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Relationship between meteorological variability and pollen sensitization over the past 10 years

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Abstract

Background: Meteorological changes can influence the type and concentration of allergenic pollen in the atmosphere.

Objective: This study aimed to investigate the relationship between the diversity of pollen sensitivity based on skin prick test (SPT) reactions and meteorological changes over the past 10 years in Konya, Türkiye.

Methods: A total of 23,111 patients who underwent skin prick testing (SPT) between January 2015 and December 2024 were included in the study. Meteorological data, including temperature, sunlight exposure, relative humidity, rainfall, and wind speed, were obtained from the 8th Regional Directorate of Meteorology.

Results: Our analysis revealed significant relationships between meteorological parameters and pollen sensitivity. Sunlight duration was positively correlated with sensitivity to tree pollen (r = 0.608, p < 0.001). Wind speed was positively correlated with sensitivity to tree pollen (r = 0.433, p = 0.002) but negatively correlated with sensitivity to Chenopodium (r = -0.353, p = 0.013). Humidity was positively correlated with sensitivity to weed and grass pollen (r = 0.367, p = 0.022; r = 0.305, p = 0.033) and negatively correlated with sensitivity to tree pollen (r = -0.605, p < 0.001). Temperature was positively correlated with sensitivity to Artemisia vulgaris (r = 0.317, p = 0.034) and negatively correlated with sensitivity to weed pollen (r = -0.734, p < 0.001). Rainfall was negatively correlated with sensitivity to grass pollen (r = -0.296, p = 0.039), tree pollen (r = -0.850, p < 0.001), and Chenopodium (r = -0.408, p = 0.004).

Conclusion: Our results revealed intricate interactions between pollen sensitivity and meteorological parameters. Notably, rainfall consistently exhibited a negative correlation with specific pollen types, suggesting a potential mitigating effect on pollen-related sensitization. These findings underscore the importance of considering meteorological variability in the management and prediction of allergic diseases.

Key words: Meteorological variability, pollen allergy, sensitization, skin prick test, allergens

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Introduction

Allergic diseases are hypersensitivity disorders of the immune system induced by an allergen-specific immunoglobulin E (IgE)-mediated response. Aero-allergens play a significant role in the pathogenesis of allergic diseases. The increasing prevalence of allergic diseases over time highlights the importance of environmental factors.[1] The atmospheric content of aero-allergens varies across different regions, depending on climate type, geography, and vegetation. Pollen, molds, house dust mites, and pets are the most common aero-allergens.[2] Pollen is one of the most important particles that cause allergic symptoms.[3] A relationship has been established between pollen exposure and sensitivity to pollen allergens. Different types of pollen are released during various times of the year.[4] Temperature, sunlight, rainfall, and humidity influence plant species. In addition to atmospheric events, environmental factors such as air pollutants determine the duration of the pollen season. Increased concentrations of CO_2 (carbon dioxide), due to climate change, are known to affect the growth of pollen-producing plants. As a result, plants grow faster, the duration of flowering extends, and the potency of pollen allergens rises.[5] The increasing prevalence of allergic respiratory symptoms has been linked to environmental factors, including climate-driven variations in pollen exposure. Upon inhalation, pollen grains interact with the mucosal surface, triggering a cascade of immunological responses that contribute to allergic pathophysiology.[6]

Agriculture plays a vital role in the livelihood of the people in Konya province, and several agricultural products from the Poaceae genus are cultivated in the region. Additionally, since pollens from Poaceae species are among the most allergenic in Turkey, this contributes to the high prevalence of pollen allergies in Konya. To facilitate the diagnosis and treatment of allergic diseases, it is important to determine the prevalence of pollens affected by atmospheric changes. Previous studies have primarily focused on the correlation between meteorological factors and pollen concentrations. However, limited research exists on the relationship between meteorological conditions and skin prick test (SPT) reactivity to specific pollen allergens. This study aimed to investigate the role of meteorological changes in the diversity of sensitivity to pollen allergens in Konya.

Methods

Study Population

Between January 2015 and December 2024, a total of 23,469 patients who visited the Allergy and Immunology Clinic and underwent allergy tests were retrospectively screened. The SPT was performed on patients presenting with allergic complaints, such as allergic rhinitis, conjunctivitis, or asthma. Data from 358 patients whose SPT results could not be found in the electronic medical records were excluded. A total of 23,111 patients were included in the study, with 66.4% female and 33.6% male. The median age of all patients was 37 (28-50).

Skin Prick Test

Allergen extracts from Allergopharma (Allergopharma GmbH & Co. KG, Reinbek, Germany) were used for the SPT. The allergens commonly found in the region and used in the study included:

- Tree mixture (Alder, Hazel, Poplar, Elm, Willow, Birch, Beech, Oak, Plane tree)
- Grasses mixture (Velvet grass, Orchard grass, Rye grass, Timothy grass, Kentucky blue grass, Meadow fescue)
- Weed mixture (Mugwort, Nettle, Wall Pellitory, Dandelion, English plantain)
- Grasses-cereals mixture (Velvet grass, Orchard grass, Rye grass, Timothy grass, Kentucky blue grass, Meadow fescue, Barley, Oat, Rye, Wheat)
- Chenopodium album and Artemisia vulgaris.

The allergens used in the study were consistent for most of the study period. However, some allergens were not tested in certain years due to logistical and supply issues: Artemisia vulgaris was not tested in 2015, the Weedmix allergen was not tested in 2017 and 2018, and the Grasses/Cereals Mixture allergen was not tested between 2015 and 2020. These allergens were excluded from the analysis due to the unavailability of the corresponding skin prick test solutions in those years.

The SPT was performed as a single test on the forearm using lancets and standardized allergens, according to international guidelines. A wheal size of ≥ 3 mm was considered a positive reaction. Histamine hydrochloride (10 mg/ml) and glycerin saline were used as positive and negative controls, respectively. All subjects analyzed showed a positive reaction to histamine, and none showed a reaction to the negative control. Allergenic pollen sensitivity data were obtained from the results of the SPT. To calculate the allergenic pollen-sensitization rates, the percentage of patients who were sensitized to specific pollen allergens was determined based on the total number of patients who underwent allergy testing in that year.

Study area and meteorologic data

Konya is the largest province in Turkey in terms of area, with a surface area of 39,000 km². Located on the Central Anatolian Plateau, its average elevation is 1,016 meters. The steppe, which is the characteristic vegetation of the Central Anatolia Region, is typical in this area. Konya has a semi-arid continental climate, with cold and snowy winters, hot and dry summers, mild and rainy autumns, and cool and rainy springs. As a result of this climate diversity, variations in aero-allergen sensitivity patterns can also be expected.

Daily records of climate variables, including mean temperature, rainfall, humidity, wind, and daily sunshine duration, were obtained from the 8th Regional Directorate of Meteorolog. Monthly and annual average data were obtained from these daily weather conditions representing Konya.

Statistical Analysis

Data entry and statistical analyzes were performed by using SPSS for Windows version 18.0 (SPSS Inc. Chicago, IL, USA) package program. Data's conformity to normal distribution was examined using visual methods (histograms and probability graphs) and analytical methods (Shapiro-Wilk test). Correlations of non-normally distributed numerical data were analyzed using Spearman's correlation coefficient. Of Spearman's correlation coefficients, < 0.19 was considered no correlation, 0.20-0.39 weak correlation, 0.40-0.69 moderately strong correlation, 0.70-0.89 strong correlation, and > 0.90 very strong correlation. A $p < 0.05$ was considered statistically significant. The unit of duration of sunlight exposure, wind speed, relative humidity, temperature and rainfall was hours, m/s, %, °C and kg/m^2, respectively.

Ethical Committee Approval

This study was a retrospective analysis of previously collected data. Informed consent, which authorized the use of their medical data for research purposes, was obtained from all patients at the time of their admission to the health-care provider. All data used in this study were anonymized to ensure patient confidentiality. The study was approved by the ethics committee of Necmettin Erbakan University (ethics approval no: 2024/5330). The study was conducted in accordance with the principles outlined in the Declaration of Helsinki.

Results

Allergenic pollen-sensitization rates

The highest rate of positivity to the grass pollen mixture occurred in 2015 at 22.1%, while the lowest rate was in 2017 and 2018 at 13.3%. The highest positivity to tree pollen mixture was observed in 2016 at 7.5%, whereas the lowest rate was in 2018 at 2.1%. The highest positivity to Artemisia vulgaris was recorded in 2023 at 7.6%, with the lowest reactivity in 2016 at 0.4%. The highest positivity to Chenopodium albüm was found in 2022 at 22.4%, while the lowest rate was in 2016 at 1.5%. The highest positivity to weed pollen mixture was in 2021 at 17.1%, whereas the lowest positivity was in 2024 at 2.5%. Additionally, data for cultivated grass pollen between 2015 and 2020 was missing; however, its prevalence was found to have increased in the following years (**Table 1**).

Annual Average Values of Meteorological Parameters

The highest annual average duration of sunlight exposure was recorded in 2024 at 5.22 hours, while the lowest annual average was in 2015 at 3.95 hours. The highest annual average wind speed occurred in 2015 at 11.12 m/s, whereas the lowest was in 2023 at 8.33 m/s. The highest annual average relative humidity was in 2015 at 60.19%, while the lowest was in 2024 at 55.82%. The highest annual average temperature was in 2024 at 14.85°C, whereas the lowest was in 2017 at 12.01°C. The highest annual average rainfall was in 2018 at 0.96 kg/m^2, while the lowest was in 2020 at 0.62 kg/m^2 (**Table 2**).

Table 1. Distribution of reactivity rates (%) to pollen allergens by year.

Year	Grass Pollen Mixture	Tree Pollen Mixture	Artemisia vulgaris	Chenopodium album	Weed Pollen Mixture	Grasses-cereals mixture
2015	22.1	5.9	*	8.5	13.7	*
2016	13.3	7.5	0.4	1.5	6.8	*
2017	13.3	2.5	3	15.8	*	*
2018	13.4	2.1	5.5	12.5	*	*
2019	15	4.6	2.3	4.3	3.6	*
2020	17	6.9	4.5	18.4	10.6	*
2021	16.5	7.4	5.6	20.5	17.1	1.1
2022	18.7	5.6	6.5	22.4	15.7	2.2
2023	19.5	4.9	7.6	20	7.9	8.5
2024	16.7	5.9	7.4	17.5	3.5	16.7

*Missing data for the given year

Table 2. Annual meteorological data.

Year	Duration of Sunlight Exposure (hours)	Maximal Wind Speed (m/s)	Average Relative Humidity (%)	Average Temperature (°C)	Total Rainfall (kg/m²)
2015	3.95	11.12	60.91	12.18	0.85
2016	5.12	9.62	53.72	12.89	0.70
2017	4.95	8.44	60.24	12.01	0.91
2018	4.91	8.84	58.36	13.99	0.96
2019	4.95	8.62	60.12	13.05	0.87
2020	5.13	8.71	57.95	13.42	0.62
2021	5.04	8.76	57.59	12.18	0.68
2022	4.98	8.81	60.18	12.37	0.71
2023	4.79	8.33	58.59	13.14	0.77
2024	5.22	8.94	55.82	14.85	0.68

Distribution of meteorological factors and allergens by years

The distribution of pollen sensitivity and meteorological factors over the years, along with their relationships, is presented in **Figure 1**. The graphs separately show the duration of sunlight exposure (**Figure 1a**), wind speed (**Figure 1b**), humidity (**Figure 1c**), temperature (**Figure 1d**), and rainfall (**Figure 1e**).

The relationship between pollen sensitization rates and meteorological parameters

A moderately strong positive correlation was found between the duration of sunlight exposure and reactivity to tree pollen mixture ($p < 0.001$). The average maximum wind speed showed a moderately strong positive correlation with reactivity to tree pollen mixture and a weak negative correlation with reactivity to Chenopodium ($p = 0.002$ and $p = 0.013$, respectively). Average relative humidity exhibited a weak positive correlation with reactivity to grass pollen mixture, a moderately strong negative correlation with reactivity to tree pollen mixture, and a moderately strong positive correlation with reactivity to weed pollen mixture ($p < 0.05$). Average temperature showed a weak positive correlation with reactivity to Artemisia vulgaris and a strong negative correlation with reactivity to weed pollen mixture ($p = 0.034$ and $p < 0.001$, respectively). Furthermore, average total rainfall demonstrated a weak negative correlation with reactivity to grass pollen mixture, a strong negative correlation with reactivity to tree pollen mixture, and a moderately strong negative correlation with reactivity to Chenopodium ($p < 0.05$) (**Table 3**).

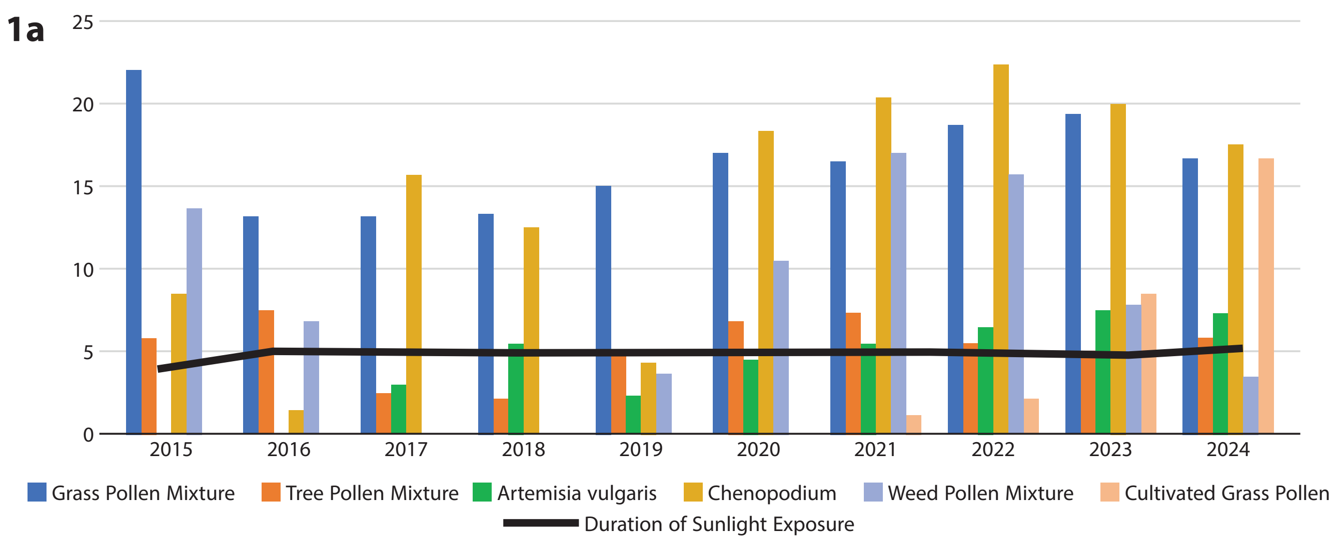
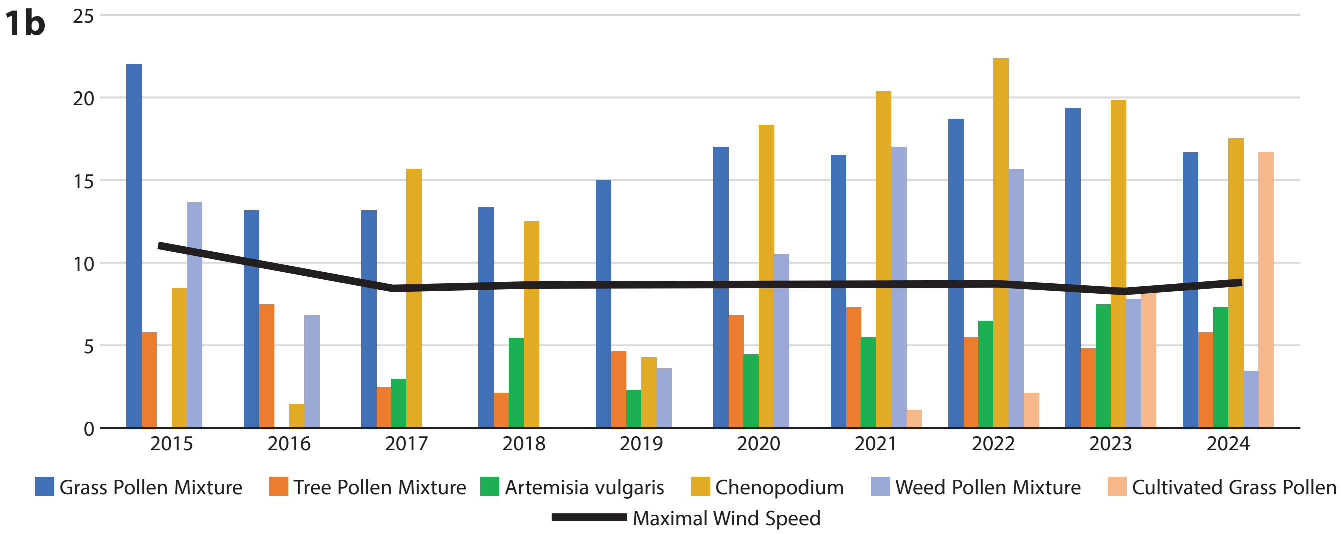
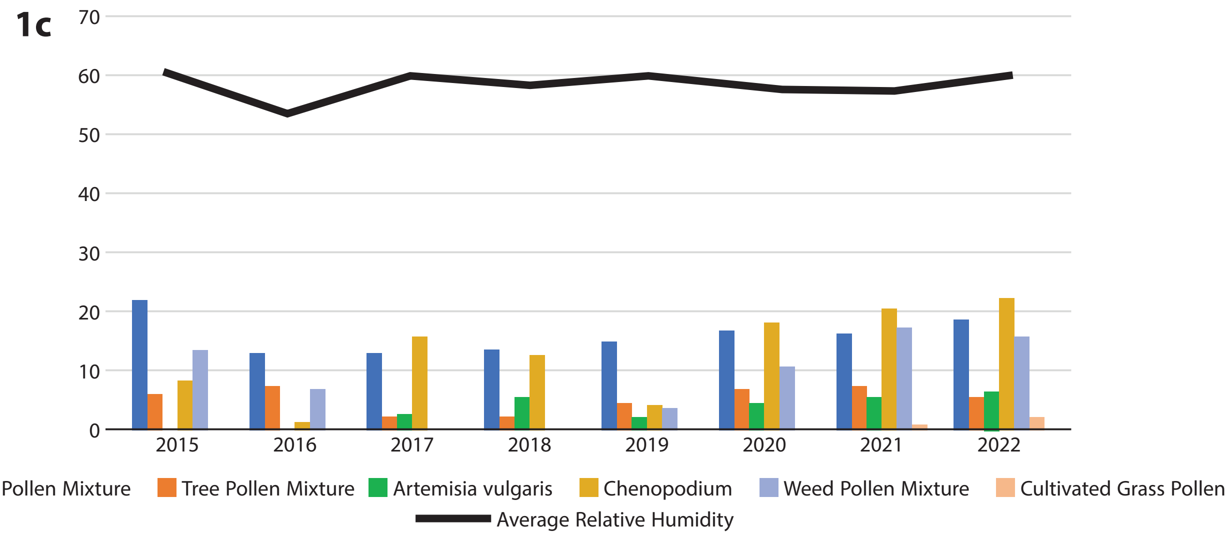


Figure 1. Distribution of meteorological variables and allergens by years: 1a) Sunlight exposure, 1b) Wind speed, 1c) Relative humidity, 1d) Temperature, 1e) Rainfall





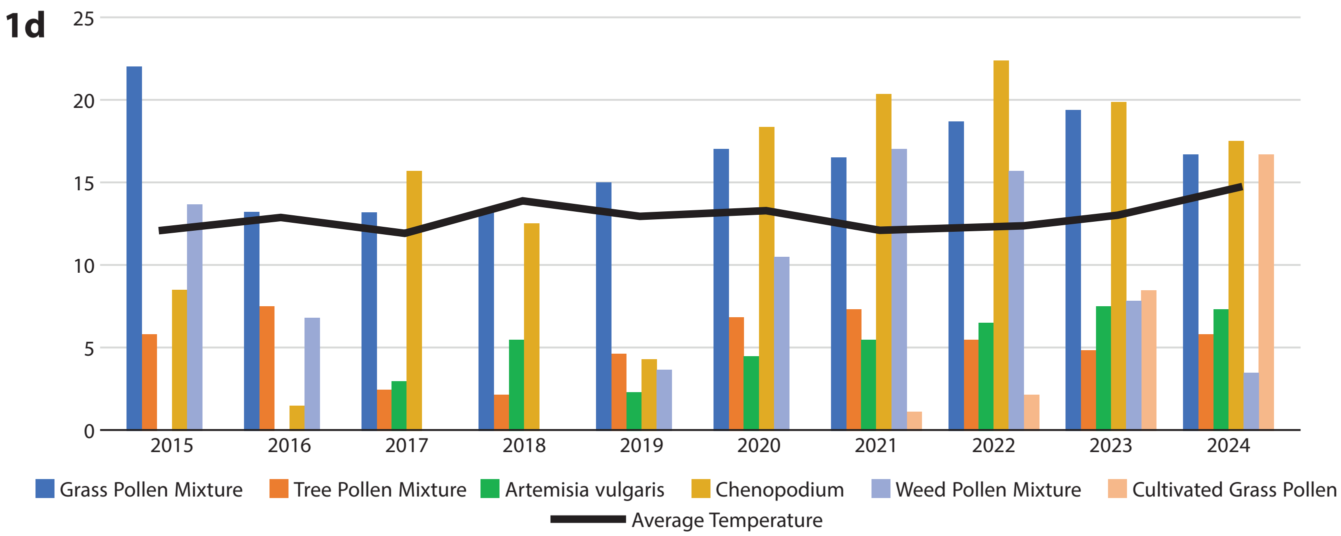


Figure 1. (Continued)

1e

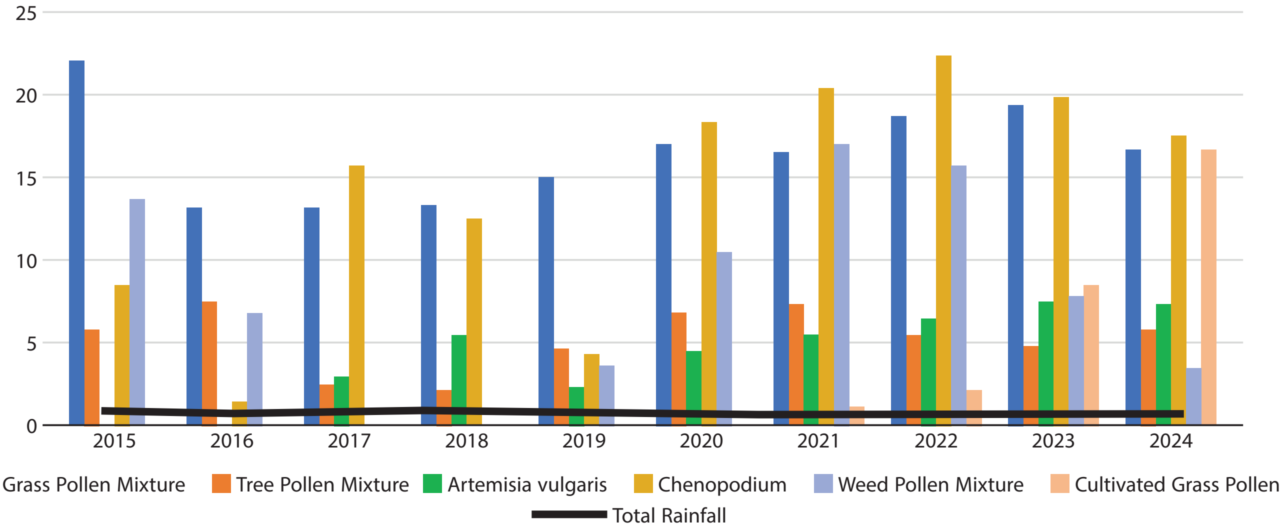


Figure 1. (Continued)

Table 3. Correlations between meteorological parameters and pollen reactivity.

		Duration of Sunlight Exposure	Maximal Wind Speed	Average Relative Humidity	Average Temperature	Total Rainfall
Grass Pollen Mixture	r	-0.232	0.002	0.305	0.111	-0.296
	p	0.109	0.990	0.033	0.449	0.039
Tree Pollen Mixture	r	0.608	0.433	-0.605	-0.095	-0.850
	p	< 0.001	0.002	< 0.001	0.515	< 0.001
Artemisia vulgaris	r	-0.109	-0.133	0.033	0.317	-0.167
	p	0.477	0.383	0.828	0.034	0.272
Chenopodium	r	0.147	-0.353	0.062	-0.055	-0.408
	p	0.312	0.013	0.673	0.706	0.004
Weed Pollen Mixture	r	-0.295	0.038	0.367	-0.734	-0.151
	p	0.068	0.818	0.022	< 0.001	0.359
Cultivated Grass Pollen	r	0.200	0.400	-0.400	*	0.105
	p	0.398	0.081	0.081	*	0.081

r: Spearman correlation coefficient. *p*-values < 0.05 are considered statistically significant and shown in bold. *Missing data.

Discussion

This study aimed to investigate the changes in the diversity of pollen sensitivities in response to meteorological variability over the past 10 years in patients who underwent SPT due to allergic diseases. Variations in annual weather conditions were observed to result in changes in pollen sensitivity diversity. Every meteorological parameter examined was found to affect at least one pollen allergen significantly. Tree mix sensitivity was positively correlated with sunlight and wind, while it was negatively correlated with humidity and rainfall. Grasses mix sensitivity was positively correlated with humidity and negatively correlated with rainfall. Weed mix sensitivity was positively correlated with humidity and negatively correlated with temperature. Artemisia vulgaris sensitivity was positively correlated with temperature. Chenopodium album sensitivity was negatively correlated with wind and rainfall. Among the meteorological variables examined, rainfall showed negative correlations exclusively with the three different pollen types that had a significant relationship. In contrast, temperature, humidity, and wind speed showed both positive and negative correlations with pollen allergens. Tree mix sensitivity exhibited the most significant correlations with multiple meteorological parameters (sunlight, wind, humidity, and rainfall). This finding emphasizes the multifaceted impact of climate on tree mix sensitivity.

Among the pollen families found in Turkey, Poaceae, Chenopodiaceae, Astraceae, Oleaceae, Cupressaceae, and Betulaceae are known to have high allergenic capacity.[7] The highest percentage of grass and weed taxa is represented by the Poaceae, Chenopodiaceae and Amaranthaceae families.[8] In this study, the relationship between meteorological factors and the sensitivity to commonly observed pollen types in Konya, including Grass Pollen Mixture, Tree Mixture, Artemisia vulgaris, Chenopodium album, Weed Pollen Mixture, and Cultivated Grass pollen, was investigated. Over the past 10 years, sensitivity to Chenopodium album reached the highest rate at 22.4% among all pollen types.

The duration of sunlight exposure necessary for blooming is called photoperiod, which is directly correlated with total and daily duration of sunlight exposure.[9] In a previous study, a significant positive correlation was found between the hours of sunlight and annual concentrations of birch tree pollen.[10] Similarly, in this study, a moderately strong positive correlation was found between Tree mix pollen sensitivity and sunlight exposure. We attributed this to increased blooming and pollen concentrations of arboreal plants.

Wind is crucial for dispersion and distribution of bioparticles in the atmosphere. Wind acts as a dispersal vector, facilitating the spread of seeds and pollen over long distances, thereby aiding the expansion of plant species into new areas.[11] A previous study demonstrated a positive correlation between wind speed and Poaceae pollen.[12] Similarly, in our study, the average maximum wind speed was found to have a moderately strong positive correlation with reactivity to tree pollen mixture. This may be explained by the fact that tree species are typically adapted to wind pollination and use wind to disperse their pollen over long distances. However, in this study, wind speed showed a weak negative correlation with Chenopodium album. This could be due to the different dispersal mechanisms of weed pollens like Chenopodium album, with factors such as the size, weight, and aerodynamic properties of the pollen grains potentially influencing this outcome.

Pollen grains are extremely hygrophilous and become hydrated in the presence of high relative humidity, which leads to increased weight and passive falling by gravity. This reduces pollen concentrations in the atmosphere.[13,14] On the other hand, some pollen grains can burst under high humidity, directly releasing allergens into the atmosphere.[15] Results of the studies in the literature regarding effects of relative humidity on pollen concentrations and dispersion are controversial. While some previous studies reported negative correlations between relative humidity and pollen concentrations.[14,16,17] Another study reported positive influences of relative humidity on pollen concentrations.[18] In our study, average relative humidity was found to have a weak positive correlation with reactivity to grass pollen mixture and a moderately strong positive correlation with reactivity to weed pollen mixture. Specifically, we suggest that grass pollen, which tends to thrive in lower humidity environments, shows a weak positive correlation with humidity, while weed pollen, which prefers more humid conditions, exhibits a stronger positive correlation with humidity. In contrast, tree pollen demonstrated a moderately strong negative correlation, possibly due to its unique physiological characteristics. These varying results highlight the need for further studies to clarify the influence of relative humidity on pollen concentrations.

Temperature affects vegetative growth, maturation of organs and fertilization. Furthermore, temperature has an impact on the formation of pollen grains and regulates amount and heterogeneity of atmospheric bioparticles. A previous study reported a positive correlation between pollen concentrations and an increase in temperature.[19] Additionally, another study has indicated that a warmer environment may facilitate pollen germination in certain species, while it may not have the same effect in others.[20] We found that average temperature was found to have a weak positive correlation with reactivity to Artemisia vulgaris and a strong negative correlation with reactivity to weed pollen mixture. Artemisia vulgaris tends to thrive in warmer and sunnier conditions, which may explain the positive correlation between temperature and reactivity. In contrast, weed pollen generally prefers cooler environments, which could explain the strong negative correlation between temperature and reactivity to the weed pollen mixture. This finding is in line with previous research, where the average daily temperature was positively associated with pollen concentrations for grasses and tree pollen species, but not with weed pollen.[17]

The phenomenon known as "rain washing" refers to the hydration of pollen grains by rainfall, which then causes them to fall due to gravity. In this process, pollen grains settle from the atmosphere, and the particles passively descend. As a result, pollen concentrations in the atmosphere decrease with rainfall.[14] Previous studies have reported a negative correlation between rainfall and pollen concentrations.[17,21] Similarly, in our study, average total rainfall was found to have a weak negative correlation with reactivity to grass pollen mixture, a strong negative correlation with reactivity to tree pollen mixture, and a moderately strong negative correlation with reactivity to Chenopodium album.

Our findings demonstrate a dynamic interaction between meteorological factors and pollen sensitization trends over the past decade in Konya. These results align with prior research indicating that climate variability influences the temporal and spatial distribution of allergens. However, this study has several limitations. Due to its retrospective design and reliance on secondary data, clinical information such as symptom severity, exposure duration, and comorbidities was not available. Furthermore, the analysis was limited to a single geographic region, which may restrict the generalizability of our findings to other areas with different climatic or vegetation profiles. Additionally, due to supply-related constraints, certain allergens were not consistently available throughout the study period and were excluded from the annual comparisons to maintain data consistency. It should also be noted that sensitization detected by SPT does not necessarily indicate clinical allergy, and the present study did not assess symptomatic responses, as its focus was limited to sensitization trends in relation to meteorological factors. Finally, environmental cofactors such as air pollution, pesticide exposure, and urbanization—which may influence both pollen levels and immune responses—were not included in our analysis. Future longitudinal studies incorporating predictive models may help to better understand the causal relationship between meteorological factors and allergen sensitization.

Conclusion

Previous studies have primarily focused on the correlation between meteorological factors and pollen concentrations. Given the limited research on the relationship between meteorological conditions and SPT reactivity to specific pollen allergens, this study aimed to contribute to the field. We found that each of the meteorological parameters examined had a significant relationship with at least one pollen sensitivity. Among these, rainfall distinguished itself by showing only a negative correlation with the pollen types it was associated with, unlike the other parameters. Tree mix sensitivity exhibited correlations with four different meteorological parameters, highlighting its multifaceted relationship with climate change.

Conflict of Interest Statement

The authors have no conflict of interests to declare.

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Author Contributions

- F.A.A, F.Ç. designed the research.
- T.Ö., R.E., M.K., F.S.A. conducted the research.
- F.A.A., Ş.A. canalyzed the data.
- F.A.A., M.E.G., M.K. wrote the paper.
- F.A.A. had primary responsibility for the final content.
- All the authors have read and approved the final manuscript.

Data Availability Statement

All data generated or analyzed during this study are included in this article. Further inquiries can be directed to the corresponding author.

Ethics Committee Approval

Ethics committee approval was received for this study from the Ethics Committee of Necmettin Erbakan University, who approved this study protocol (2024/5330). The study followed the guidelines and principles of the Declaration of Helsinki.

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