

The Impact of Climate Change on Pollen Season and Allergic Sensitization to Pollens



Young-Jin Choi, MD, PhD^a, Kyung Suk Lee, MD, PhD^{a,b},
Jae-Won Oh, MD, PhD^{a,b,*}

KEYWORDS

• Climate change • Allergy • Sensitization • Pollen • Pollination

KEY POINTS

- Climate change may affect the seasonal allergic diseases due to longer pollen seasons and increase both allergic sensitization and symptom prevalence with severity.
- The complex interaction of air pollution and temperature on pollen production and allergenicity makes the overall risk assessment of tree pollens challenging.
- The future direction of research on climate change is speculative, because the influence on humans is complex.

INTRODUCTION

Climate change represents a massive threat to global health that could affect many disease factors in the twenty-first century. Among previous reports, climate change influences the development of asthma and allergic diseases and influences pollen productions that induce allergic manifestations.^{1–4} The influence of a changing climate on allergic disease has generated interest from the public and the scientific community. The climate is constantly changing and variable over time and is dependent on incoming solar radiation, outgoing thermal radiation, and the composition of the atmosphere on earth. Climate change is a constant process that affects allergy. Impacts on pollen may be one of the most important consequences of climate change for human health.¹ There are multiple interrelated, potential consequences of climatic change on plant phenology. Therefore, the change subsequently can influence the occurrence of

^a Department of Pediatrics, Hanyang University Guri Hospital, 153 Gyungchun-Ro, Guri, Gyunggi-Do 11923, South Korea; ^b Department of Pediatrics, College of Medicine, Hanyang University, Seoul, South Korea

* Corresponding author. Department of Pediatrics, Hanyang University Guri Hospital, 153 Gyungchun-Ro, Guri, Gyunggi-Do 11923, South Korea.

E-mail address: jaewonoh@hanyang.ac.kr

pollen allergy. Especially respiratory allergic disease, such as asthma, allergic rhinitis (AR), allergic conjunctivitis (AC), and even atopic dermatitis, will increase under climate change in part because of the impact on allergenic plant species.^{2,3} Pollens are a major cause of symptoms in allergic individuals, but because the influence of climate change is complex, there is no predictable quantitative assessment of how climate change may affect the levels of pollen allergy in humans in the future.⁴ For example, an altered climate will affect the range of allergenic plant species as well as the length of the pollen season, and elevated atmospheric carbon dioxide (CO₂) may increase plant productivity and pollen production.⁵ Climate change also may affect the release and atmospheric dispersion of pollen.² The overall impact will be alteration of pollen season timing and load and, hence, changes in exposure. Modeling all of these processes is needed to evaluate the consequences of climate change on pollen-related allergic disease.

The future consequences of these trends are speculative, but the allergy community must be knowledgeable about the issues; understand the anticipatable effect on allergic diseases, including asthma, AR, and AC; and be well-versed in possible means to mitigate adverse health consequences. The public and scientific community has generally interested in The influence of future climate on pollen allergy.^{5,6} Most studies on the impact of climate change on aeroallergens can be divided into pollen amount, pollen allergenicity, pollen season, distribution of allergic plants, and pollen.^{7,8} Several research articles on climate change effects on distributions of allergenic pollens have focused typically on analysis of observed pollen counts and their regression relationships with local meteorologic factors.^{9–11} There are 3 major issues by which climate change could influence allergic disease. First, warmer temperatures and a longer pollen season could increase the duration of human exposure to aeroallergens with consequences for increased allergic sensitization.¹² The dates of phenological events, such as the release of pollen and subsequent bud burst, could be the same after climatic warming. In warmer weather, bud bursting would occur slightly earlier but would require a greater thermal time in order for the risk of frost damage to be the same. Second, climate change could increase the level of allergenic airborne pollen and allergic symptoms associated with exposure. The onset, duration of pollination, and abundance of pollen grains in the air vary from year to year. Finally, climate disruptions with air pollution and/or increased CO₂ and the other greenhouse gases might change allergen concentration of the pollen and alter the allergenicity and its symptom severity.^{13,14} Weather variables, mainly air temperature, sunlight, and rainfall, together with CO₂ are among the main factors affecting phenology, which means the times of the appearance of first leaves, first flowers, autumn leaf coloration, and so on and pollen production by plant. In addition, weather patterns influence the movement and dispersion of all aeroallergens in the atmosphere through the action of winds and rainfall and depend on the atmospheric stability.^{15,16} The relationships between changing start dates for pollen seasons, which immediately precede bud burst, and changing spring temperatures provide an indication of the current status of the response to future changes in spring temperatures, although the start of the pollen season may be influenced by factors affecting pollen dispersal, such as rainfall or lack of wind.^{10,17,18} Monitoring pollen must be recorded with meteorologic variables when pollen is in the air and when pollen matures on the plants for the evaluation of pollination.

WEATHER AND POLLEN SEASON

Plants basically require a certain amount of heat to complete their development; then, air temperature plays a key role, together with day length, water and nutrient

availability, soil type, and so forth. Therefore, weather conditions, including rainfall, humidity, wind speed, and air temperature, may alter the concentrations of pollens. Increasing worldwide evidence demonstrates that the timing of life-cycle events of a large number of plants have responded to the increase in air temperature. Increased temperatures may lead to earlier pollination of many plants and longer duration of pollination. Several species have been shown to produce more pollen with warmer temperatures. Additionally, climate change is thought to increase the quantity of allergenic protein that individual pollen grains contain. Changes also involve plants producing allergenic pollen, with expected consequences on allergic individuals.^{19–23} Longer pollen seasons increase duration of exposure, potentially resulting in more sensitization. Longer pollen seasons also lead to longer symptomatic periods in those with allergic disease, and higher pollen concentrations may lead to more severe symptoms. An earlier start of pollen season was confirmed in studies focused on allergenic plant. Due to the earlier onset, the pollen seasons are interrupted more often by adverse weather conditions in late winter or early spring.^{13,17,24–30} Duration of the pollen season also is extended, especially in summer and in late flowering species. Moreover, there is some evidence of significantly stronger allergenicity in pollen from trees growing at increased temperatures.^{28,29}

Several studies regarding the relationship between climate change and pollen allergy have indicated that plant phenology is shifting in response to global warming.^{30–32} Research about trends in pollen concentrations, however, has focused either on limited site-specific studies or on a single source or small subset of allergenic pollen taxa, such as ragweed, across a larger geographic area, with several studies varying with respect to temporal increases in pollen season duration or pollen load.^{33–35} Hence, along-term analysis of compound allergenic plant species across different continents and different environmental regimes is needed to assess whether recent climate-induced changes are affecting seasonal exposure to airborne pollen on a global scale. Cumulative pollen concentrations and a preset percentage threshold level are used to define the start and end of the pollen season. The start of the pollen season can be defined as the point when the cumulative pollen count reaches 5% of the annual pollen integral, the yearly cumulative count, and the end of the season defined as the point when the count reaches 95%.

Analyses of recent trends that include multiple pollen sources across large geographic areas are scarce. Ziello and colleagues³⁶ analyzed data set consisting of 1221 pollen time series at 97 locations in 13 European countries from 23 pollen taxa across 97 stations in Europe, but most stations had pollen records ranging from 10 to 28 years. A tendency toward an increase in pollen was noted; however, substantial variability in the seasonal pollen index, and no significant correlation between seasonal trends and mean air temperature was reported. Zhang and colleagues³⁷ presented a similar spatiotemporal analysis within the United States; they also reported increasing trends in seasonality and pollen amounts for a subset of allergenic plants, such as birch, oak, ragweed, mugwort, and grass, over a 17-year period. Although a significant correlation with latitude was observed, correlations between temperature and pollen seasonality or load were not established. Overall, the long-term data indicate significant increases in both pollen loads and pollen season duration over time across the pollen collection locations, although without a clear latitudinal trend. Recently, analysis from Ziska and colleagues³⁸ illustrates a clear positive correlation between recent global warming and an increase in the seasonal duration and amount of pollen for multiple allergenic plant species on a decadal basis for the northern hemisphere. If the change in pollen load over time for a given location is compared with the temporal change in either maximum temperature (Tmax) or

minimum temperature (Tmin), 12 (71%) of the 17 locations showed significant increases in seasonal cumulative pollen or annual pollen load. Similarly, 11 (65%) of the 17 locations showed a significant increase in pollen season duration over time, increasing, on average, 0.9 days per year. Across the northern hemisphere locations analyzed, annual cumulative increases in Tmax over time were significantly associated with percentage increases in seasonal pollen load as were annual cumulative increases in Tmin. A significant association is observed in the present study, indicating that temperature contributed to seasonal changes in pollen load on a global level (Fig. 1). Changes in Tmax and Tmin for cumulative degree day were significant (Fig. 2). The lengthening of pollen seasons is related to both earlier springs and later autumns. Although the increase in temperature is known to vary with latitude, its impact on the increase in pollen concentrations, in terms of intensity and duration, appears to be global and independent of latitude.³⁸ These data indicate that recent climatic changes, through temperature, are affecting pollen amounts as well as season duration and timing in the northern hemisphere.

These observed changes may implicate the future respiratory allergic diseases, such as AR and asthma. Future climate projections also suggest changes in the duration of the pollen season and an estimated rising in sensitization to allergenic plants, such as ragweed.^{39,40} Similarly, projections for other allergenic species, such as oak, indicate that a longer duration of the pollen season might be related to increased emergency department visits in future in the United States.⁴¹ Hazards are naturally occurring physical events that can have an impact on human health both directly and indirectly through disarrangement of ecosystems and the services they provide with climate-driven shifts in their distribution, frequency, and intensity. In contrast to the depth of knowledge available for anthropogenic-related threats, climate change drivers can interact in synergistic ways, yet the interactive effect of global change drivers on plant pollination are poorly represented in several previous studies.^{41,42} For illuminating global change drivers, a study paired manipulative experiments to probe 2 mechanistic pathways through which plant invasion and global warming may alter phenology and reproduction of native plant species. They tested how experimental warming (+1.7°C) modulated flowering phenology and how this affected flowering overlap between a native plant and an invasive plant. The flowering overlap of native and invasive plants would be altered by warming, given that invading plants typically exhibit greater phenological plasticity than native plants. These results illustrate a pathway through which global change drivers can operate synergistically to alter pollination.⁴¹

SENSITIZATION TO ALLERGIC POLLEN

Hypersensitivity to pollens is one of the most common aspects of the allergic disease, leading to AR, AC, and asthma.⁴² Subjects with pollen allergy can be sensitized to a single or to several pollen species, depending on their exposure to regional pollens.⁴³ Sensitization to multiple allergens, including pollens, has been reported to lead to more serious allergic symptoms and to increase the risk of asthma.^{44–46} An interaction between the exposure to pollen and being sensitized to pollen allergens was detected that the effect was less pronounced in individuals who were sensitized to only 1 type of pollen, compared with who are sensitized to all types of pollen (trees, grasses, and weeds).⁴⁷ Furthermore, because different pollen types are released at different periods of the pollen season, atopic individuals sensitized to more than one type of pollen are experiencing a longer period of exposure, which may lead to a stronger effect on airway hyperreactivity and reduced lung function.⁴⁷

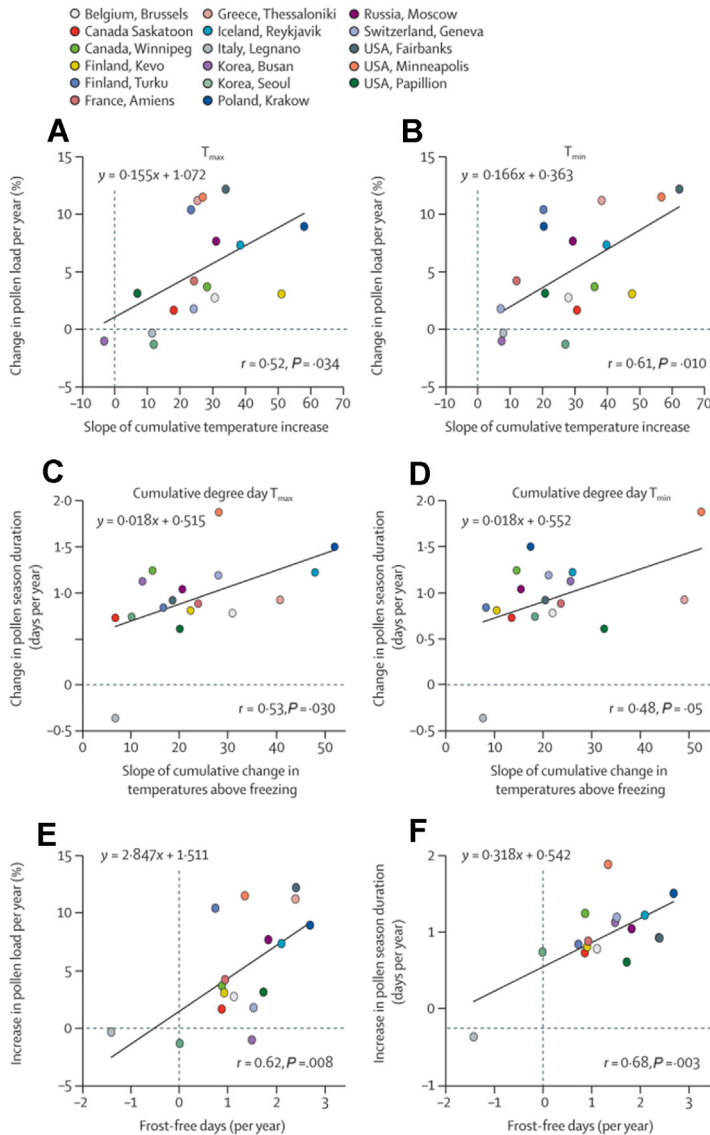


Fig. 1. Changes in annual pollen load and pollen season duration. (A) Relative change in annual pollen load as a function of slope of cumulative T_{max} by location over time. (B) Relative change in annual pollen load as a function of slope of cumulative T_{min} by location over time. (C) Change in pollen season duration as a function of the cumulative degree day above freezing for T_{max} by location over time. (D) Change in pollen season duration as a function of the cumulative degree day higher than the freezing point for T_{min} by location over time. (E) Average annual percentage change in pollen load as a function of temporal changes in frost-free days by location. (F) Average annual percentage change in pollen season duration as a function of temporal changes in frost-free days by location. (From Ziska LH, Makra PL, Harry SK, et al. Temperature-related changes in airborne allergenic pollen abundance and seasonality across the northern hemisphere: a retrospective data analysis. *Lancet Planet Health*. 2019;3:e124-131; Reprinted with permission from Elsevier.)

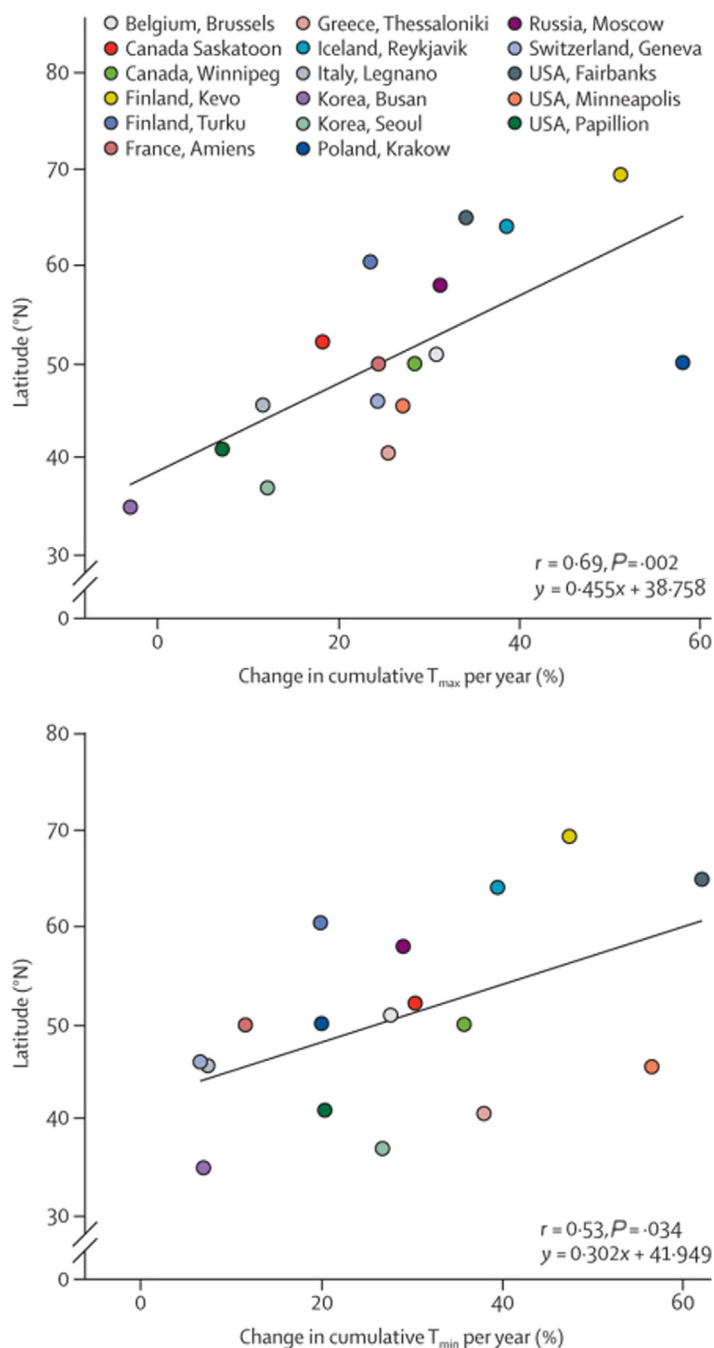


Fig. 2. Change over time in cumulative T_{max} (top panel) and T_{min} (bottom panel) for each of the 17 locations used in the study as a function of latitude. (From Ziska LH, Makra PL, Harry SK, et al. Temperature-related changes in airborne allergenic pollen abundance and seasonality across the northern hemisphere: a retrospective data analysis. *Lancet Planet Health*. 2019;3:e124-131; Reprinted with permission from Elsevier.)

There is the different threshold level of allergic sensitization among plant species. Because the threshold level of grass pollen concentration needed to develop allergy symptoms is considered to be significantly lower than the corresponding level for birch, it may be taken more days with pollen levels above this threshold for grass than for birch pollen.⁴⁸ In previous studies, an increase in sensitivity to grass pollen has been observed as the pollen season progresses.⁴⁹ Subjects who perceived allergen sensitization were more likely to have actual sensitization to at least 1 aeroallergen; 83.9% perceived allergen sensitization to at least 1 outdoor allergen. A US study of 247 adults with asthma found no significant correlation between reported allergic symptoms to pollens and skin prick test (SPT) wheal size to pollens and mild correlation for reported pet allergy and SPT wheal size to cat and dog.⁵⁰ In contrast, a separate Finnish study of 290 young adults found that reported AR from pollen or animal dander and furs had a specificity and sensitivity of 87% for sensitization to any allergen by serum IgE or SPT.⁵¹

There are multiple interrelated, potential consequences of climatic change on respiratory allergic disease. Rising air temperatures can influence pollen season duration with commensurate changes in the duration of human exposure to aeroallergens and plant distribution with allergenic mixtures. Warmer temperature might increase seasonal intensity of the allergenic load and the concentration of pollen. These changes are important, given that the duration of the pollen season is correlated with the duration of symptomatic periods among atopic individuals and that allergenic pollen concentration is positively correlated with symptom severity at a population level. Climate change could alter the allergenicity or allergen concentration of the pollen.^{19,52} Overall, climate changes in contact to allergenic pollens are likely to affect both sensitization rates and allergic symptom prevalence and severity.^{2,3,53}

POLLUTION AND POLLINATION

Environmental and meteorologic changes, driven by increased concentrations of greenhouse gases, have widespread impacts on biotic systems, including direct and indirect effects on human health.⁵⁴ Several studies have suggested that traffic-related pollutants can disrupt pollen, a modification that aggravate allergic symptoms.^{13,55–57} In particular, it has been suggested that particulate matter (PM) may interact with aeroallergens, promoting airway sensitization by modulating the allergenicity of pollen.⁵⁸ Several epidemiologic studies have investigated the synergic effects of air pollution and pollen exposure on rhinitis symptoms, with conflicting findings.^{59,60} Different models suggest that an increase in the concentration of atmospheric CO₂ is one of the most certain predictors of climate change. The CO₂ concentration has increased by 29% since preindustrial times. The average tropospheric CO₂ concentration has risen from 290 parts per million (ppm) in 1850 (preindustrial era) to 353 ppm in 1990.⁶¹ Over the past 50 years, the global earth temperature has risen markedly. Approximately 75% of the anthropogenic CO₂ emissions to the atmosphere during the past 50 years resulted from fossil fuel burning.⁶² The key determinants of greenhouse gas emissions are energy production, transportation, agriculture, food production, and waste management. Moreover, rising temperatures contribute to the elevation of the concentrations of ozone (O₃) and PM with CO₂ at ground level.^{63,64} Urbanization and high levels of vehicle emission have been shown to increase the frequency of seasonal respiratory allergy in people living in urban areas in comparison with those living in rural areas.⁶⁵ Published data suggest an increasing effect of aeroallergens on allergic patients, leading to a greater likelihood of development of an

allergic respiratory disease in sensitized patients and an aggravation in patients already symptomatic.^{27,66}

Increasing CO₂ and temperature seem to substantially increase pollen production from ragweed in experimental conditions. The same results were obtained in a study on ragweed plants growing in urban and rural areas, providing a natural model for evaluating possible effects of global warming. Some studies showed that Amb a 1 concentration in ragweed pollen increased as a function of CO₂ concentration. The difference in Amb a 1 as a result of increased CO₂ also may be affected by influences among and within different ragweed populations.^{10,67,68} Furthermore, ragweed pollen collected along high-traffic roads showed a higher allergen city due to traffic-related pollution. Pollen from birch trees exposed to higher O₃ levels induces larger wheals and flares in SPT compared with lower O₃-exposed pollen, suggesting an allergenicity increasing effect of O₃.^{27,68} Other factors, however, might modify the distribution of allergenic plants in Europe. The cases of grass and ragweed are explanatory. Grass pollen is responsible for a high portion of pollen allergy worldwide, and variations in total pollen count have been observed in past decades. Rogers and colleagues²⁵ reported faster growth of spikes as a result of high CO₂ concentrations over a limited period of time. Furthermore, Kim and colleagues⁶⁹ recently presented the oak trees under the elevated CO₂ levels, which are expected in the changing climate, produced significantly higher amount of pollen and allergenic protein than under the present air conditions. The number and weight of oak pollen grains from the CO₂-enriched open-top chamber per plant and per catkin increased from the ambient CO₂ (Fig. 3, Table 1). Although there are few reports on the response of tree pollens to CO₂ concentrations, these results are supported by those of other studies on weed species.⁶⁹ The analysis of the time series of aerobiological data from the United Kingdom, the longest of the world, showed a decreasing trend in terms of yearly grass pollen counts and severity of pollen season and an earlier start of the season. There are remarkable differences between the 3 study sites, however, underlining the role of local determinants, such as meteorologic factors, plant adaptation, changes in land use, and changes in species

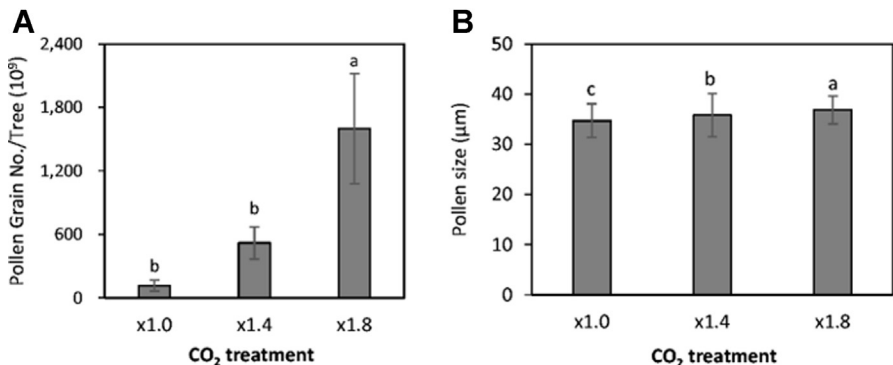


Fig. 3. (A) Total number of pollen grains and (B) mean diameter of the pollen grains collected from the CO₂ open-top chambers, ×1.0 CO₂, ×1.4 CO₂, and ×1.8 CO₂ concentrations; ×1.0 CO₂, ×1.4 CO₂, and ×1.8 CO₂ expresses 400 ppm, 560 ppm, and 720 ppm of CO₂ concentrations, respectively. Different lowercase letters on the bars indicate significant differences among treatments in OTCs at 5% significance level by Tukey test. Data represent mean ±SD. (From Kim KR, Oh JW, Woo SY, et al. Does the increase in ambient CO₂ concentration elevate allergy risks posed by oak pollen? *Int J Biometeorol*. 2018 Sep;62(9):1587-1594; with permission.)

Table 1

Number of pollen grains per catkin, weight of pollen per catkin, number of pollen grains per tree, pollen size, and allergenic protein content and their ratio to the ×1.0 treatment

Treatment	Grains/ Catkin		Weight/ Catkin		Grains/Tree		Size		Allergen Content	
	(10 ⁶)	Ratio	(mg)	Ratio	(10 ⁹)	Ratio	(μm)	Ratio	(ng/mL)	Ratio
×1.0	324.2	1.00	3.50	1.00	114.4	1.00	34.7	1.00	419.7	1.00
×1.4	388.8	1.20	7.05	2.01	518.3	4.53	35.8	1.03	472.2	1.12
×1.8	590.2	1.82	8.91	2.54	1600.7	13.99	36.9	1.06	467.2	1.11
<i>P</i> value	.045		.003		<.001		<.001		.011	

The *P* values from the 1-way ANOVA also are indicated.

and effects of air pollutants.⁷⁰ These studies suggested that the complex interaction of CO₂ concentration and temperature on pollen production and allergenicity makes the overall risk assessment of tree pollens a good challenge. Climate change may induce changes in the ecological suitability of allergenic plants, which may result in new allergy symptoms in groups with no previous problems.⁴

Change of weather pattern may increase episodes of long-distance transport of pollutants as well as of pollen grains, such as ragweed, making large-scale circulation patterns as important as regional ones.⁷¹ Over the past decades, many studies have shown changes in the production, dispersion, and allergen content of pollen and that nature of the changes may vary in different regions and species. Climate change is also having an impact on the biogeographical distribution of plants with consequences for the composition of pollen diversity as well as the magnitude and duration of pollen seasons.^{5,72}

CLINICAL CARE POINTS

- Climate change may influence pollen season duration, with human exposure to pollen allergens, and increase seasonal intensity of the allergenic load. Sensitization to pollens lead to serious allergic symptoms and to increase the risk of asthma.^{44–46}
- Pollen from birch trees exposed to high O₃ levels induces larger wheals and flares in SPTs, suggesting an allergenicity increasing effect of O₃.^{27,68} The interaction of CO₂ concentration and temperature on pollen production and allergenicity might imply to aggravate the risk of tree pollens.^{67,69}
- Because the influence of climate change is complex, there is no predictable quantitative assessment that climate change may affect the levels of pollen allergy in humans in the future.⁴

Data from Refs.^{4,27,44–46,68}

DISCLOSURE

No commercial or financial conflicts of interest for all authors.

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