrast to studies of sensitization to household allergens such as dust mites, which are highly allergenic, sensitization rates to tree pollens have received little attention, with even fewer studies of sensitization rates in children. Thus, the aim of this study was to investigate changes in pollen-sensitization rates in children with allergic diseases, based on the results of allergy tests, in response to the shift in the pollen season over the last 22 years. We found that, during this period, both the sensitization rates to tree pollens and pollen allergy have increased in allergic children (3–18 years of age) living in the Seoul metropolitan area, and that increasingly younger children (< 10 years of age) are becoming sensitized. Allergic rhinitis and allergic conjunctivitis are not uncommon in teenagers⁹ but pediatricians and allergists have reported a gradual increase in the prevalence of these diseases in children < 6 years old.¹⁷ A shift in the timing of the common tree pollen seasons may aggravate the symptoms of respiratory allergic diseases.

In this study, the difference in pollen exposure rates depending on the annual weather was taken into account in determining the sensitization rates. Changes in the weather could influence allergic sensitization to pollen in three ways: First, warmer temperatures such as due to climate change could increase pollen concentrations and thus the seasonal intensity of the allergenic load.¹⁸ Second, climate change could increase both the level of allergenic pollens, and, in turn, allergic symptoms that are dependent on the exposure level, and the duration of the pollen season.^{2,3} Finally, the CO₂ concentration, together with warmer temperatures, also increases pollen concentrations but it might also alter the allergenicity or allergen concentration of the pollen, and therefore symptom severity.^{11,12}

Our study also showed that with the expanded pollen season both concentrations of pollens and sensitization rates increased annually. Sensitization to allergens is an important step in the development of allergic disease. A longer pollen season and an increased amount of pollen will increase human exposure to pollen, especially aeroallergens, thus increasing the risk of allergic sensitization during childhood.^{17,19}

Few epidemiological and experimental studies have examined the relationship between allergic diseases, the environment, and climate change.^{20,21} An epidemiological study reported a progressive and significant increase in the sensitization rate to tree pollens in Korea: from 8.8% in the 1980s, to 19.0% in the 1990s, and 36.4% in the 2010s.²² In the Korean version of the International Study of Asthma and Allergies in Childhood of Korean children^{23,24}, the reported nationwide prevalence of “diagnosis of allergic rhinitis, ever” in 1995, 2000, and 2006 was 15.5%, 20.4%, and 28.5%, respectively

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In our study, as the pollen season shifted, the pollen-sensitization rates in younger children became higher than those in children > 10 years of age. A study of sensitization to weed pollens also found that increasingly younger children were becoming sensitized (4–6 years of age: 3.5% in 1997 and 6.2% in 2009; 7–9 years of age: 4.2% in 1997, and 6.4% in 2009).¹⁷ Differences in exposure rates to allergens with increasing age result in different sensitization rates. Although the effects of environmental change on respiratory allergic diseases are not completely understood, these differences in sensitization rates may reflect the fact that younger children are more likely to play outdoors whereas adolescents tend to spend most of their after-school hours indoors, either studying or playing video games, a recent trend in Korea. Thus, in the management of allergic diseases in children, both regional differences and age-related changes in the child's living environment should be considered.

Oak, hazel, and alder accounted for the steepest rise in sensitization to tree pollens. In addition, a relationship between sensitization rates and the pollen season was identified except in the case of pine, probably because it is either not or only mildly allergenic. Oak is expected to dominate over other species during the vegetation transition induced by climate change,²⁵ so that its distribution will be broader. By developing phenological models based on weather conditions, the distribution and length of the pollen season can be predicted. Hazel pollen causes asthma and allergic rhinitis, especially in early spring, in individuals allergic to it.^{26,27} Pollen from alder and birch trees is a significant cause of asthma, allergic rhinitis, and allergic conjunctivitis, also in spring.²⁸ In patients with poly-sensitization to alder, hazel, and oak pollen, initial symptoms occur as early as February, with abrupt exacerbations from March to May.

Among the meteorological variables examined in this study, the cumulative temperature had the strongest effect on the pollen season. For the different tree species, the rates of sensitization to oak and birch had the strongest correlation with the cumulative temperature. The reproductive rhythm of birch and thus pollen production is characterized by high and low years and is also temperature-dependent.²⁹

This study had several limitations. First, it was a retrospective study conducted at two institutions. Second only tree pollens were considered. In Korea, the tree pollen count peaks in spring and the weed pollen count peaks in autumn.³⁰ Since the pollen count of grass in summer is relatively low, we confined our study to tree pollen. Third, although pollen sensitization plays a crucial role in the development of allergic disease, sensitization takes place over a period of years, such that a direct association with allergic disease cannot be made. Further studies of the relationship between climate-related changes in the pollen

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season and the prevalence and severity of allergic disease are still needed.

In conclusion, this study demonstrated a positive correlation between changes in the pollen season over the past 22 years and sensitization rates to major tree pollens among children in the Seoul metropolitan area. With climate change, a continuous increase in the concentrations of tree pollens and thus in sensitization rates, especially in younger children, can be expected.

AUTHOR CONTRIBUTIONS

Kyung Suk Lee: Conceptualization (equal); Data curation (equal); Formal analysis (equal); Writing- original draft (equal); Writing- review & editing (equal). **Kyunghoon Kim:** Conceptualization (equal); Data curation (equal); Formal analysis (equal); Writing- original draft (equal); Writing- review & editing (equal). **Young-Jin Choi:** Data curation (equal); Formal analysis (supporting); Writing- review & editing (supporting). **Seung Yang:** Formal analysis (equal); Supervision (supporting); Writing- review & editing (supporting). **Chang-Ryul Kim:** Conceptualization (supporting); Formal analysis (equal); Supervision (equal). **Jin-Hwa Moon:** Formal analysis (equal); Supervision (equal); Writing- review & editing (supporting). **Kyu Rang Kim:** Data curation (equal); Formal analysis (equal); Writing- review & editing (equal). **Yung-Seop Lee:** Data curation (equal); Methodology (equal); Formal analysis (equal); Writing- review & editing (equal). **Jae-Won Oh:** Conceptualization (equal); Data curation (equal); Formal analysis (equal); Funding acquisition (lead); Methodology (lead); Supervision (lead); Writing- original draft (equal); Writing- review & editing (equal).

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Tables

Table 1. Diagnosis of the subjects with allergy sensitization to tree pollen

Year	Total	Asthma	Allergic rhinitis	Atopic dermatitis	Others
1998	312	71 (22.8)	75 (24.0)	69 (22.1)	97 (31.1)
1999	331	74 (22.4)	101 (30.5)	77 (23.3)	79 (23.9)
2000	241	44 (18.3)	63 (26.1)	55 (22.8)	79 (32.8)
2001	305	59 (19.3)	88 (28.9)	88 (28.9)	70 (23.0)
2002	336	73 (21.7)	89 (26.5)	88 (26.2)	86 (25.6)
2003	396	81 (20.5)	115 (29.0)	98 (24.7)	102 (25.8)
2004	453	94 (20.8)	103 (22.7)	133 (29.4)	123 (27.2)
2005	423	88 (20.8)	120 (28.4)	115 (27.2)	100 (23.6)
2006	396	78 (19.7)	118 (29.8)	114 (28.8)	86 (21.7)
2007	377	93 (24.7)	100 (26.5)	124 (32.9)	60 (15.9)
2008	415	89 (21.4)	96 (23.1)	135 (32.5)	95 (22.9)
2009	401	76 (19.0)	115 (28.7)	123 (30.7)	87 (21.7)
2010	452	99 (21.9)	113 (25.0)	119 (26.3)	121 (26.8)
2011	422	80 (19.0)	111 (26.3)	120 (28.4)	111 (26.3)
2012	395	72 (18.2)	102 (25.8)	121 (30.6)	100 (25.3)
2013	404	79 (19.6)	108 (26.7)	115 (28.5)	102 (25.2)
2014	407	86 (21.1)	117 (28.7)	122 (30.0)	82 (20.1)
2015	392	81 (20.7)	93 (23.7)	113 (28.8)	105 (26.8)
2016	375	95 (25.3)	85 (22.7)	98 (26.1)	97 (25.9)
2017	390	72 (18.5)	141 (36.2)	90 (23.1)	87 (22.3)
2018	357	83 (23.2)	136 (38.1)	76 (21.3)	62 (17.4)
2019	315	69 (21.9)	106 (33.7)	66 (21.0)	74 (23.5)
Total	8,295	1,736 (20.9)	2,295 (27.7)	2,259 (27.2)	2,005 (24.2)

Data are presented as n (%)

Table 2. Mean accumulated temperatures and sensitization rate to major tree pollen during the study

Year	Accumulated temperature (°C)	Sensitization rate to pollen (%)					
		Oak	Hazel	Pine	Birch	Alder	Willow
1998	206.35	4.7	4.0	3.2	4.2	2.6	3.8
1999	153.80	5.1	3.5	3.3	4.5	4.3	4.7
2000	163.60	4.9	3.1	5.1	4.8	3.3	3.7
2001	140.55	5.3	3.8	4.3	5.1	3.8	4.3
2002	158.85	4.8	4.3	5.4	4.8	4.6	4.7
2003	133.85	5.0	4.1	5.8	5.5	3.8	3.6
2004	170.15	4.5	3.8	4.8	5.3	5.7	3.2
2005	144.20	5.4	3.2	5.5	5.8	6.2	3.5
2006	218.50	5.2	4.7	6.3	5.4	5.9	3.8
2007	130.45	5.7	4.4	4.8	4.6	5.6	4.4
2008	102.35	5.2	5.2	5.7	5.3	6.4	4.2
2009	170.75	5.8	4.8	6.0	5.8	6.5	3.4
2010	105.55	5.5	5.1	6.2	5.7	5.2	4.3
2011	163.35	5.6	6.5	6.2	6.5	6.2	6.5
2012	138.35	7.6	7.3	7.7	7.3	8.7	7.3
2013	189.80	8.5	7.3	8.3	6.3	7.5	6.4
2014	264.30	9.3	9.5	7.3	8.3	8.4	7.2
2015	257.70	9.6	8.7	8.2	9.4	9.7	8.5
2016	245.20	9.9	8.5	8.5	9.7	9.5	8.5
2017	252.90	9.2	8.3	7.5	9.9	8.5	7.3
2018	244.85	9.5	7.6	8.1	8.4	7.4	8.4

2019	251.85	9.8	8.1	8.7	8.7	8.1	8.3
Mean $\pm$ SD	182.14 $\pm$ 52.02	6.64 $\pm$ 2.03	5.72 $\pm$ 2.06	6.22 $\pm$ 1.63	6.42 $\pm$ 1.82	6.27 $\pm$ 2.03	5.45 $\pm$ 1.93
Correlation coefficient (r, p<0.05)*		0.71	0.66	0.53	0.69	0.53	0.64

*Correlation coefficient (r, p<0.05) between sensitization rates to pollens and the accumulated temperature

Table 3. The prediction of starting and ending date of tree pollination in future at Seoul metropolitan area by using ARIMA-11 analysis.

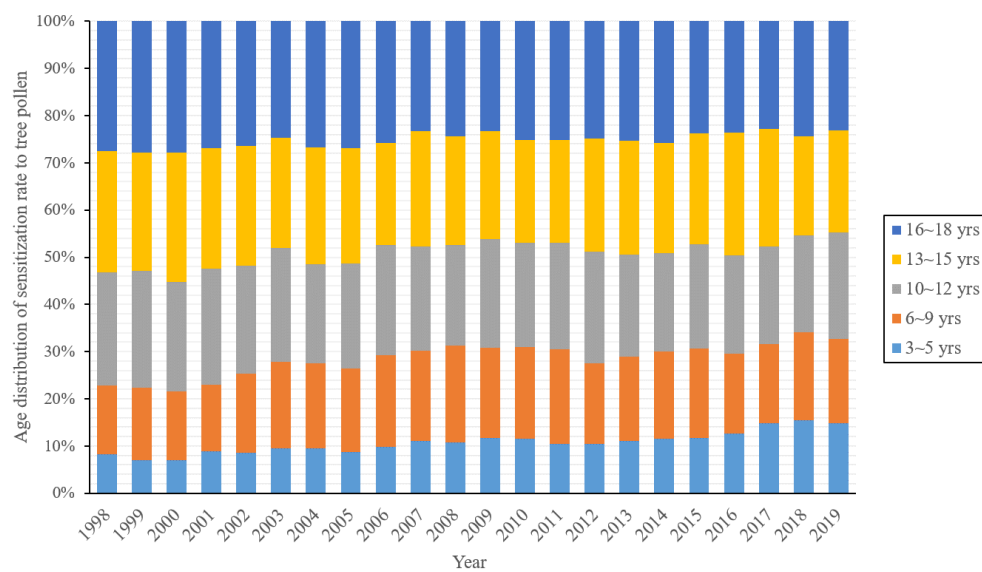
Year	Starting date (Month/Day)	Ending date (Month/Day)
2020	2/16	6/21
2021	2/15	6/22
2022	2/14	6/22
2023	2/13	6/22
2024	2/12	6/22
2025	2/11	6/23
2026	2/10	6/23
2027	2/09	6/24

Figure legends

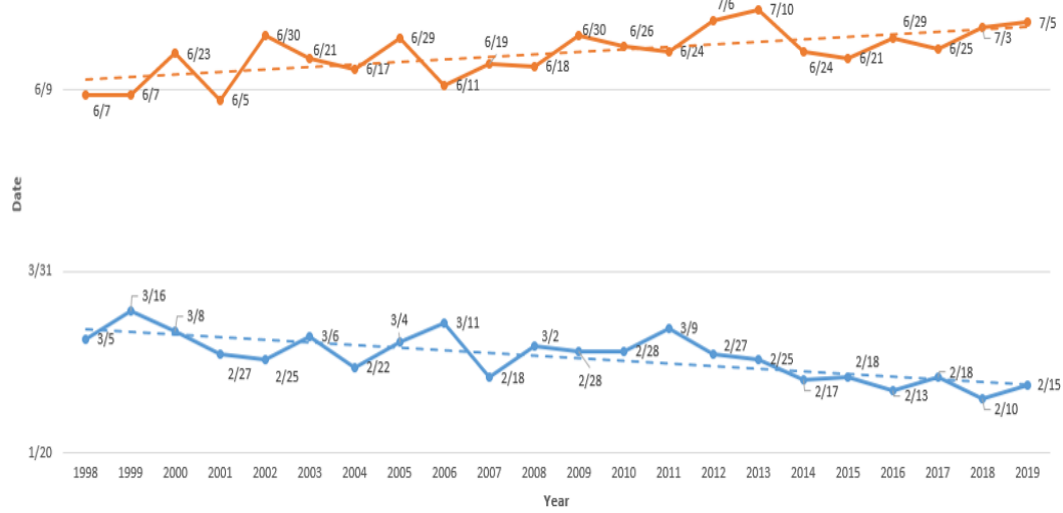
Fig. 1. Age distribution of sensitization rates to the major pollens in the Seoul metropolitan area during the study period. Between 1998 and 2019, pollen-sensitization rates increased in children <10 years of age (1998: 3–5 years: 8.3%, 6–9 years: 14.4%, 10–12 years: 24.0%, 13–15 years: 25.4%, and 16–18 years: 27.6%; 2019: 3–5 years: 10.7%, 6–9 years: 17.7%, 10–12 years: 22.5%, 13–15 years: 23.9%, and 16–18 years: 25.3%).

Fig. 2. The start and end dates of the pollen season for the major allergenic tree pollens in the Seoul metropolitan area during the past 22 years. In 1998, the start and end dates were March 5 and June 7, respectively, and the duration of the pollen season was 94 days. In 2019, the start and end dates were February 15 and July 5, respectively, and the duration of the pollen season was 140 days.

Fig. 3. The trend in the total concentrations (A) and the peak concentrations (B) of the studied pollens in the Seoul metropolitan area during the 22 years of the study. Both the total and the peak concentrations of pollens increased gradually over time.

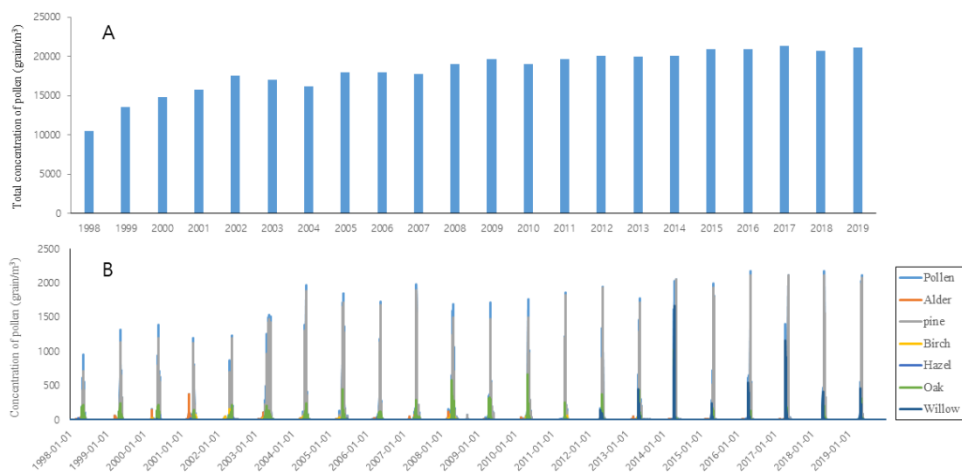


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Fig 3.



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