

Associations among air pollutants, grass pollens, and daily number of grass pollen allergen-positive patients: a longitudinal study from 2012 to 2016

Yuhui Ouyang, MD, PhD^{1,2}, Zhaoyin Yin, MD³, Ying Li, BD², Erzong Fan, BD² and Luo Zhang, MD, PhD^{1,2} 

Background: Grass pollen is the most prevalent sensitizing aeroallergen to cause respiratory allergies in northern China. Air pollutants have a substantial effect on respiratory health and some pollens. This study aimed to investigate relationships among airborne grass pollen, air pollutants and allergic diseases, in order to determine their effects on patients with grass pollen allergies in Beijing, China, during the period from 2013 to 2016.

Methods: Data regarding autumnal grass pollens and air pollutants measured in Beijing from 2012 to 2016 were obtained from local governmental agencies. Patient data regarding specific immunoglobulin E (IgE) analyses from 2013 to 2016 were obtained from the Department of Allergy in Beijing Tongren Hospital. Spearman's rank correlation analysis was used to assess associations between the daily number of grass pollen allergen-positive patients and the following parameters: 3 clinically-relevant grass pollen genera (*Artemisia*, *Humulus*, and *Chenopodium*) and inhalable pollutants.

Results: Correlation analysis indicated that the daily number of grass pollen-positive patients was significantly associated with the peak period of grass pollens, as well

as pollutants SO₂ and NO_x. Moreover, concentrations of air pollutants (eg, ozone, oxides of nitrogen [NO_x], and SO₂) were consistently and significantly associated with concentrations of grass pollens; particulate matter 2.5 μm in diameter was negatively associated with *Artemisia* and *Chenopodium* pollens.

Conclusion: Grass pollens exhibited substantial impact on allergic disease morbidity. Air pollutants impacted allergic disease and grass pollen. Thus, public health and clinical approaches to anticipate and reduce allergic disease morbidity from pollen and pollutants are needed. © 2019 ARS-AAOA, LLC.

Key Words:

Poaceae; particulate matter; ozone; *Humulus*; sulfur dioxide; *Artemisia*; *Chenopodium*; respiratory hypersensitivity; immunoglobulin E; China

How to Cite this Article:

Ouyang Y, Yin Z, Li Y, Fan E, Zhang L. Associations among air pollutants, grass pollens, and daily number of grass pollen allergen-positive patients: a longitudinal study from 2012 to 2016. *Int Forum Allergy Rhinol.* 2019;00:1-7.

Airborne pollen is a major source of outdoor allergens, which have been associated with higher rates of

allergic rhinitis (AR), rhinosinusitis, conjunctivitis, and asthma. Recent studies have suggested that the incidence of inhalant allergies due to pollen may have reached epidemic proportions in some parts of the world.^{1,2} The species and concentrations of airborne pollen vary according to geographical location, weather conditions, and season. A recent multicenter epidemiologic study in China revealed that grass pollens were the most prevalent sensitizing aeroallergens in north China; in particular, sensitization rates for *Artemisia* pollen were 58.2% in northwest China.³ Another epidemiological study in the northern grassland regions of China also suggested that grass pollens were the most common allergens.⁴ Our previous studies have indicated that major airborne pollen allergens are derived from grass during July to September in Beijing, China; the major pollens are *Artemisia* L., *Chenopodium album*, and *Humulus scandens*.⁵

¹Department of Otolaryngology–Head and Neck Surgery and Department of Allergy, Beijing Tongren Hospital, Affiliated to the Capital University of Medical Science, Beijing, China; ²Beijing Key Laboratory of Nasal Diseases, Beijing Institute of Otolaryngology, Beijing, China; ³Beijing Weather Information Service, Beijing, China

Correspondence to: Luo Zhang, MD, PhD, Department of Otolaryngology–Head and Neck Surgery and Department of Allergy, Beijing Tongren Hospital, Affiliated to the Capital University of Medical Science, No. 17, HouGouHuTong, Dongcheng District, Beijing 100730, China; e-mail: dr.luozhang@139.com

Funding sources for the study: National Natural Science Foundation of China (81371104); Beijing Health System High-level Talents Training Program (2014-3-017).

Potential conflict of interest: None provided.

Received: 19 February 2019; Revised: 30 May 2019; Accepted: 4 July 2019

DOI: 10.1002/alr.22389

View this article online at wileyonlinelibrary.com.

Rapid economic growth and urbanization has resulted in severe and deteriorating regional haze, which has overwhelmed some regions of China; this haze includes fossil fuel-related air pollutants, such as sulfur dioxide (SO₂), nitrogen dioxide (NO₂), ozone (O₃), and ultrafine particulate matter (PM), which exert direct adverse effects on human health. Air pollutants act as irritants, which can induce airway inflammation and disrupt epithelial barrier homeostasis; these changes facilitate allergen access to effector cells of the allergic immune response,⁶ or induce the production of reactive oxygen species, which aggravate allergic inflammation.^{7,8} Importantly, air pollutants can also affect plant pollen. Our study showed that oak pollen exposed to elevated levels of SO₂ or NO₂ could significantly increase the fragility and disruption of the pollen, subsequently leading to increased release of pollen cytoplasmic granules.⁹ This increased bioavailability of airborne pollen allergens has been shown to cause an increased incidence of allergic disease. Several studies have shown that air pollution can affect pollen viability, production, and allergenicity.^{10–12} Hence, there is a need to identify conditions that coincide with high exposure to pollen and air pollution, and to determine the extent to which pollutants contribute to airway symptoms. Such information is useful in forecasting and early-warning systems integrating air pollution and pollen, and is necessary for the development of public health policy to mitigate future adverse effects of air pollution and pollen.

Previously, we developed an extensive database of daily concentrations of pollens beginning in 2012, which were collected by pollen monitors. We have also maintained a database of patients who have undergone allergen testing in our allergy clinic since 2013. The objective of the present study was to investigate relationships among airborne grass pollen, air pollutants, and onset of allergic diseases, in order to determine their effects on patients with grass pollen allergies during the period from 2013 to 2016 in Beijing.

Materials and methods

Air pollution data

Air quality data for daily concentrations of PM 2.5 µm in diameter (PM_{2.5}), O₃, carbon monoxide (CO), SO₂, NO, oxides of nitrogen (NO_x), and NO₂ present in the air in Beijing between January 1, 2012, and December 31, 2016, were provided by the Beijing Meteorological Administration. These daily data were obtained as average values of the hourly data collected from 7 monitoring stations in the Dongcheng District of Beijing; daily hourly mean values were used for subsequent analyses. Monitoring of the air pollutants was performed continuously for 24 hours per day, with analysis of the data from the 7 monitoring sites demonstrating no significant variability in the levels of air pollution between these sites.

Pollen data

Daily pollen data were collected from the Dongcheng monitoring station situated in the vicinity of the air quality monitoring station, and managed by Beijing Meteorological Administration. Pollen grains were collected continually for 24 hours every day from 1 January 2012 to 31 December 2016 using a gravitational Durham sampler (Yamato Co. Ltd., Tokyo, Japan), and counted under a microscope. The data were expressed as grains per 1000 mm². The pollen season was estimated to begin on the day when the pollen count was 1% of the cumulative annual total pollen count and to end on the day when the pollen count was 99% of the total annual pollen count.

Patient data

Data for patients who had a history of symptoms of AR (including sneezing, anterior rhinorrhea, bilateral nasal obstruction, and nasal pruritus) lived in Beijing for at least 1 year and undergone allergy testing for specific allergens in the Department of Allergy in Beijing Tongren hospital during the period from 2013 to 2016 were reviewed retrospectively. Data for patients not from Beijing were excluded. Appropriate data were reviewed only for this period because part of data for 2012 was lost because of a change in the hospital network system. Serum-specific immunoglobulin E (IgE) was used for allergen tests. Patients who tested positive for grass pollen (including *Artemisia*, *Humulus*, and *Chenopodium*) allergens were selected for this study. Age, sex, date of allergy test, and daily numbers of patients were analyzed. Only 1 test per individual per day was included in the tabulation of the daily test counts. Information for the same patient (name, age, and sex) were excluded, in order to avoid double counting.

Data analysis

All data were analyzed using SPSS version 15.0 statistics software (SPSS, Inc., Chicago, IL). Spearman's rank correlation analysis was performed to assess correlations between the daily number of pollen allergen-positive patients and pollen concentrations, as well as between pollen variables and air pollutant concentrations. Differences with $p < 0.05$ were considered to be statistically significant.

Results

Distributions of daily values for all variables

Distributions of daily values for all variables are shown in Table 1. The average number of daily pollen allergen-positive patients during July to September (19.79) was higher than the corresponding annual number (9.29, $p < 0.05$). The average age of the patients was 34.4 years old. The 3 primary grass pollen species in Beijing were in genera *Artemisia* (38.9%), *Humulus* (32.2%), and *Chenopodium* (16.2%). Figure 1 shows time-series plots of the daily number of pollen allergen-positive patients, pollen counts, and pollutant levels during July to September; and indicates that

TABLE 1. Data distributions from July 1st through September 30th, 2012 to 2016 (2013 to 2016 for patients tested for allergens)

Variables	Mean	SD	Minimum	Maximum
Patients tested for allergens per day				
Annual patients	9.29	11.83	0	69
Patients (July–September)	19.79 ^a	16.75	0	69
Age	34.40	17.38	3	80
Grass/pollen (grains/1000 mm ²)				
<i>Artemisia</i>	28.75	50.23	0	275
<i>Humulus</i>	23.83	42.73	0	251
<i>Chenopodium</i>	11.97	17.48	0	64
Total	73.89	84.32	0	524
Air pollutant				
PM2.5 (µg/m ³)	47.41	26.99	9.55	131.04
Ozone (ppb)	35.80	12.82	11.65	73.01
NO _x (ppb)	36.32	17.79	10.53	75.42
SO ₂ (ppb)	2.87	1.90	0.63	8.00
CO (ppb)	0.75	12.82	0.27	1.49

^aStatistically significant at $p < 0.05$.

CO = carbon monoxide; NO_x = oxides of nitrogen; PM2.5 = particulate matter 2.5 µm in diameter; ppb = parts per billion; SD = standard deviation; SO₂ = sulfur dioxide.

the concentration of grass pollen had a typical beginning, peak, and ending (flowering) period each year.

Correlation between daily number of pollen allergen-positive patients and daily pollen counts or component of air pollution

Figure 2 shows the concentrations of grass pollens and daily numbers of pollen allergen-positive patients in Beijing from 2013 to 2016. The flowering period and peak of total autumnal pollen for the 3 main grass genera (*Artemisia*, *Humulus*, and *Chenopodium*) can be observed in Figure 2. The flowering period of total autumnal pollen extended from July to September and peaked from late August (21st to 31st) to early September (1st to 10th). The red lines in Figure 2 indicate the daily numbers of allergen-positive patients, which were consistent with the pollen concentration curve. Spearman rank correlations of the corresponding daily numbers of pollen allergen-positive patients and daily concentrations of pollens from 2013 to 2016 were statistically significant (Table 2). Spearman rank correlations were also significant between daily numbers of pollen allergen-positive patients and daily concentrations of pollutant SO₂ from 2013 to 2016, as well as for daily NO_x in 2014 and 2016 (Table 2).

Correlations between daily pollen counts and daily components of air pollution

Of the 5 air pollutants, daily concentrations of ozone and NO_x were consistently and significantly positively associated with the daily concentrations of total grass pollens as well as *Artemisia*, *Chenopodium*, and *Humulus* pollen (Table 3). Similarly SO₂ was positively associated with the concentrations of total grass pollens ($\rho = 0.159$, $p < 0.01$), as well as the individual *Artemisia* ($\rho = 0.146$, $p < 0.01$) and *Chenopodium* pollens ($\rho = 0.121$, $p < 0.01$), but not *Humulus* pollen ($\rho = 0.034$, $p > 0.05$). CO was also positively associated with the concentration of *Artemisia* pollen ($\rho = 0.242$, $p < 0.01$). In contrast, PM2.5 was negatively associated with the concentrations of *Artemisia* ($\rho = -0.200$, $p < 0.01$) and *Chenopodium* pollens ($\rho = -0.139$, $p < 0.01$), but not the concentration of *Humulus* pollen ($\rho = -0.041$, $p > 0.05$) (Table 3).

Figure 3 shows the monthly concentrations of air pollutants from 2012 to 2016, including PM2.5, O₃, CO, SO₂, and NO_x. Although the monthly concentrations of PM2.5, CO, SO₂, and NO_x remained high from October to the following January, O₃ showed the opposite trend.

Discussion

Our correlation analysis of the year-to-year correspondence between daily numbers of pollen allergen-positive patients and the concentrations of pollens indicated that the peak periods of some grass pollen types were significantly associated with the daily numbers of patients who were positive for grass pollen allergens, suggesting that the visit of patients with pollen allergy is closely related to pollen concentration. Moreover, the daily numbers of pollen allergen-positive patients were significantly related to SO₂ and NO_x levels. These results suggested that the onset of allergen response in affected patients was also affected by exposure to some air pollutants. Similarly, our results also revealed that the levels of air pollutants (eg, ozone, NO_x, and SO₂) were significantly positively associated with the concentrations of grass pollens; PM2.5 showed negative associations with the concentrations of *Artemisia* and *Chenopodium* pollens.

In the population of northern China, patients who experience pollinosis are most frequently allergic to grass pollens, particularly *Artemisia*.^{3–5} Because of the large number of grass species, the duration of the grass pollen season is approximately 3 months in Beijing. Grass pollen allergens are found in respirable particles, including whole pollen grains (mean diameter, 15 to 30 µm) and pollen-derived starch cytoplasmic granules (0.6 to 2.5 µm in diameter).⁹ These particulates can be inhaled, thereby causing respiratory symptoms in allergic patients. In our study, the correspondence between the onset of patient sensitivity to grass pollens and the peak pollen counts suggests that elevated pollen counts may induce or exacerbate allergic diseases. Thus, monitoring and prediction of grass pollen counts can provide a preventive measure for pollinosis patients;

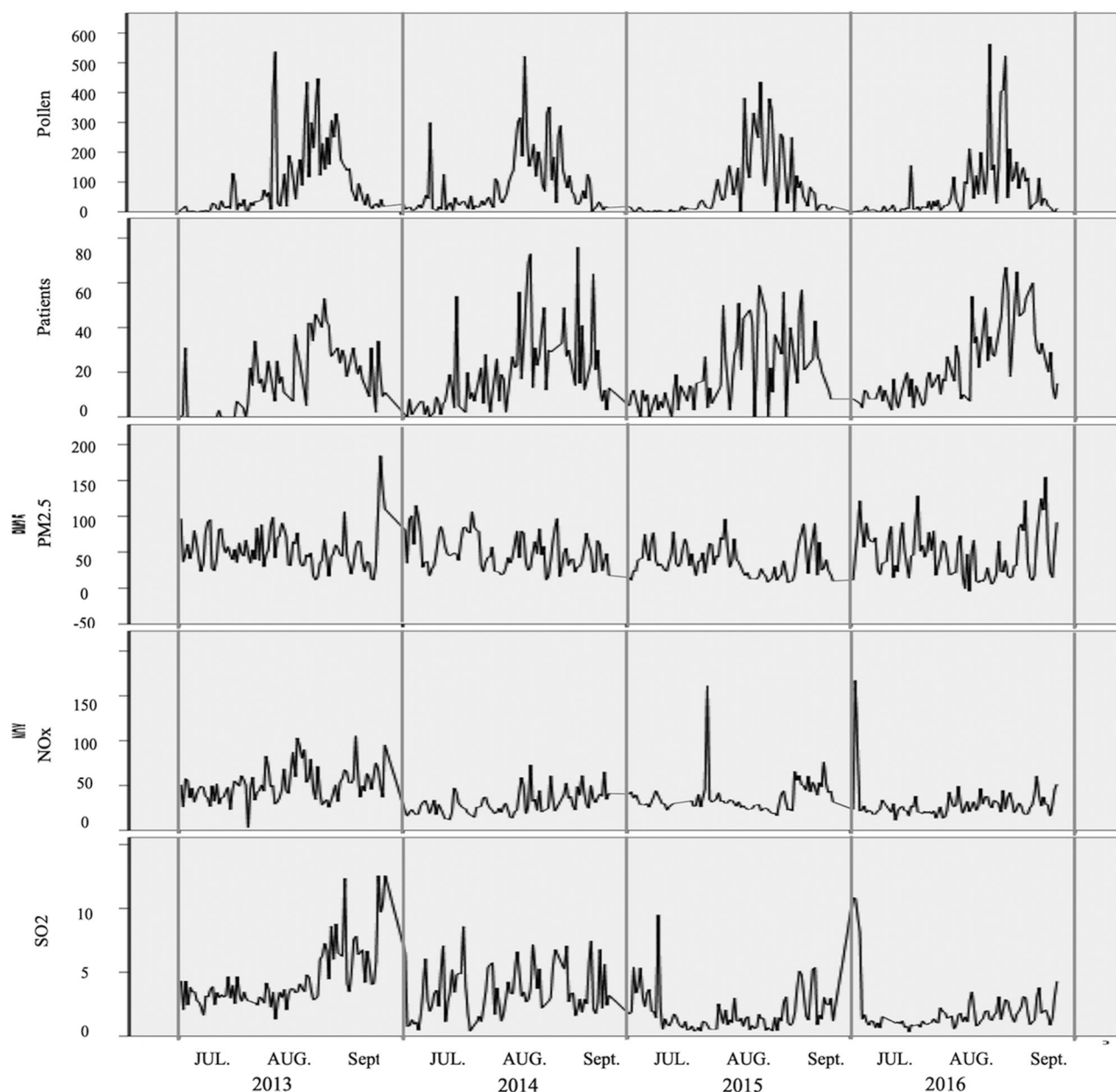


FIGURE 1. Time-series plots of the daily numbers of pollen allergen-positive patients, pollen counts, and pollutant levels from July to September.

moreover, these data may guide development of public health policy, thereby mitigating future adverse effects of these pollens.

Recent studies have shown an association between high levels of air pollution and an increased risk of allergic sensitization, as well as between high levels of air pollution and prevalence of AR.^{2,13} Teng et al.¹⁴ revealed that the prevalence of AR was significantly associated with levels of PM_{2.5}, PM₁₀ μm in diameter (PM₁₀), SO₂, and NO₂ in a large population-based sample. A significant link between the severity of AR and PM₁₀ has also been shown.¹⁵ Similarly, a study conducted on 2598 children aged 3 to 6 years demonstrated that early life exposure to the air pollutant NO₂ during pregnancy and the first year of life may

contribute to childhood AR.¹⁶ The results of the present study suggested that elevated levels of NO_x and SO₂ worsened symptoms in patients who were sensitive to pollens, thereby causing substantial increases in clinic allergen testing.

Air pollutants also impact grass pollen. Depending on the plant species and the pollutant type and concentration, such effects may include altered vitality, shape, size, physiologic features, and metabolism of the pollen grain.^{17–19} Motta et al.²⁰ reported that traffic-related pollutants (eg, NO₂ and O₃) could trigger the release of allergen-containing granules from grass pollen and increase the bioavailability of airborne pollen allergens. Another study confirmed that the pollutants NO₂ and O₃ altered levels of

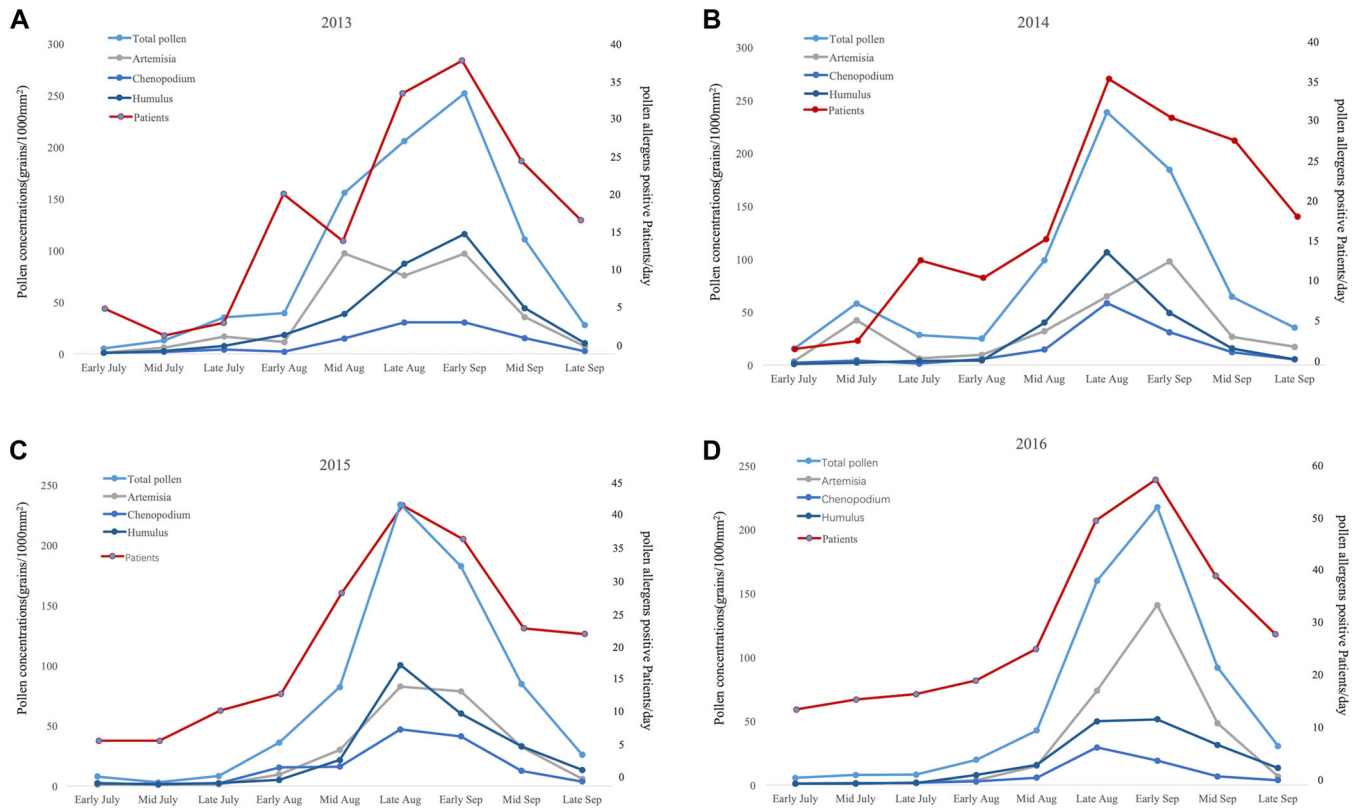


FIGURE 2. (A-D) Concentrations of grass pollens and daily numbers of pollen allergen-positive patients from 2013 to 2016. The flowering period of autumnal pollen extended from July to September, and peaked from late August (21st to 31st) to early September (1st to 10th). The red lines indicate daily numbers of pollen allergen-positive patients. Pollen counts are shown in grains/1000 m²; pollutant concentrations are shown in µg/m³.

TABLE 2. Correlations between numbers of daily pollen allergen-positive patients and daily pollen or pollutant concentrations (July 1st to September 30th in 2013 to 2016)*

Year	Pollen	SO ₂	NO _x
2013	0.659 ^b	0.416 ^b	0.198
2014	0.565 ^b	0.473 ^b	0.348 ^b
2015	0.594 ^b	0.321 ^a	0.271
2016	0.738 ^b	0.278 ^a	0.309 ^a
Total	0.639 ^b	0.372 ^a	0.282 ^a

*Values are correlations between daily numbers of pollen allergen-positive patients and daily pollen or pollutant concentrations in the years given.

^aStatistically significant at $p < 0.05$.

^bStatistically significant at $p < 0.01$.

NO_x = oxides of nitrogen; SO₂ = sulfur dioxide.

allergen-encoding transcripts of ragweed pollen and corresponding allergenic potential.¹² Consistent with the findings of previous research, the present study showed that grass pollen count was correlated with ozone, SO₂, and NO_x. Furthermore, a negative correlation was found between PM2.5 and grass (*Artemisia* and *Chenopodium*) pollen counts. This result may be related to meteorological factors, which impact both pollen concentration and

TABLE 3. Spearman's rank correlation analysis between daily pollen variables and daily air pollutant concentrations in Beijing (2012 to 2016)

Pollen	PM2.5	NO _x	SO ₂	O ₃	CO
Total	-0.087	0.078 ^a	0.159 ^b	0.094 ^b	-0.106
<i>Artemisia</i>	-0.200 ^b	0.126 ^b	0.146 ^b	0.95 ^b	-0.242 ^b
<i>Chenopodium</i>	-0.139 ^b	0.164 ^b	0.121 ^b	0.176 ^b	-0.092
<i>Humulus</i>	-0.041	0.189 ^b	0.034	0.147 ^b	-0.034

^aStatistically significant at $p < 0.05$.

^bStatistically significant at $p < 0.01$.

CO = carbon monoxide; NO_x = oxides of nitrogen; O₃ = ozone; PM2.5 = particulate matter 2.5 µm in diameter; SO₂ = sulfur dioxide.

pollination. Similarly, climate change influences outdoor air pollution because of a robust correlation between generation and dispersal of air pollution and local patterns of temperature, wind, and precipitation.^{21,22}

In the present study, we found trends in the monthly concentrations of PM2.5, CO, SO₂, and NO_x from 2012 to 2016. In particular, these pollutants were at high levels during October to January, whereas they were at low levels during February to September. In contrast, the monthly concentration of O₃ showed the opposite trend, increasing in February and peaking during May and June. Because



FIGURE 3. (A-E) Monthly concentrations of air pollutants (PM_{2.5}, SO₂, NO_x, CO, and O₃) from 2012 to 2016. Pollutant concentrations are shown in µg/m³. CO = carbon monoxide; NO_x = oxides of nitrogen; O₃ = ozone; PM_{2.5} = particulate matter 2.5 µm in diameter; SO₂ = sulfur dioxide.

O₃ is the primary component of photochemical oxidants, the high concentration of O₃ in summer may be related to the high solar ultraviolet radiation intensity and high temperature in summer, which results in so-called “summer smog.” Indeed, studies have suggested that the concentrations of NO_x and O₃ are negatively correlated,²³

which would be consistent with the findings of the present study.

However, this study is somewhat limited in that it was a single-center study and the data for daily pollen and air pollutant levels were collected from only the monitoring site near the hospital, rather than also from monitoring sites in

other parts of the city. Furthermore, data were reviewed for patients who had undergone allergen testing in our clinic and included both local patients living near the hospital as well as patients living in different parts of Beijing. However, analysis of data collected for daily pollen and air pollution levels from 7 other monitoring sites in Beijing showed no significant differences between the levels of air pollution or timing of pollen release at these 7 monitoring sites and the monitoring site near the hospital. A further limitation of the study is that it was not possible to take into account the confounding effects of cigarette smoke, indoor pollutants, or respiratory infections, because this was a retrospective analysis. Despite these limitations, which can be obviated in future well-designed multicenter studies conducted in different centers in Beijing, this study provides useful evidence for the effects of combinations of pollen and air pollutants in AR morbidity, and consequently useful pointers toward the control of AR symptoms in areas with combinations of high pollen and environmental pollutant levels.

In this respect future studies could investigate the effect of traditional pharmacotherapy in combination with specific avoidance measures; eg, nose/mouth face masks that filter out pollen and pollutants. Because the species of grass pollens vary among regions, similar assessments of the impact of individual grass pollens on allergic disease outcomes are also needed for developing region-specific public health programs to mitigate the adverse impact of region-specific pollens and pollutants.

Conclusion

In summary, grass pollens that peak in autumn exhibit substantial impacts on allergic disease morbidity. Air pollutants impact both allergic disease manifestation and grass pollen counts. Thus, public health and clinical approaches to anticipate and reduce allergic disease morbidity from pollen and pollutants should be developed. 

References

1. Sozańska B, Błaszczyk M, Pearce N, Cullinan P. Atopy and allergic respiratory disease in rural Poland before and after accession to the European Union. *J Allergy Clin Immunol*. 2014;133:1347-1353.
2. Zhang Y, Zhang L. Prevalence of allergic rhinitis in China. *Allergy Asthma Immunol Res*. 2014;6:105-113.
3. Lou H, Ma S, Zhang L, et al. Sensitization patterns and minimum screening panels for aeroallergens in self-reported allergic rhinitis in China. *Sci Rep*. 2017;7:9286.
4. Wang XY, Ma TT, Wang XY, et al. Prevalence of pollen-induced allergic rhinitis with high pollen exposure in grasslands of northern China. *Allergy*. 2018;73:1232-1243.
5. Ouyang Y, Fan E, Li Y, et al. Onset feature and efficacy of early interventional treatment of *Artemisia pollinosis*. *Zhonghua Er Bi Yan Hou Tou Jing Wai Ke Za Zhi*. 2014;49:272-276.
6. Traidl-Hoffman C, Jakob T, Berendt H. Determinants of allergenicity. *J Allergy Clin Immunol*. 2009;123:558-566.
7. Klein T, Kukkonen J, Dahl A, Bossioli E, et al. Interactions of physical, chemical, and biological weather calling for an integrated approach to assessment, forecasting, and communication of air quality. *Ambio*. 2012;41:851-864.
8. Hashemi A, Shirkani A, Farrokhi S, et al. Role of air pollution on pathogenesis of asthma and allergic diseases. *J Air Pollut Health*. 2018;2:205-210.
9. Ouyang Y, Xu Z, Zhang L, et al. Effect of nitrogen dioxide and sulfur dioxide on viability and morphology of oak pollen. *Int Forum Allergy Rhinol*. 2016;6:95-100.
10. Ribeiro H, Costa C, Abreu I, da Silva JC. Effect of O₃ and NO₂ atmospheric pollutants on *Platanus x acerifolia* pollen: immunochemical and spectroscopic analysis. *Sci Total Environ*. 2017;599:291-297.
11. Grundström M, Å Dahl, Ou T, et al. The relationship between birch pollen, air pollution and weather types and their effect on antihistamine purchase in two Swedish cities. *Aerobiologia*. 2017;33:457-471.
12. Zhao F, Durner J, Winkler JB, et al. Pollen of common ragweed (*Ambrosia artemisiifolia* L.): Illumina-based de novo sequencing and differential transcript expression upon elevated NO₂/O₃. *Environ Pollut*. 2017;224:503-514.
13. Ito K, Weinberger KR, Robinson GS, et al. The associations between daily spring pollen counts, over-the-counter allergy medication sales, and asthma syndrome emergency department visits in New York City, 2002-2012. *Environ Health*. 2015;14:71-82.
14. Teng B, Zhang X, Yi C, et al. The association between ambient air pollution and allergic rhinitis: further epidemiological evidence from Changchun, Northeastern China. *Int J Environ Res Public Health*. 2017;14:226.
15. Annesi-Maesano I, Rouve S, Desqueyroux H, et al. Grass pollen counts, air pollution levels and allergic rhinitis severity. *Int Arch Allergy Immunol*. 2012;158:397-404.
16. Deng Q, Lu C, Norbäck D, et al. Early life exposure to traffic-related air pollution and allergic rhinitis in preschool children. *Respir Med*. 2016;121:67-73.
17. Malayeri BE, Noori M, Jafari M. Using the pollen viability and morphology for fluoride pollution biomonitoring. *Biol Trace Elem Res*. 2012;147:315-319.
18. Depciuch J, Kasprzyk I, Roga E, Parlinska-Wojtan M. Analysis of morphological and molecular composition changes in allergenic *Artemisia vulgaris* L. pollen under traffic pollution using SEM and FTIR spectroscopy. *Environ Sci Pollut Res*. 2016;23:23203-23214.
19. Naas O, Mendez M, Quijada M, et al. Chemical modification of coating of *Pinus halepensis* pollen by ozone exposure. *Environ Pollut*. 2016;214:816-821.
20. Motta AC, Marliere M, Peltre G, et al. Traffic-related air pollutants induce the release of allergen-containing cytoplasmic granules from grass pollen. *Int Arch Allergy Immunol*. 2006;139:294-298.
21. Ouyang Y, Li J, Zhang L, et al. A model to predict the incidence of allergic rhinitis based on meteorological factors. *Sci Rep*. 2017;7:10006.
22. D'Amato G, Bergmann KC, Cecchi L, et al. Climate change and air pollution: effects on pollen allergy and other allergic respiratory diseases. *Allergo J Int*. 2014;23:17-23.
23. Carrillortorres E, Hernandezpaniagua I, Mendoza A. Use of combined observational- and model-derived photochemical indicators to assess the O₃-NO_x-VOC system sensitivity in urban areas. *Atmosphere*. 2017;8:22.