A. Acar Şahin / Hacettepe J. Biol. & Chem., 2024, (3), 171-179

Research Article

Hacettepe Journal of Biology and Chemistry

journal homepage: www.hjbc.hacettepe.edu.tr

Impact of Meteorological Factors and Air Pollution on Urban Salicaceae Pollen Levels

Meteorolojik Faktörler ve Hava Kirliliğinin Kentsel Salicaceae Polen Konsantrasyonuna Etkisi

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ABSTRACT

The objective of the research was to examine how meteorological conditions and air pollution affect the levels of Salicaceae pollen in the Ankara province. Salicaceae, a plant family encompassing willows and poplars, generates pollen that may contribute to respiratory allergies. The study employed a Burkard volumetric 7-day spore trap for airborne pollen monitoring throughout the pollen season, spanning from March to June in the year 2023. The relations between pollen concentrations, various meteorological parameters and air pollutants were revealed by correlation and regression analysis. While, the wind direction was found to be positively correlated with *Populus* pollen concentration, there was also a positive relationship between relative humidity and *Salix* pollen loads. Additionally, air pollutants, including PM10, PM2.5 and nitrogen oxides, were found be positive impact on the abundance of *Populus* pollen. Understanding these relationships is crucial for assessing the potential health risks associated with airborne pollen and for developing strategies to mitigate the impact of urban environmental factors on pollen concentration.

Key Words

Salicaceae, pollen, wind direction, nitrogen oxides.

ÖZ

Bu çalışmada Ankara ilinde meteorolojik faktörlerin ve hava kirliliğinin Salicaceae polen konsantrasyonuna etkisinin araştırılması amaçlandı. Bu familyayı oluşturan söğüt ve kavak ağaçlarının polenleri solunum yolu alerjilerini tetikleyebilmektedir. Havadaki polen izlemesi, 2023 yılının Mart ayından Haziran ayına kadar polen mevsimi boyunca Burkard volumetric spor tuzağı kullanılarak gerçekleştirildi. Polen konsantrasyonları, çeşitli meteorolojik parametreler ve hava kirleticileri arasındaki ilişkiler korelasyon ve regresyon analizi ile ortaya çıkarıldı. Rüzgar yönü ile *Populus* polen konsantrasyonu arasında pozitif korelasyon bulunurken, bağıl nem ile *Salix* polen yükü arasında pozitif ilişki bulunmuştur. Ayrıca PM10, PM2.5 ve nitrojen oksitler de dahil olmak üzere hava kirleticilerinin *Populus* poleninin bolluğu üzerinde olumlu etkisi olduğu tespit edildi. Bu ilişkilerin anlaşılması, havadaki polenlerle ilişkili potansiyel sağlık risklerinin değerlendirilmesi ve kentsel çevresel faktörlerin polen konsantrasyonu üzerindeki etkisini hafifletmeye yönelik stratejiler geliştirilmesi açısından çok önemlidir.

Anahtar Kelimeler

Salicaceae, polen, rüzgar yönü, nitrik oksit.

Article History: Jan 16, 2024; Revised: Feb 29, 2024; Accepted: Mar 1, 2024; Available Online: Jun 29, 2024.

DOI: https://doi.org/10.15671/hjbc.1420899

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INTRODUCTION

Pollen allergies affect a substantial portion of the population, causing allergic rhinitis, conjunctivitis, and asthma symptoms [1]. The airborne pollen grains loads directly influences the severity and duration of allergic reactions. Various factors, including meteorological parameters and air pollution, can significantly impact the abundance and distribution of pollen in the air [2,3].

The Salicaceae family comprises 56 genera and approximately 1220 species worldwide, according to the Angiosperm Phylogeny Group (APG). Among these, two genera, *Populus* L., and *Salix* L., are naturally distributed in Türkiye. In total, Türkiye is home to eight species of *Populus* and 38 species of *Salix* [4]. *Populus* is among the economically significant plants in Anatolia with four naturally distributed species in Türkiye; *Populus alba* L*., P. nigra* L*., P. tremula* L., and *P. euphratica* Oliv,. Additionally, hybrid poplar (*Populus* x *euramericana* (Dode) Guinier), American black poplar (*Populus deltoides* Marsh.) are cultivated in temperate regions of the country. *Populus nigra*, widely found in various population types, from individual trees to pure or mixed stands, is a dioecious species that typically reaches reproductive maturity in 10 to 15 years in healthy natural populations [5]. It effectively disperses pollen and seeds through wind and water [6,7]. On the other hand, there are around 500 *Salix* species globally with 27 of which naturally distributed in Türkiye. In Ankara province, *Salix* encompasses 8 taxa: *Salix alba* L., *S. babylonica* L., *S. amplexicaulis* Bory & Chaub., *S. excelsa* S. G. Gmel., *S. caprea* L., *S. pseudomedemii* E. Wolf., *S. cinerea* L., and *S. fragilis* L [8].

Airborne pollen release from urban plants during the pollination period poses a significant health risk for citizens, especially those residing in urban areas who tend to experience higher pollen allergies compared to individuals in rural regions [9]. In early spring and spring seasons, pollen grains of *Populus* sp. and *Salix* sp. are one of the important sources as airborne tree allergens in Ankara province where these trees grow natively and are commonly planted largely for ornamental purposes in gardens, parks, roadsides and wetlands [10–12].

Pollen allergies caused by *Populus* (poplar) and *Salix* (willow) trees are prevalent in many regions, triggering allergic rhinitis, conjunctivitis, and asthma symptoms. Studies conducted across Türkiye indicate that children exhibit a sensitivity to poplar tree pollen ranging from 1.4% to 14.9%, while in adults, this sensitivity is observed at a higher range, spanning from 6.5% to 38%. On the other hand, sensitivity to *Salix* pollen varies between 1.4% and 26.5% in children and between 10-31.3% in adults [10,13,14]. These trees are characterized by their high pollen production and wide distribution across various ecosystems, including urban, suburban, and rural areas [11]. In numerous regions where aerobiological studies have been conducted in Türkiye, pollen grains from poplar trees are prevalent in the air, particularly during the March-April period, while pollen grains from willow trees are observed in the air during the April-May period. Also pollen levels of *Populus* trees determined in the air of Ankara were found 5% on average of the total pollen concentration in previous studies [12,15,16]. This amount is high enough to be negligible. On the other hand, *Salix* pollen concentration is generally lower than *Populus*, since *Salix* pollen is pollinated not only by wind but also mostly by insects.

Global climate change and air pollution affect the prolongation or shortening of the pollination period of plants, the development and distribution of airborne pollen grains [17–20]. In various aeropalynological studies, the overall quantity of airborne pollen fluctuates from year to year [9,21,22]. Meteorological factors like temperature, humidity, wind speed, and precipitation, which influence the dispersion of pollen into the atmosphere, also exhibit yearly variations. Air pollutants such as particulate matter (PM10 and PM2.5), nitrogen oxides (NO_2, NO, NO_x), carbon monoxide (CO), and sulfur dioxide (SO_2) can directly affect pollen in the following ways: modifying their biological and reproductive functions, reducing viability and germination rates, altering the physicochemical characteristics of pollen surfaces, changing their allergenic potential, and acting as adjuvants, thereby increasing their potential health risks [23].

Consequently, understanding the factors governing the seasonal dynamics of *Populus* and *Salix* pollen is essential for accurately assessing allergenic exposure and developing effective management strategies. It is aimed that i) determining atmospheric concentrations and seasonal dynamics of *Populus and Salix* pollen in Ankara (2023), ii) identifying potential effects of meteorological factors and air pollutants with correlation analysis.

MATERIALS and METHODS

Study area and land cover

Ankara, the capital and the second largest city of Türkiye, is predominantly situated in the Inner Anatolian region of Türkiye, positioned at 39°57′ N, 32°53′ E. A small part of the northern section of the province lies within the Black Sea region of Türkiye. The average altitude of Ankara city is 938 meters. The province encompasses the Irano-Turanian, EuroSiberian and Mediterranean floristic regions. The primary flora of the province consists of steppe vegetation, flourishing due to the arid and semiarid characteristics of the Mediterranean climate, which is characterized as a dry sub-humid climate with minimal water surplus [24]. Ankara has different habitats (biomes) that support species richness such as forests, steppes, wetlands and salty soils. Steppe plants dominate across much of the province, transitioning from green in spring to yellowed and dried grass in summer. The impact of the maritime climate is noticeable in the north and northwest of the province, where extensive forests are present [25].

In terms of accurate prediction of local Salicaceae pollen sources, land cover data has been utilized. In this context, the land cover map was acquired from the Dynamic Land Cover 2019 dataset, supplied by Copernicus Global Land Service (Copernicus, 2019). Single class forest (2019), high-resolution layer water and wetness (2018) at 10m spatial resolution and riparian zones (2018) layers were used. Pollen sampling location were putted at the center of map (Figure 1). Station of pollen sampling is located in an urban area. The urban greenery consists mainly of numerous parks, lawns, and recreation areas for social relations. Other land covers include various forest types such as, broad-leaved, coniferous, mixed and also shrubland, herbaceous vegetation, cropland, natural grasslands, wetlands and permanent water bodies.

Aerobiological Study

Airborne pollen monitoring was conducted using a Burkard volumetric 7-day spore trap during the pollen season from March to June in 2023. The trap was strategically placed on the roof of the building (F block) in

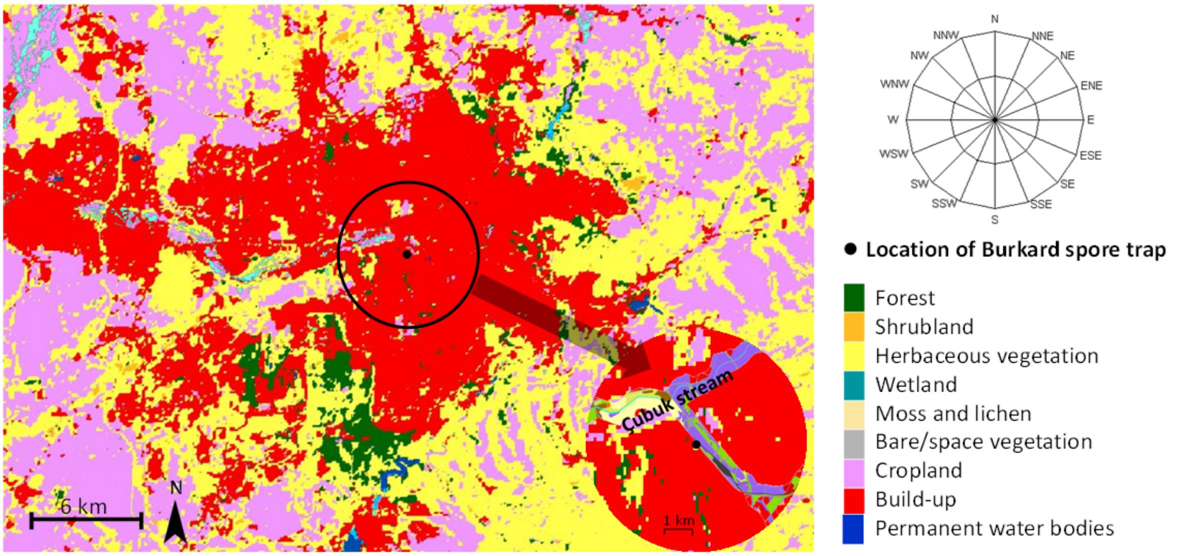


Figure 1. Sampling location area and the land use by Corine land cover.

Beşevler 10th. year campus at Ankara University, positioned at a height of 30 meters above ground level. Moviol was utilized to adhere the Melinex tape onto the drum of the pollen trap, which completed a full rotation weekly. The tape was replaced every week. Upon retrieval, the adhesive tape was brought to the laboratory and partitioned into seven equal segments, with each segment representing one day for preparation. Daily average concentrations of *Populus* and *Salix* pollen counts were converted to grains/m^3 and referenced in REA (The Spanish Aerobiology Network) [26]. The Main Pollen Season (MPS) was determined using 98% method [27,28] and the Seasonal Pollen Integral (SPIn) was calculated as the integral over time of pollen concentration expressed as pollen day m^3. Additionally, pollen threshold levels were established following the classification of the American Academy of Asthma Allergy and Immunology's (AAAAI) [24].

Meteorological Data and Air Pollution Parameters

All meteorological data including daily mean temperature, daily mean relative humidity, daily total rainfall, daily mean wind speed and daily dominant wind direction were obtained from the Turkish State Meteorological Service in Ankara for the period 2022-2023. Data on air quality parameters (CO, NO, SO_2, NO_2, NOx, PM10, PM2.5) for the study period are available on the website of the Ministry of Environment and Urbanization, within the scope of the National air quality monitoring network (http://www.havaizleme.gov.tr. 2023) was obtained from the data of Ankara-Bahçelievler Station, which is the closest station to the pollen monitoring station.

Statistical Analysis

The Kolmogorov-Smirnov normality test was employed to assess whether the daily airborne pollen concentrations and the meteorological parameters exhibited a normal distribution throughout the entire MPS. As the pollen concentration data that were not normally distributed, a log base 10 transformation was applied, and 1 was added to the pollen concentrations to prevent a negative log before applying parametric statistics. The log base 10 transformation was chosen for its ease of characterizing the pollen season at the original data level [29]. After transformation, the data's normal distribution was checked using the Kolmogorov-Smirnov test. Pearson correlation was applied to incorporating all meteorological and air pollutant parameters. Multicollinearity was assessed using the variance inflation factor (VIF) among the three temperature parameters, and the temperature parameter with the highest determinant coefficient (R) value was included in the model. All calculations were conducted using IBM SPSS Statistics V21. Additionally, wind rose plots were generated using R's openair package [30], to illustrate the relationship between the daily wind conditions (direction and speed) and the daily pollen loads of *Populus* and *Salix.*

RESULTS and DISCUSSION

In the Salicaceae pollen season of 2023, the average monthly temperatures were 8.2 °C, 5.6 °C, and 8.7 °C in March, April, and May, respectively. The rainy days number before the main pollen season was found 14 for *Populus* and 21 days for *Salix* in 2023. It was also observed that the daily average temperatures before the pollen season (January, February, March) were higher (3.9 °C, 2.7 °C, 8.2 °C, respectively) than those of both the previous year (0.9 °C, 4 °C, 2.3 °C, respectively) except for February, and the long-term average (0.2 °C, 1.7 °C, 5.7 °C, respectively). Seasonal pollen characteristics were given in Table 1. *Populus* pollen were observed from the second week of March to the third week of April. The highest pollen concentration was observed on 10th. March. *Salix* pollen were detected from the third week of March to the second week of May. The peak concentration of *Salix* pollen were recorded on 2nd. April. *Salix* pollen season lasted a little longer than the *Populus* pollen season, but the seasonal pollen integral (SPIn) was found very lower than the SPIn of *Populus*. Furthermore, the peak concentration of *Populus* pollen was significantly higher than that of *Salix*. In addition, the moderate and high risky day numbers were found reasonably higher in *Populus* than in *Salix*. In contrast to willows, which are primarily pollinated by insects (entomogamy), poplar trees rely on wind pollination (anemogamy), resulting in a higher release of pollen into the atmosphere.

As illustrated in Figure 2a, the days just preceding the onset of flowering exhibit a high temperature, and the absence of rain promotes rapid pollen release. There are two distinct episodes in the season. The first peak (in March) should belongs to *Populus alba* pollen which is more common than the other poplar species in Ankara. The second pollen peak (in April) can refer to *Populus nigra* which has later flowering. On the other hand, the *Salix* season appears to be more fluctuated due to the varying flowering periods of many *Salix* species. The

Table 1. Figure-of-merit (FOM) calculation of the sensor at different glycerol concentrations (FWHM represents full width at half. maximum of the curves).

2023	MPS start	MPS end	duration days	peak value p/m^3	peak date	SPIn pollen* day/m^3	moderate risky days	high risky days
Populus	9th March	15th April	46	178	10th March	868	11	3
Salix	21th March	10th May	51	17	2nd April	121	2	none

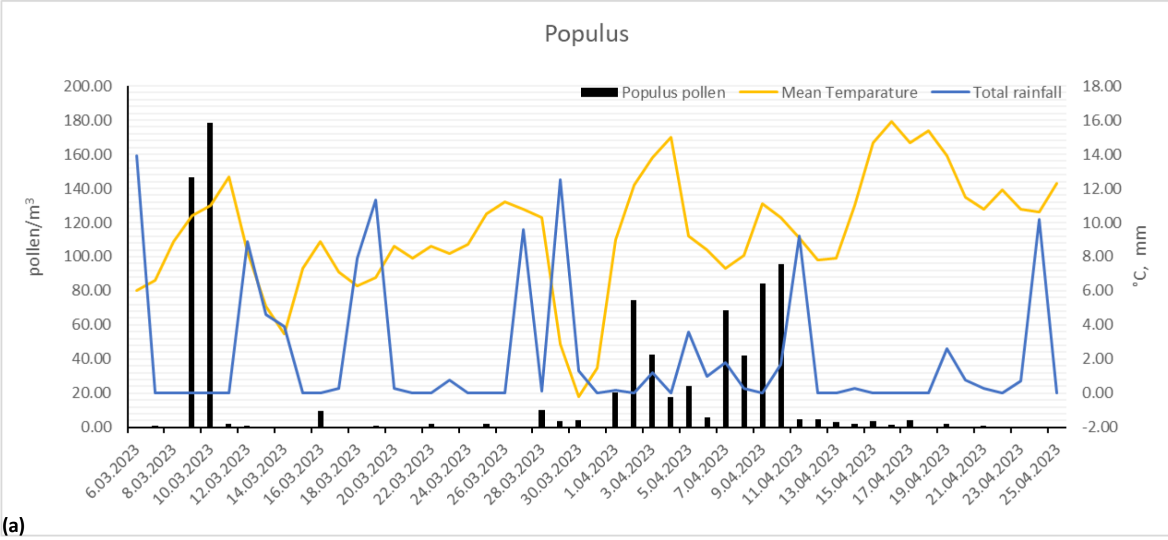
increase in pollen concentration is observed on days with high humidity, a trend consistent with the natural distribution of willow plants in wetlands. (Figure 2b).

In the study period, some positive and negative correlations were found between pollen levels, meteorological factors and air pollutants. Daily *Populus* pollen loads were significantly correlated with the wind direction. There were also positive correlation between pollen concentration PM10, PM2.5, nitrogen dioxide (NO_2), nitrogen oxides (NO_x) and nitric oxide (NO). On the other hand, *Salix* pollen loads were significantly positively correlated with only relative humidity (Table 2). In the correlation analysis, daily pollen levels were based on MPS period and meteorological data were collected on the same date. Multiple regression analysis results supported correlation results (Tables 2-3). In *Salix,* the multiple regression analysis between the pollen concentrations, meteorological and air pollutant parameters showed lower R^2 values than the results of *Populus* and the same parameters. Multiple regression models explained almost 50 percent of the total variance for *Populus*. PM2.5 had a significant association with *Populus* pollen concentration. Wind direction was also found related with the dispersal of *Populus* pollen. Multiple regression model explained only little part of the total variance (Adj R^2=0.124) in *Salix*. A significant relationship was found with the mean relative humidity based on both correlation and regression analysis.

According to the results of the wind rose plot analysis, higher concentrations of *Populus* pollen were observed on days when the wind blew from the south-western and north-western directions, consistent with the land cover data. As depicted in Figure 1, the land cover in the southwest direction comprises broad-leaved forest, coniferous forest, and mixed forest. Additionally, Çubuk stream and its surroundings form a wetland, serving as a natural habitat for *Populus* and *Salix* trees, and constituting a significant source from which a substantial portion of the pollen load originates, particularly from the north-western direction (Figure 3).

In previous aerobiological studies conducted in Türkiye, *Populus* and *Salix* pollen were found in most of the provinces [11]. In particular, *Populus* pollen were found at a slightly higher rate in Zonguldak [31], Bartın [32] and Ankara [12], while *Salix* pollen were found at higher level in Ankara (Beytepe) [33], Sakarya [34] and Edirne [35]. *Populus* and *Salix* pollen were detected in the spring months (mainly in March and April) in our country. The main *Populus* pollen concentration was observed in Ankara [12,16], Kayseri [36], Kırıkkale [37] and Kastamonu [38] in March and April; in İstanbul [39], Zonguldak [31], Edirne [35], Sakarya [34], Bursa-İznik [40] and Antalya [41] in February, March and April; in Bartın [32] in March, April and May.

In Ankara, there appears to be a significant decrease in the annual pollen concentration of *Populus* pollen over the years. Daily pollen counts were reported as 7809, 6389, 2202, and 2894 m³/grain in 1990, 1991, 1992, and 1994, respectively [15,16]. While this phenomenon does not align with the commonly held belief about the effect of global climate change on pollen concentration, it is likely strongly related to the changing tree species chosen for plantation. Many of these trees have been removed from the physiognomy of Ankara due to the dense dispersion of poplar seeds into the air [13]. In Sivrihisar (Eskişehir), one of the neighboring provinces of Ankara, the seasonal *Populus* pollen integral was recorded as 241 pollen*day/m^3 in 2005, 373 pollen*day/m^3 in 2005 in 2006. However gravimetric method with Durham sampler was used in that study. Seasonal pollen integral was recorded as 285 pollen*day/m^3 in 2012 [12,42]. Seasonal *Populus* pollen concentration was found as 351 pollen*day/m^3 in 2022 [43], while it was detected as 861 pollen*day/m^3 in this study for 2023. Compared to the previous year, higher average temperatures and preseason rains may have increased pollen production, leading to a higher detection of pollen in our study.



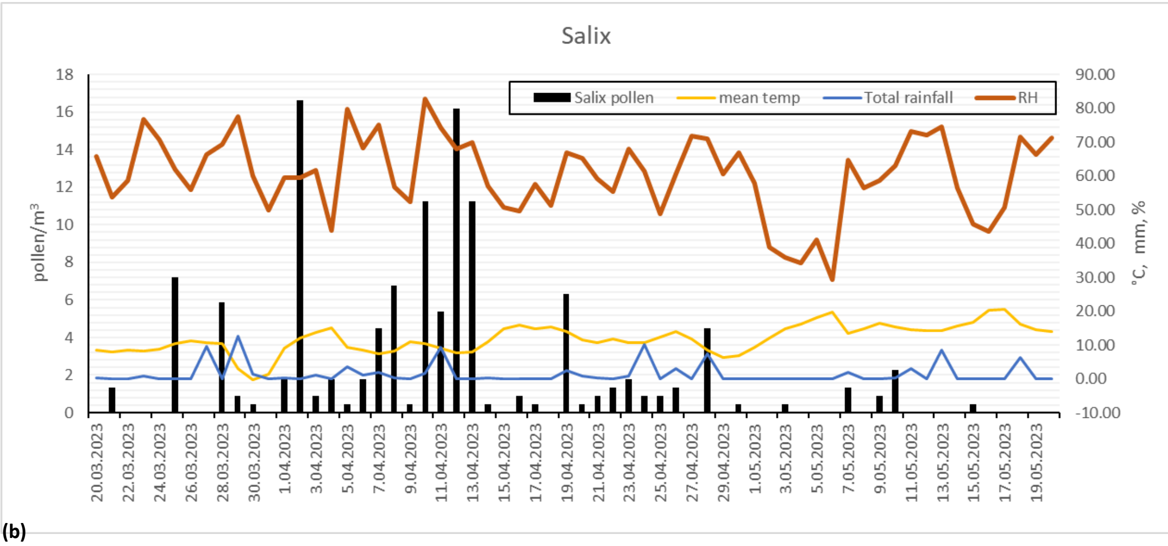


Figure 2. Pollen emission pattern of *Populus* (a) and *Salix* (b) with meteorological data in 2023.

Table 2. Pearson correlation coefficients between pollen levels, meteorological factors and air pollutants.

Pearson Correlation	Meteorological factors							Air pollutants						
MPS (98%)	wd	ws	T mean	T max	T min	RH	rainfall	PM10	PM2.5	SO_2	CO	NO_2	NO_x	NO
Populus	0.370*	-0.095	0.236	0.152	0.255	-0.107	-0.244	0.477 **	0.508 **	0.022	0.125	0.457 **	0.467 **	0.512 **
Salix	0.064	-0.155	-0.167	-0.226	-0.016	0.379 **	0.277	-0.068	0.042	-0.177	-0.183	-0.173	-0.263	-0.068

*p<0.05, **p<0.01 Abbreviations: RH, relative humidity; Tmean, mean temperature; Tmax, maximum temperature; Tmin, minimum temperature; wd, wind direction; ws, wind speed.

Table 3. Multiple linear regression results for both pollen type (PC: pollen concentration).

	R^2	R^2adj	Std. Error of the Estimate	p	Regression equations
Populus	0.519	0.47	0.51	0.001	PC= -0.288 + 0.146 x PM2.5 + 0.002 x WD
Salix	0.144	0.124	0.36	0.001	PC= -0.492 + 0.012 x RH

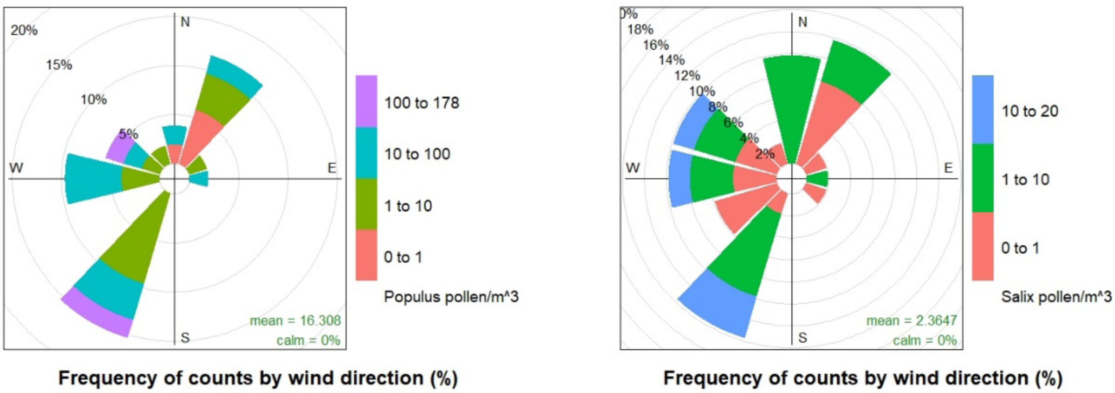


Figure 3. Wind rose plots summarizing the wind conditions which give rise to elevated *Populus* and *Salix* pollen concentrations.

Salix pollen grains were most intensely detected in the atmosphere in April and May in previous aerobiological studies. *Salix* pollen loads in has been fluctuating over the years in studies conducted in Ankara [12,15,16]. Daily pollen counts for *Salix* were reported as 1059, 1882, 341, and 2894 m^3/grain in 1990, 1991, 1992, and 1994, respectively. Wetlands play a pivotal role in our ecosystems, providing not only rich, moist soils and reed beds for cultivation but also a vital source of water for domestic use. Their ecological significance extends beyond these services, encompassing the reduction of the urban heat island effect and playing a critical role in urban stormwater management. Moreover, wetlands serve as habitats for diverse living species. Despite legislative efforts designed to protect them, these invaluable ecosystems continue to face degradation and loss at an alarming rate due to the pressures of urban growth. These areas, which are also the natural habitats of poplars and willows, seem to have been largely disappeared in Ankara from 1990 to 2018 [44]. Seasonal pollen integral was recorded as 54 pollen*day/m^3 in 2012 [12,42]. Similarly, in previous year, seasonal *Salix* pollen concentration was found as 67 pollen*day/m^3 in 2022 [43]. Decreasing patterns in the abundance of airborne Salicaceae pollen may be associated with an increased human impact on the landscape and vegetation, ultimately affecting pollen production. This trend can also be attributed to the urbanization of the area close to the sampler as a result of city development.

Meteorological parameters exert a notable, mild-to-moderate impact on the occurrence and distribution of pollen grains in the atmosphere [21]. Statistical analyses revealed no significant correlations between the meteorological factors except wind direction and *Populus* pollen loads and relative humidity and *Salix* pollen loads in our study. There is no study conducted in and around Ankara explaining the effects of environmental factors on *Populus* and *Salix* pollen concentrations from Türkiye. In contrary, there are some studies that show the impacts of many meteorological factors on *Populus* pollen concentration in the world literature. In a study conducted in Poland, the poplar pollen season exhibited a negative correlation with maximum temperature and average air humidity, while showing a positive correlation with rainfall levels, humidity, and wind speed. [45]. In a study investigating the effect of atmospheric air pollution (including ozone, SO_2, CO_2, PM 10, NO_2) and meteorological factors on some pollen taxa in city of Szczecin, Poland, it was reported an increase in the pollen levels of *Salix, Populus* and some other taxa with elevated NO_2 levels in the air, consistent with our findings [46]. In our study, higher *Populus* pollen concentration coincided with higher PM10, PM2.5 and nitrogen oxides levels. Since both airborne pollen and PM10 are originated from common sources such as vegetation, dust, and anthropogenic activities and influenced by similar environmental factors, it is possible that increased pollen release and higher PM10 levels may occur simultaneously. Urban areas with various pollution sources, including traffic and industrial activities, can contribute to both nitrogen oxides and pollen levels. Local emission sources may release particles and pollen into the air, leading to a correlation between their concentrations [47]. It's important to note that the specific relationship between pollen and NO_2/NO_x levels can vary based on local conditions, sources of pollution, and other environmental factors. Continuous monitoring and research are essential to understand the complex interactions between different airborne particles and pollutants and their implications for air quality and public health.

CONCLUSION

The current study assesses the impact of meteorological parameters and air pollutants on airborne Salicaceae pollen in the urban city of Ankara. Our findings indicate that PM10, PM2.5, nitrogen dioxide, nitrogen oxides, nitric oxide and wind direction may influence the seasonal pollen dynamics of *Populus*. The majority of pollen loads likely originate from the south-western (forest zone) and north-western (wetland area) directions. However, there was no significant correlation between wind direction and *Salix* pollen loads according to statistical analysis. Still, the majority of pollen loads appear to come from the south-western direction, consistent with land cover, similar to *Populus*. Furthermore, daily mean relative humidity shows a positive correlation with *Salix* pollen concentration, as *Salix* exhibits high tolerance for wet soil and thrives in damp conditions. Understanding these relationships is crucial for assessing potential health hazards associated with airborne pollen and formulating strategies to mitigate the impact of urban environmental factors, including meteorological and air pollutant parameters, on pollen concentration.

Acknowledgments – The author expresses gratitude to Nur Münevver Pınar and Resul Duman for their assistance during the airborne pollen sampling phase.

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