Annals of Agricultural and Environmental Medicine 2022, Vol 29, No 4, 502–512
www.aaem.pl

ORIGINAL ARTICLE

Influence of meteorological factors on the dynamics of hazel, alder, birch and poplar pollen in the 2021 season in Kielce, Poland

Joanna Ślusarczyk[1,A,C-F], Anna Kopacz-Bednarska[2,A-E], Joanna Posłowska[1,B]

[1] *Department of Environmental Biology, Institute of Biology, Jan Kochanowski University, Kielce, Poland*
[2] *Department of Medical Biology, Institute of Biology, Jan Kochanowski University, Kielce, Poland*
A – Research concept and design, B – Collection and/or assembly of data, C – Data analysis and interpretation, D – Writing the article, E – Critical revision of the article, F – Final approval of the article

Ślusarczyk J, Kopacz-Bednarska A, Posłowska J. Influence of meteorological factors on the dynamics of hazel, alder, birch and poplar pollen in the 2021 season in Kielce, Poland. Ann Agric Environ Med. 2022; 29(4): 502–512. doi: 10.26444/aaem/152837

Abstract

Introduction and Objective. Hazel, alder, birch, and poplar pollen allergens are a common cause of pollen allergies. In a temperate climate, wind-pollinated plants are characterized by a seasonal pollen release cycle associated with the seasons of the year and weather conditions. Therefore, the aim of the present study was to assess the course of pollen seasons of some allergenic plants and to determine the effect of meteorological factors on the content of pollen grains in the bioaerosol in 2021 in Kielce, Poland.

Materials and method. In relation to selected meteorological parameters, the length of the total and main pollen season, the sum of daily pollen grain concentrations in the season, the peak pollen concentration, and the number of days with values exceeding the species-specific threshold concentrations, were determined.

Results. Hazel and alder pollen were the first to appear in the air of Kielce. The longest pollen season was observed for birch, while hazel was characterized by the shortest season. The alder pollen release was intense, with the highest maximum concentration of pollen grains. The study revealed a significant influence of the maximum air temperature on the dynamics of hazel, alder and poplar pollen release. Birch pollen release was significantly correlated with the average air humidity. The concentration of alder and birch pollen grains also depended on rainfall intensity. The wind force had a significant impact on the pollen season of plants.

Conclusions. There were various relationships between the meteorological factors and the content of pollen grains in the air. The wind speed and temperature had the greatest impact on plant pollen release, with birch and alder being particularly sensitive to weather conditions.

Key words

meteorological factors, aeroallergens, pollen grains, pollen season, 2021 season

INTRODUCTION

Hazel, alder, birch, and poplar pollen allergens are the most common causes of pollen allergy in Poland and affect many inhabitants of northern and central Europe [1]. In the conditions of the Polish climate, hazel pollen grains are the first to appear in the air. The onset of its flowering is regarded as the beginning of botanical early spring [2–4]. The concentration of hazel pollen at measurement stations located in large urban agglomerations does not reach very high values. Due to the shorter outdoor stay during the pollen season (January-March), the exposure of patients to hazel pollen allergens is limited. Additionally, the low air temperature and methods for saving heating energy (closed windows) minimize the penetration of hazel pollen allergens into the interior of residential and office buildings. To date, several types of hazel pollen allergens have been isolated and relatively well investigated. *Cor a 1* with a mass of 17 kDa, which is a homologue of the *Bet v* 1 birch allergen, has been identified as the main hazel allergen. Four isoforms of the allergen have been described in the literature (*Cor a 1.0401–1.0404*) [5, 6]. Hazel pollen allergens are highly important in allergology, as they can cross-react with alder and birch pollen allergens and with certain food allergens, e.g. hazelnuts. Specific IgE antibodies cannot discriminate between antigens with identical or very similar epitopes. With the protein sequence homology of 70%, the cross-reaction is considered highly probable. In turn, cross-reactions at an up to a 50% homology level are considered rare. Protein homology may involve both related and unrelated plant species [5, 6].

The common hazel (*Corylus avellana* L.) is a representative of the family *Corylaceae* from the order *Fagales*. This order includes the families *Betulace* (represented by birch and alder), *Corylaceae* (e.g. hazel and hornbeam), and *Fagaceae* (e.g. oak and beech) [2]. The families are closely related, and the homology of their antigenic protein structure is sufficiently high for cross-reactions to occur between representatives of different families within the order *Fagales*. For instance, the main antigen of hazel pollen *Cor a 1* and the cross-reactive antigens of *Fagales* trees show high similarity of the tertiary structure, such as *Bet v 1* (in birch), *Aln g 1* (in alder), or homologues present in vegetables and fruits: *Mal d 1* (in apples), *Pru ar 1* (in cherries), *Api g 1* (in celery), and *Dau c 1* (in carrots). Hence, approximately 15–20% of patients who

✉ Address for correspondence: Joanna Ślusarczyk, Department of Environmental Biology, Institute of Biology, Jan Kochanowski University, Uniwersytecka 7, 25-406 Kielce, Poland
E-mail: joanna.slusarczyk@ujk.edu.pl

Received: 13.06.2022; accepted: 17.08.2022; first published: 06.09.2022

are allergic to hazel pollen allergens exhibit hypersensitivity to some fruits (mainly apples, pears, peaches) and hazelnuts [6–8]. Cross-reactivity may involve one group of allergens or may involve different groups. The amino acid sequence and the antigen protein sequence homology are responsible for cross-reactivity. Thus, allergy to hazel pollen allergens is usually accompanied by allergy to alder and birch pollen allergens. The cross-reactions between some inhaled and food allergens may evoke hypersensitivity to food allergens upon patient's contact with airborne allergens [6].

Alder pollen allergens appear in the atmosphere immediately after hazel pollen allergens. Alder pollen concentrations reach very high levels at measurement stations located in urban agglomerations and extremely high values in suburban areas. The exposure to alder pollen allergens is very high but partially limited, as in the case of hazel, due to the shorter stay of patients outdoors (end of winter/early spring). The main alder allergen is *Aln g 1* with a molecular weight of 17–20 kDa, pI=5.3, and over 90% reactivity. Alder pollen allergens play an important role in allergology due to their frequent cross-reactions with birch and hazel pollen allergens [9, 10]. Approximately 10% of patients with alder pollen allergy exhibit hypersensitivity to some fruits (mainly apples, pears, and peaches), which may be a result of the cross-reactions between alder pollen and fruit allergens. It may also be a result of co-allergy to alder and birch pollen allergens [11].

Birch pollen allergens are one of the main causes of pollinosis in northern and central Europe. In Poland, after grass pollen allergens, they are the most common cause of symptoms of periodic allergic rhinitis and atopic asthma in susceptible subjects [12]. Due to the cross-reactions, allergic symptoms may appear in patients with birch pollen allergy during the hazel and alder pollen seasons and after consumption of certain fruits and vegetables, e.g. apples, peaches, pears, cherries, hazelnuts, carrots, celery, and soybeans. Current scientific reports show that birch pollen contains 10 major molecular allergens and several tens of isoforms, mainly of allergen *Bet v 1* [13]. The complete amino acid sequence of three birch pollen allergens has been fairly well investigated. The most important allergen of silver birch, i.e. *Bet v 1*, consists of 159 amino acids with a molecular weight of 17 kDa, pI=5.2. It has been shown to cross-react with the 17-kDa allergen in apples. Another major birch allergen, i.e. *Bet v 2*, has 133 amino acids with a known sequence similar to the group of proteins called profilins (playing a key role in actin polymerization). The third birch pollen allergen is the 20-kDa protein calmodulin, which is an enzyme activator [14].

The poplar pollen season in Poland usually begins in mid-March and lasts until the end of April, depending on the region. The peak pollen season is noted in April, as very high concentrations of pollen grains are recorded during this period [15]. Poplar pollen allergens have not been fully described. *Pop a* from the white poplar (*Populus alba* L.), *Pop n* from the black poplar (*Populus nigra* L.), and *Pop t* from the aspen (*Populus tremula* L.) are regarded as the most important allergens for allergological diagnostics [16]. Despite the high concentrations of airborne poplar pollen, the hypersensitivity to the allergens of these trees in the Polish population is relatively low [16]. There are only few literature data confirming the role of poplar pollen in the etiology of allergic rhinitis [17]. Cross-reactions between poplar pollen and willow pollen have been described [18]. However, there are increasing numbers of reports on the clinical significance of poplar pollen allergens in the international literature [19, 20, 21].

OBJECTIVE

The time of plant flowering as well as the amount of produced pollen and its dispersal in the air depend, e.g., on weather conditions, with winter and early spring temperature and precipitation rates as important determinants of the presence of airborne plant pollen [22, 23]. Hazel and alder pollen grains are recorded already at the turn of winter and spring, with birch and poplar pollen noted in spring, i.e. in a period with changeable weather conditions. The onset and course of pollen seasons of these taxa are characterized by high variability [24, 25]. Basic diagnostics of pollen allergy should be supplemented with information about local concentrations of plant pollen. This may facilitate undertaking therapeutic measures, formulation of preventive recommendations, and prediction of the intensity of reactions after exposure of the organism to allergens [26].

Therefore, the aim of the present study was to assess the dynamics of pollen seasons in plant taxa that have been classified as the most allergenic species and for a long time have attracted allergists' attention. The study also analyzes the impact of meteorological factors on the concentration of hazel, alder, birch, and poplar pollen grains in the air of Kielce, Poland, in 2021.

MATERIALS AND METHODS

Study area and sampling methods. The study was carried out in Kielce (50°52′N, 20°37′E), i.e. the capital of Świętokrzyskie Province, located in south-eastern Poland. The concentration of pollen grains was measured with the volumetric method using a Lanzoni VPPS 2000 device. The apparatus was placed 18 m above ground level on the terrace of the building of the Institute of Biology at the Jan Kochanowski University in Kielce. According to the manufacturer's data, the VPPS 2000 device has a suction rate of 10 liters of air per minute, i.e. 14.4 m^3 of air per day. Pollen grains were collected in a continuous mode. The collecting tape mounted on the drum was changed once a week. The clock-driven drum moved at a speed of 2 mm per hour. The air entering the apparatus directed the pollen grains directly onto the tape, which was then cut into sections corresponding to 24-hour periods. The pollen grains were stained with alkaline fuchsin. The microscope slides were analyzed using a Nikon optical microscope at a magnification of ×300. The pollen grains were counted with the method of horizontal stripes. Previously prepared standards were used for the morphological pollen analysis.

Quantitative analysis. The concentration of pollen grains of the analyzed plant taxa was expressed in 1 m^3 of air (P/m^3). The study determined the length of the total pollen season (TPS) and the main pollen season (MPS), the total daily pollen grain concentrations in the season (seasonal pollen index SPI), the peak pollen concentration, and the dates of maximum pollen concentrations. The number of days with concentrations exceeding the plant species-specific threshold values were also calculated. In accordance with literature data, the MPS length was determined using the 98% method, where days with 1% and 99% of the annual pollen sum were regarded as the onset and end of the season, respectively [27].

The values of meteorological parameters: maximum air temperature (°C), average wind speed (m/s), average air humidity (%), and daily precipitation sum (mm) were provided by the Institute of Meteorology and Water Management of the National Research Institute for the Kielce-Suków station [28]. The meteorological factors were summarized for the total pollen season (TPS) of the plants.

Statistical analysis. Statistical analyses were performed using the Statistica 10.0 programme (Statsoft, Poland) assuming the $p<0.05$ value for statistical significance of differences. Basic descriptive statistics of all analyzed meteorological parameters were calculated with determination of the maximum (max), minimum (min), and mean (mean) values, standard deviations (SD), variance (V), and skewness.

The statistical analyses consisted in the determination of correlations between the weather conditions and their impact on the dynamics of pollen release. The relationship between the maximum air temperature, average wind speed, average air humidity, and daily precipitation sum in the total pollen season (TPS) of hazel, alder, birch and poplar was analyzed using non-parametric Spearman's correlation. Spearman's correlation was also used to assess the impact of the meteorological factors on the total (TPS) and main (MPS) pollen seasons of the plants. In addition to the Spearman's analysis, the relationships between the weather factors and the total number of pollen grains per season were determined using Pearson's correlation.

RESULTS

Hazel, alder, birch, and poplar pollen season analysis. The characteristics of the pollen season of hazel, alder, birch, and poplar in Kielce in 2021 are presented in Table 1. Fig. 1 shows the dynamics of the total pollen season of the analyzed plant taxa in 2021 in comparison with the 2020 season.

The hazel MPS began on 24 February and ended on 27 March. The seasonal pollen index (SPI) for hazel was 933. The maximum pollen concentration of 264 P/m^3 was recorded on 3 March. The TPS of the species in 2021 persisted for 45 days, with 6 days characterized by a concentration of pollen grains exceeding the threshold value of 35 P/m^3, 3 days with values higher than 80 P/m^3, and only 1 day with the concentration above 150 P/m^3 (Tab. 1). In 2021, hazel pollen grains persisted in the air of Kielce until 9 April, i.e. for a shorter time than in 2020 (Fig. 1).

The alder MPS started on 25 February and lasted 42 days. The maximum pollen concentration was 1,561 pollen grains 1 m^3 of air, with the annual concentration sum of 7,050. The alder TPS persisted for 74 days; the threshold value of 45 P/m^3 was exceeded on 24 days, concentrations higher than 85 P/m^3 were recorded on 16 days, and a concentration over 1,200 P/m^3 was noted on only 1 day (Tab. 1). The total alder pollen season in 2021 was more intense than in 2020. The last single alder pollen grains were recorded in Kielce in 2021 on 28 April, which was comparable with the previous year (Fig. 1).

The birch pollen season in 2021 began on 18 April and lasted 43 days – until 30 May. Over the entire pollen season, there were 25 days with pollen grain concentrations higher than 20 P/m^3, 17 days with concentrations above 75 P/m^3, and 12 days with values exceeding the threshold of 155 P/m^3. The highest concentration of birch pollen in the air of Kielce (414 P/m^3) was observed on 28 April versus the annual pollen sum of 4,761 (Tab. 1). In comparison to 2020, the total pollen

Table 1. Characteristics of the hazel, alder, birch, and poplar pollen seasons in Kielce in 2021.

Corylus							
Duration of pollen season		Peak value [P/m^3]	Peak date	Seasonal Pollen Index (SPI)	No. of days with concentration above threshold		
Start (day of year)	End (day of year)				≥ 35 P/m^3	≥ 80 P/m^3	≥ 150 P/m^3
24/02 (55 day)	27/03 (86 day)	264	3/03	933	6	3	1
Alnus							
Duration of pollen season		Peak value [P/m^3]	Peak date	Seasonal Pollen Index (SPI)	No. of days with concentration above threshold		
Start (day of year)	End (day of year)				≥ 45 P/m^3	≥ 85 P/m^3	≥ 1200 P/m^3
25/02 (56 day)	7/04 (97 day)	1 561	25/02	7 050	24	16	1
Betula							
Duration of pollen season		Peak value [P/m^3]	Peak date	Seasonal Pollen Index (SPI)	No. of days with concentration above threshold		
Start (day of year)	End (day of year)				≥ 20 P/m^3	≥ 75 P/m^3	≥ 155 P/m^3
18/04 (108 day)	30/05 (150 day)	414	28/04	4 761	25	17	12
Populus							
Duration of pollen season		Peak value [P/m^3]	Peak date	Seasonal Pollen Index (SPI)	No. of days with concentration above threshold		
Start (day of year)	End (day of year)				≥ 50 P/m^3	≥ 80 P/m^3	≥ 150 P/m^3
13/03 (72 day)	9/05 (129 day)	120	31/03	445	2	1	0

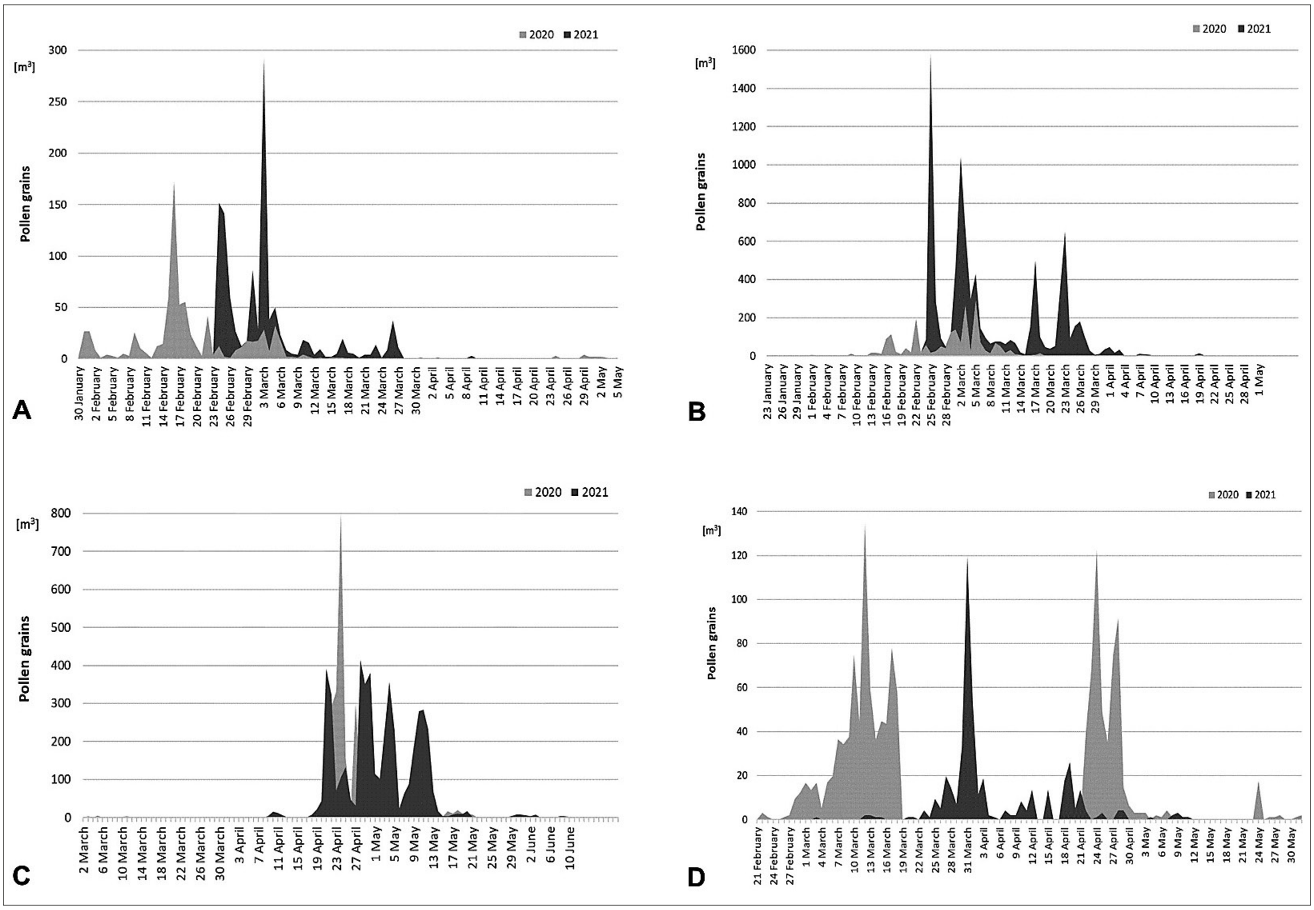


Figure 1. Dynamics of total pollen season (TPS) of hazel (A), alder (B), birch (C), and poplar (D) in Kielce in 2020–2021. Due to the epidemiological status in Poland, the aeropalinological measurements in 2020 were suspended between 19 March – 21 April

season of birch in 2021 was substantially longer, i.e. 76 days. It started and ended later than the 2020 season (Fig. 1).

In the poplar MPS, which lasted from 13 March – 9 May, the maximum concentration of pollen grains (120 P/m^3) was recorded on 31 March. The poplar SPI was estimated at 445. In TPS, there were only 2 days with a poplar pollen concentration exceeding the threshold value of 50 P/m^3 and 1 day with a concentration higher than 80 P/m^3. No concentrations of poplar pollen grains exceeding the value of 150 P/m^3 were recorded in the air of Kielce (Tab. 1). In the 2021 season, poplar pollen was detected in the bioaerosol in Kielce for 70 days. The first poplar pollen grains in 2021 were recorded 10 days later than in 2020, and persisted in the air until 11 May, the same as in the 2020 season (Fig. 1).

Analysis of meteorological parameters. Table 2 presents the characteristics of selected meteorological parameters recorded in the TPS of hazel, alder, birch, and poplar. The weather observations show that the highest maximum temperature (27.2 °C) at the time of pollen release by poplars and birch trees was recorded on 11 May. The maximum temperature during the hazel and alder pollen season (21.2 °C) was noted on 31 March. The lowest maximum temperature (-0.3 °C) was recorded on 21 March, which was the period covering the pollen season of hazel, alder and poplar. The maximum value of average air humidity (90.9%) during the hazel pollen season was recorded on 30 March. In turn, the highest air humidity during the alder, birch, and poplar TPS (94.8%) was recorded on 17 April. The lowest air humidity was observed on 9 April (61.5%) in the hazel pollen season, and on 28 April (43.9%) in the alder, birch, and poplar pollen seasons.

There were differences in the average wind speed between the hazel pollen season and the alder, birch, and poplar pollen seasons. On 5 April, the highest wind speed (4.4 m/s) was recorded in the hazel pollen season. In turn, in the pollen seasons of the other plant taxa, the maximum wind speed was recorded on 2 May (5.1 m/s). The minimum wind speed (0.6 m/s) was recorded on 9 March, during the pollen season of hazel, alder and poplar. The greatest variation in the weather parameters between the pollen seasons was exhibited by the daily rainfall sum. The highest precipitation rates were recorded on12 March (3.8 mm) in the hazel pollen season, on 16 April (8.3 mm) in the alder and poplar pollen seasons, and on 5 June (10.3 mm) in the birch pollen season. The meteorological data showed 25, 34, 37, and 38 days without rainfall in the hazel, poplar, alder, and birch pollen seasons, respectively (Tab. 2).

Statistical analyses revealed no correlations between the meteorological factors in the hazel TPS. The alder and poplar TPS was characterized by a negative correlation between the maximum temperature and average air humidity, and a positive correlation between the rainfall level and humidity and wind speed. The relationships between the maximum temperature and air humidity and the amount of precipitation, as well as between precipitation and humidity were also observed in the birch TPS (Fig. 2).

Table 2. Characteristics of selected meteorological factors during the total pollen season (TPS) of hazel, alder, birch, and poplar in Kielce in 2021

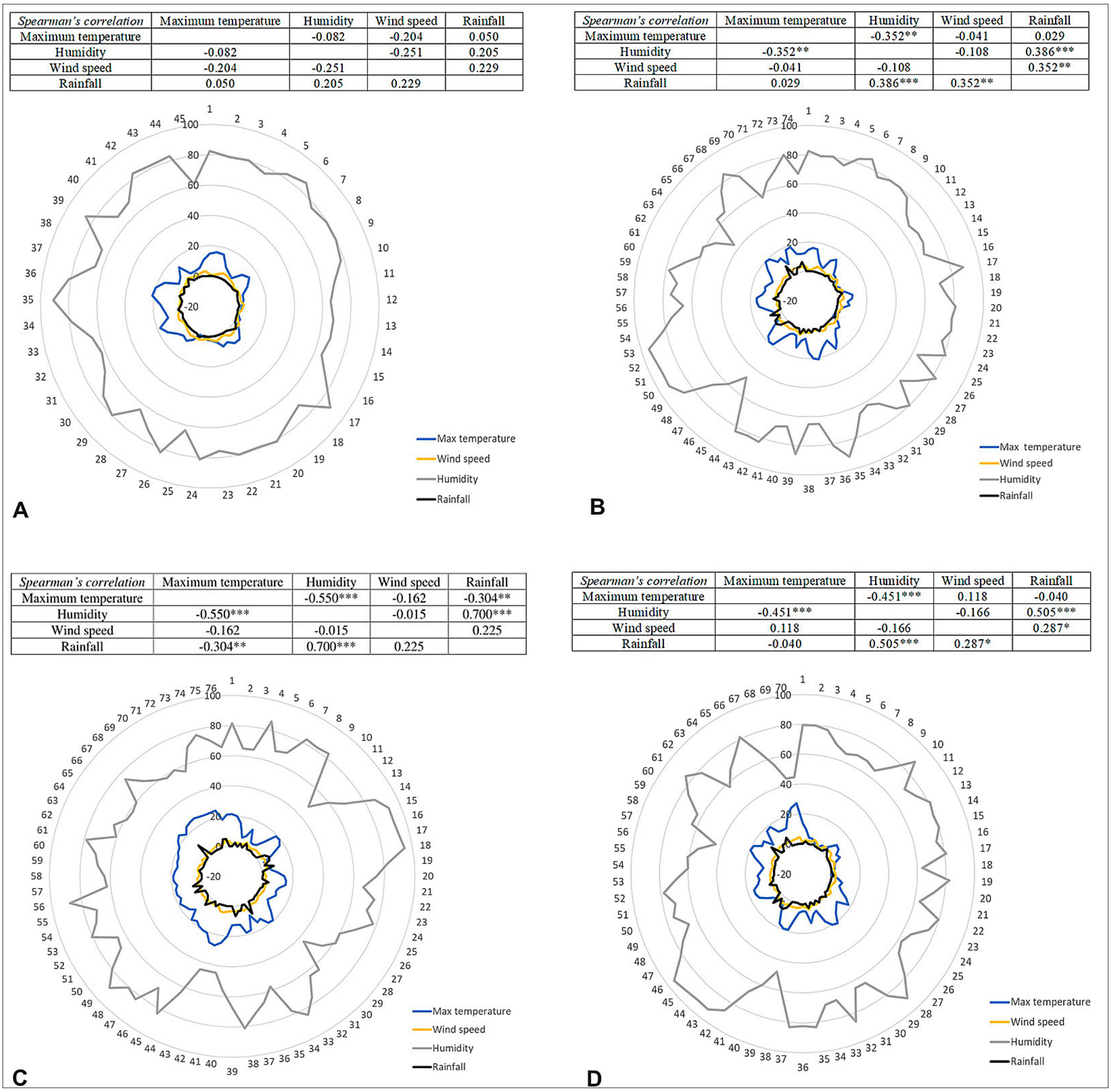
Meteorological factors	Statistical parameters	*Corylus*	*Alnus*	*Betula*	*Populus*
Maximum temperature	max (day)	21.2 (31/03)	21.2 (31/03)	27.2 (11/05)	27.2 (11/05)
	min (day)	-0.3 (21/03)	-0.3 (21/03)	3.0 (14/04)	-0.3 (21/03)
	mean	8.49	10.07	16.18	10.60
	SD	5.41	5.52	6.02	6.21
	V (%)	29.29	30.52	36.26	38.57
	skewness	0.51	0.13	-0.33	0.39
Humidity	max (day)	90.9 (30/03)	94.8 (17/04)	94.8 (17/04)	94.8 (17/04)
	min (day)	61.5 (9/04)	43.9 (28/04)	43.9 (28/04)	43.9 (28/04)
	mean	75.26	73.87	69.93	72.12
	SD	7.81	10.39	12.05	11.61
	V (%)	61.03	107.93	145.23	134.76
	skewness	-0.14	-0.32	-0.02	-0.33
Wind speed	max (day)	4.4 (5/04)	5.1 (2/05)	5.1 (2/05)	5.1 (2/05)
	min (day)	0.6 (9/03)	0.6 (9/03)	0.9 (1/06)	0.6 (9/03)
	mean	2.44	2.60	2.65	2.69
	SD	1.00	0.97	0.90	0.98
	V (%)	1.01	0.93	0.81	0.96
	skewness	0.09	0.05	0.48	0.02
Rainfall	max (day)	3.8 (12/03)	8.3 (16/04)	10.3 (5/06)	8.3 (16/04)
	min (day)	(25 days)	0.0 (37 days)	0.0 (38 days)	0.0 (34 days)
	mean	0.54	1.15	1.60	1.21
	SD	0.97	2.09	2.56	2.13
	V (%)	0.94	4.35	6.56	4.53
	skewness	2.04	2.17	1.64	2.08

SD – standard deviation; V – variance.

Effect of meteorological parameters on pollen season. The results of Spearman's analysis between the meteorological factors and the total (TPS) and main (MPS) pollen seasons of the analyzed plant taxa in the bioaerosol in Kielce are presented in Table 3. There was no correlation between the weather conditions and the concentration of hazel pollen grains in TPS. A positive correlation was found only between the maximum air temperature and the hazel pollen concentration in MPS ($p<0.01$). In TPS, negative correlation coefficients at $p<0.05$ were found between the alder pollen count and the maximum air temperature, wind speed, and rainfall sum. In turn, the number of alder pollen grains in MPS was not significantly correlated with the meteorological conditions. No statistically significant correlation was found between the concentration of birch pollen and the maximum air temperature. In turn, the relationship between the number of birch pollen grains in the atmosphere of Kielce in TPS and MPS and the average air humidity was negatively correlated at $p<0.01$. A negative relationship was also shown between the birch pollen count in TPS and the rainfall sum ($p<0.05$). It was shown that the dynamics of birch pollen in the TPS ($p<0.05$) and MPS ($p<0.01$) periods was also influenced by the wind force. Spearman's correlations revealed a clear relationship between the poplar pollen count and the maximum temperature value in TPS ($p<0.001$) and MPS ($p<0.001$) and the average wind speed in MPS ($p<0.05$) (Tab. 3). To illustrate the impact of meteorological factors on the hazel, alder, birch, and poplar pollen seasons in TPS, dependencies were determined based on Pearson's correlation (Fig. 3, 4, 5, 6). Analysis revealed a statistically significant effect of the maximum air temperature on the concentration of poplar pollen ($R=0.341$; $p<0.01$) (Fig. 3). The birch pollen count was negatively correlated with the mean air humidity ($R=-0.378$; $p<0.001$) (Fig. 4). The wind speed exerted a significant effect on the intensity of hazel ($R=-0.357$; $p<0.05$), birch ($R=0.301$; $p<0.01$), and poplar ($R=0.295$; $p<0.05$) pollen release (Fig. 5). In turn, no significant correlation was found between the count of pollen grains of the studied plant taxa and the rainfall sum (Fig. 6).

DISCUSSION

Given the high variability of the dynamics of pollen seasons, the literature highlights the need to carry out constant pollen monitoring [29, 30]. Plant pollen released into the atmosphere is the main inhalation allergen playing an important role in the development of allergic diseases, e.g. allergic rhinitis [31]. Pollen grains released by spring plants are one of the most frequently identified inhalation allergens. Therefore, it seems extremely valuable to conduct aeropalinological studies of the pollen seasons of plants with high allergenic potential, taking into account environmental conditions and meteorological factors. Climatic conditions largely determine the flora of a given region. They can also influence the concentrations of pollen grains in the atmospheric air [32]. Hence, the present study focused on the assessment of the dynamics of hazel, alder, birch, and poplar pollen seasons in relation to selected weather conditions.



Spearman's correlation	Maximum temperature	Humidity	Wind speed	Rainfall
Maximum temperature		-0.082	-0.204	0.050
Humidity	-0.082		-0.251	0.205
Wind speed	-0.204	-0.251		0.229
Rainfall	0.050	0.205	0.229	

Spearman's correlation	Maximum temperature	Humidity	Wind speed	Rainfall
Maximum temperature		-0.352**	-0.041	0.029
Humidity	-0.352**		-0.108	0.386***
Wind speed	-0.041	-0.108		0.352**
Rainfall	0.029	0.386***	0.352**	

Spearman's correlation	Maximum temperature	Humidity	Wind speed	Rainfall
Maximum temperature		-0.550***	-0.162	-0.304**
Humidity	-0.550***		-0.015	0.700***
Wind speed	-0.162	-0.015		0.225
Rainfall	-0.304**	0.700***	0.225	

Spearman's correlation	Maximum temperature	Humidity	Wind speed	Rainfall
Maximum temperature		-0.451***	0.118	-0.040
Humidity	-0.451***		-0.166	0.505***
Wind speed	0.118	-0.166		0.287*
Rainfall	-0.040	0.505***	0.287*	

Figure 2. Dynamics of meteorological conditions and Spearman's correlation between selected meteorological parameters in the total pollen season (TPS) of hazel (A), alder (B), birch (C), and poplar (D)
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Table 3. Spearman's correlation coefficient between meteorological parameters and the total and main pollen seasons of hazel, alder, birch, and poplar.

Spearman's correlation		*Corylus*		*Alnus*		*Betula*		*Populus*	
		TPS (*N*=45)	MPS (*N*=32)	TPS (*N*=74)	MPS (*N*=42)	TPS (*N*=76)	MPS (*N*=43)	TPS (*N*=70)	MPS (*N*=58)
Maximum temperature	*R*	-0.014	**0.478**	**-0.256**	0.086	0.041	-0.042	**0.473**	**0.423**
	p	0.922	**0.005**	**0.027**	0.583	0.724	0.784	**0.000**	**0.000**
Humidity	*R*	-0.001	0.089	0.095	-0.023	**-0.345**	**-0.426**	-0.151	-0.184
	p	0.992	0.624	0.420	0.881	**0.002**	**0.004**	0.211	0.164
Wind speed	*R*	-0.100	-0.195	**-0.269**	-0.036	**0.263**	**0.403**	-0.187	**-0.295**
	p	0.509	0.283	**0.020**	0.817	**0.021**	**0.007**	0.119	**0.024**
Rainfall	*R*	-0.209	0.078	**-0.269**	-0.141	**-0.250**	-0.224	-0.029	-0.058
	p	0.167	0.669	**0.020**	0.370	**0.029**	0.148	0.809	0.660

TPS - total pollen season, MPS - main pollen season

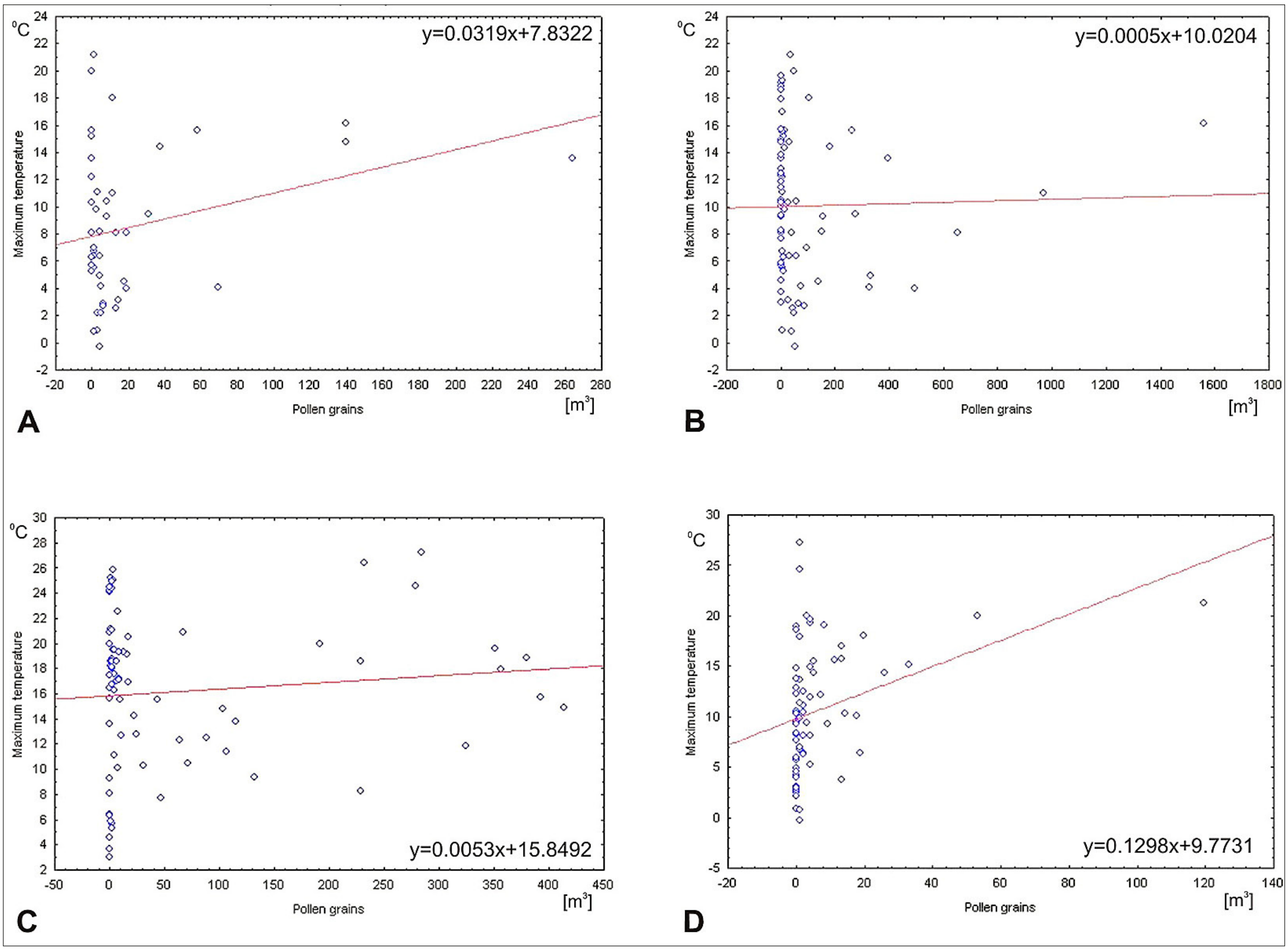


Figure 3. Relationship between the maximum air temperature and total count of hazel (A), alder (B), birch (C), and poplar (D) pollen in the bioaerosol in Kielce

The present aerobiological observations show that hazel and alder pollen grains were the first to appear in the air of Kielce. Hazel pollen release usually begins the pollen season in Poland and is considered the onset of phenological early spring [4]. The length of the hazel pollen season in Kielce was similar to that recorded in other regions of Poland, e.g. Kraków, Sosnowiec, and Warsaw [4]. The highest concentration of hazel pollen grains in Kielce was recorded on 3 March, i.e. only a day earlier than in Bydgoszcz and Piotrków Trybunalski in 2021 [4]. The present study revealed that the peak hazel pollen concentration in Kielce was slightly higher than in other regions of Poland [4]. In turn, the number of days with concentrations exceeding the threshold values was the same as in Wrocław [4]. In the presented study, the hazel pollen season in Kielce in 2021 had a compact character. High concentrations of pollen grains were recorded at the end of February and the beginning of March. The species was characterized by the shortest TPS and MPS of all the plant taxa analyzed in the study.

In the presented research, the alder pollen release in Kielce in 2021 exhibited higher intensity than in 2020. As shown by literature data, the concentrations of alder pollen grains in various regions of Poland in 2020 were quite low [33]. In 2021, high concentrations of pollen grains were noted in many Polish cities [34], also in Kielce. The concentration of alder pollen grains in Kielce in 2021 was similar to that of *Alnus* pollen in Piotrków Trybunalski [34]. The onset of the alder pollen season in Kielce in 2021 was similar to that recorded in Lublin, Białystok, and Kraków, whereas the end dates were similar to those noted in Lublin and Olsztyn [34].

Alder pollen is small and can be transported over long distances by the wind [35]. Hence, it is possible that the transport of alder pollen from distant places may contribute to its high concentrations. Plants exhibit variable intensity of pollen release [12]. A high intensity of alder pollen release was recorded in Kielce in 2021, with a maximum pollen grain count exceeding 1,500 P/m^3 of air. The pollen peak was recorded on 25 February, i.e. only a day earlier than in Opole, Piotrków Trybunalski, Warsaw, and Białystok [34]. Literature data indicate that the severity of allergic symptoms depends on the concentration of the allergen in the air and the degree of exposure of the organism to the allergen. Therefore, the information on the threshold concentrations of plant pollen necessary to induce allergic symptoms is extremely valuable [12]. In Kielce in 2021, the alder and birch pollen seasons were characterized by the greatest number of days with values exceeding the threshold concentrations.

In the spring period, birch pollen grains persisted for the longest time in the air of Kielce. Birch pollen is the most common cause of allergies in April and May [36]. The onset and course of the birch pollen season depend on various factors, e.g. weather conditions. The birch pollen season usually has a compact and dynamic character [37]. Birch pollen reaches very high concentrations in the air (often 2,000–4,000 P/m^3); the concentration in the vicinity of a flowering tree may even exceed 16.2 million pollen grains per

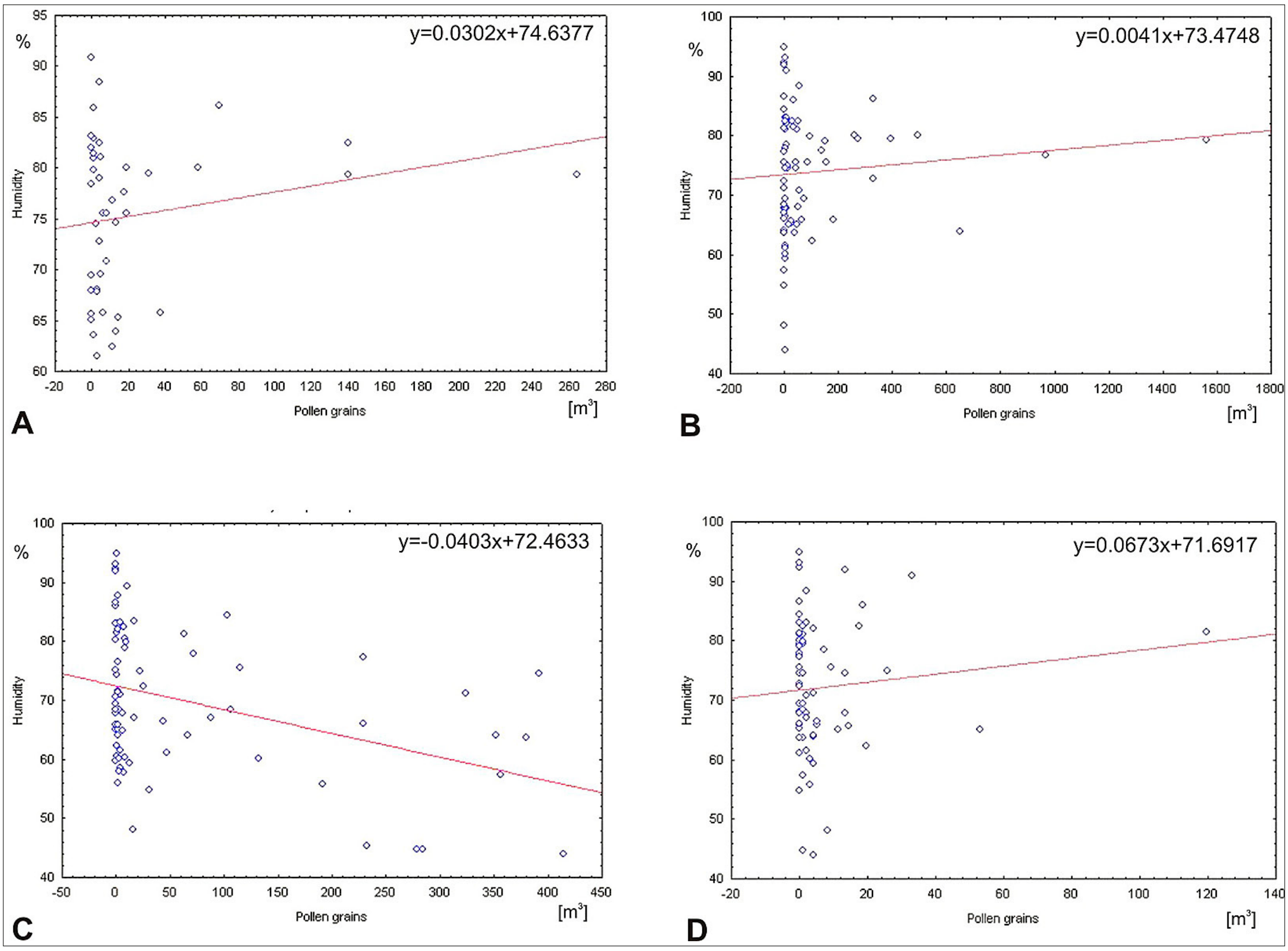


Figure 4. Relationship between the average air humidity and total count of hazel (A), alder (B), birch (C), and poplar (D) pollen in the bioaerosol in Kielce

m^3 of air. There may be substantial differences in the onset date and pollen intensity between years. Concentrations exceeding 18–20 thousand grains in 1 m^3 of air have been recorded in some years [38]. As reported by Piotrowska-Weryszko et al. [39], the average annual sum of birch pollen grains in 2001–2005 in some Polish cities ranged from 4,665 – 14,551. This indicates that the birch pollen count in the air of Kielce in 2021 was one of the lower values (Tab. 1; Fig. 1). The low sum of birch pollen grains in the 2021 season was also observed in other regions of Poland [40]. In Kielce, the MPS birch season began in the second decade of April, as in Olsztyn, Kraków, Bydgoszcz, and Białystok [40]. The pollen peak of this occurred on 28 April, a day earlier than, for example, in Olsztyn, Bydgoszcz, Szczecin and Białystok [40].

The poplar pollen season is recorded in March and April. In Kielce in 2021, it had a compact character, with only one peak value exceeding 80 pollen grains/m^3 air. In Poland, poplar pollen has no high allergenic importance, although there are literature data emphasizing its clinical relevance [41]. Currently, there are few data on the poplar pollen season, with the available information showing the varied intensity of poplar pollen release in different regions of Poland [41]. The poplar pollen season in Kielce in 2021 began in the second 10 days of March, i.e. earlier than in other regions of Poland in 2018, and lasted for a considerably longer time [41].

Literature data show that plant flowering and the concentration of airborne pollen grains may be influenced by meteorological conditions. It has been found that the onset of pollen seasons largely depends on the meteorological factors prevailing before and during the release of hazel and alder pollen grains [35, 42]. As reported by Kasprzyk et al. [24], low temperatures in February and March may contribute to shorter pollen seasons in spring; therefore, it is advisable to assess the impact of weather conditions on the dynamics of plant pollen release. The present study showed varied relationships between the meteorological factors and the tree pollen season (Tab. 3, Fig. 3–6). The maximum air temperature had a significant impact on the pollen season of hazel, alder and poplar (Tab. 3, Fig. 3). A significant impact of temperature on plant pollen seasons was reported by Kizilpinar et al. [43], and Ślusarczyk et al. [44]. In turn, the average air humidity was strongly correlated only with the birch pollen season (in both TPS and MPS) (Tab. 3, Fig 4). A highly variable effect of the wind speed on concentration of pollen grains of the analyzed plant taxa was also noted. The study confirmed the relationship between the wind speed and the amount of pollen of alder and hazel (in TPS), as well as birch and poplar (in TPS and MPS) in the air of Kielce (Tab. 3, Fig. 5). The conducted research shows that the total pollen season of alder and birch was also significantly influenced by the rainfall rates (Tab. 3). The impact of the meteorological parameters on the concentration of pollen grains in the air of Kielce varied depending on the analyzed pollen season (TPS/MPS).

Research on continuous pollen biomonitoring which allows the creation of pollen calendars are highly important

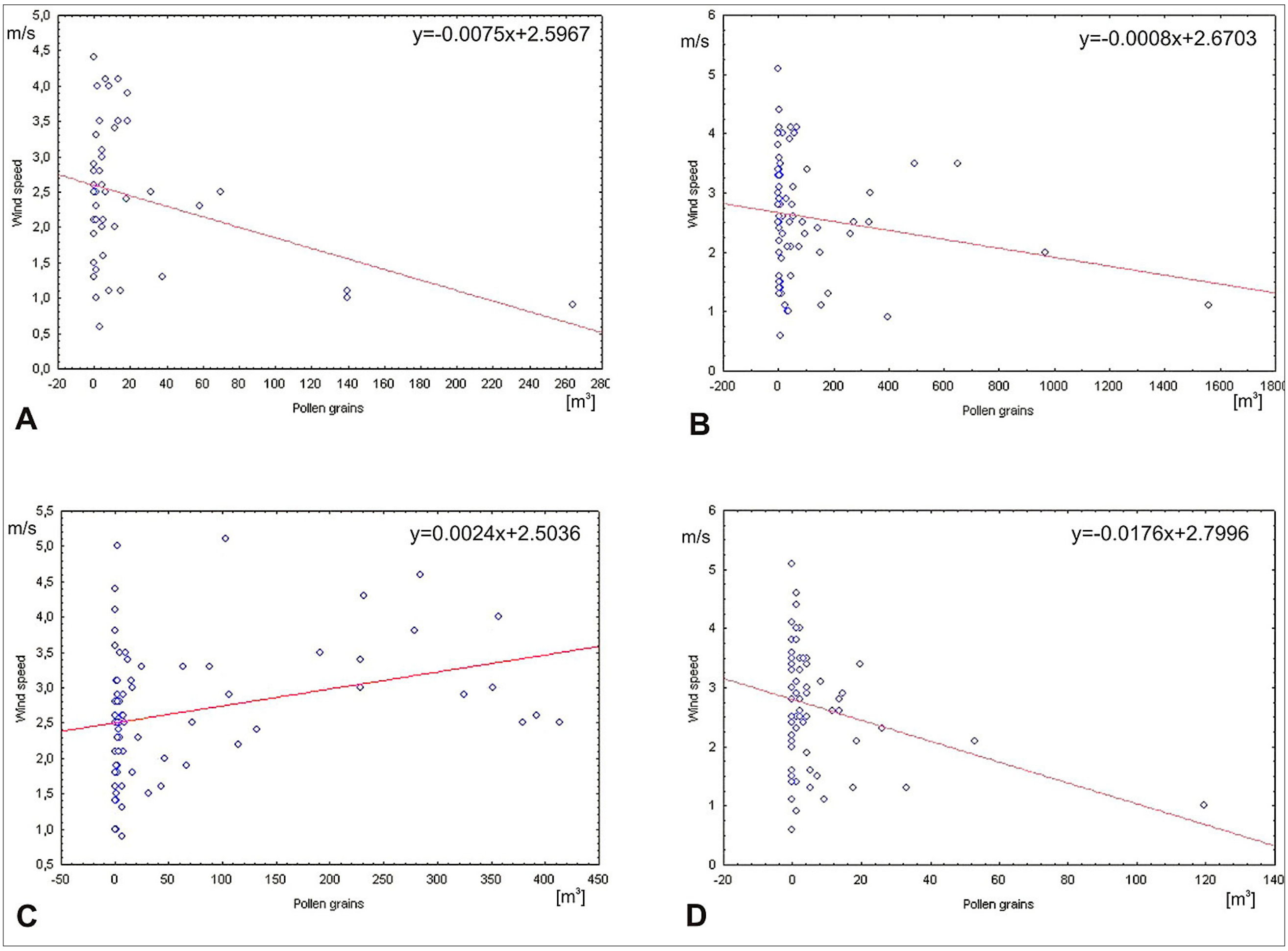


Figure 5. Relationship between the average wind speed and total count of hazel (A), alder (B), birch (C), and poplar (D) pollen in the bioaerosol in Kielce.

for both patients and allergists. Moreover, aerobiological data combined with analyses of meteorological parameters allow determination of the dynamics of plant pollen release specific for a region or the entire country.

CONCLUSIONS

This is the first published report on the characteristics of the pollen seasons of the listed plant species in the Kielce region of Poland. The study revealed high concentrations of spring tree pollen persisting in the air of Kielce from February – May 2021. In February, high concentrations of hazel and alder pollen grains were recorded. Hazel, alder, and poplar pollen dominated in March, whereas poplar and birch pollen was dominant in April. Maximum concentrations of pollen grains were recorded in each month, i.e. the analyses showed peaks of alder pollen in February, hazel and poplar pollen in March, and birch pollen in April.

Hazel and alder pollen were the first to appear in the air of Kielce in 2021. The longest and shortest pollen seasons were recorded in the case of birch and hazel, respectively. Intense alder pollen release, with the highest maximum concentration of pollen grains in spring, was noted in Kielce in 2021.

The study showed variable relationships between the amounts of pollen grains of the studied tree taxa and meteorological conditions. It was found that the wind speed and temperature had the greatest impact on plant pollen release, and alder and birch were particularly sensitive to the weather conditions prevailing in Kielce in 2021.

Funding
This work was supported by a research project of the Jan Kochanowski Uniwersity in Kielce, grant No. SUPB. RN.22.133.

REFERENCES

1. Rapiejko P, Stankiewicz W, Szczygielski K, et al. Threshold pollen count necessary to evoke allergic symptoms. Otolaryngol Pol. 2007; 61(4):591–94. https://doi.org/10.1016/s0030–6657(07)70491–2.
2. Seneta W, Dolatowski J, Zieliński J. Dendrologia. PWN Warszawa, 2021.
3. Rapiejko P, Lipiec A. Pyłek roślin jako aeroalergen. Terapia. 2001; 3: 3–9.
4. Piotrowska-Weryszko K, Weryszko-Chmielewska E, Dąbrowska-Zapart K, et al. Analysis of Corylus pollen season in Poland in 2021. Alergoprofil. 2021; 17(2): 54–59. https://doi.org/10.24292/01.AP.172290621.
5. Jacob T, Seutter von Loetzen C, Reuter A, et al. Identification of a natural ligand of the hazel allergen Cor a 1. Sci Rep. 2019; 9(1):8714. https://doi.org/10.1038/s41598–019–44999–2.
6. Rapiejko P, Lipiec A. Alergeny pyłku leszczyny. Alergoprofil. 2007; 3(2): 24–29.
7. Roux KH, Teuber SS, Sathe SK. Tree nut allergens. Int Arch Allergy Immunol. 2003; 131(4): 234–244. https://doi.org/10.1159/000072135.
8. Mehlenbacher SA, Brown RN, Nouhra ER, et al. A genetic linkage map for hazelnut (Corylus avellana L.) based on RAPD and SSR markers. Genome. 2006; 49(2):122–33. https://doi.org/10.1139/g05–091.

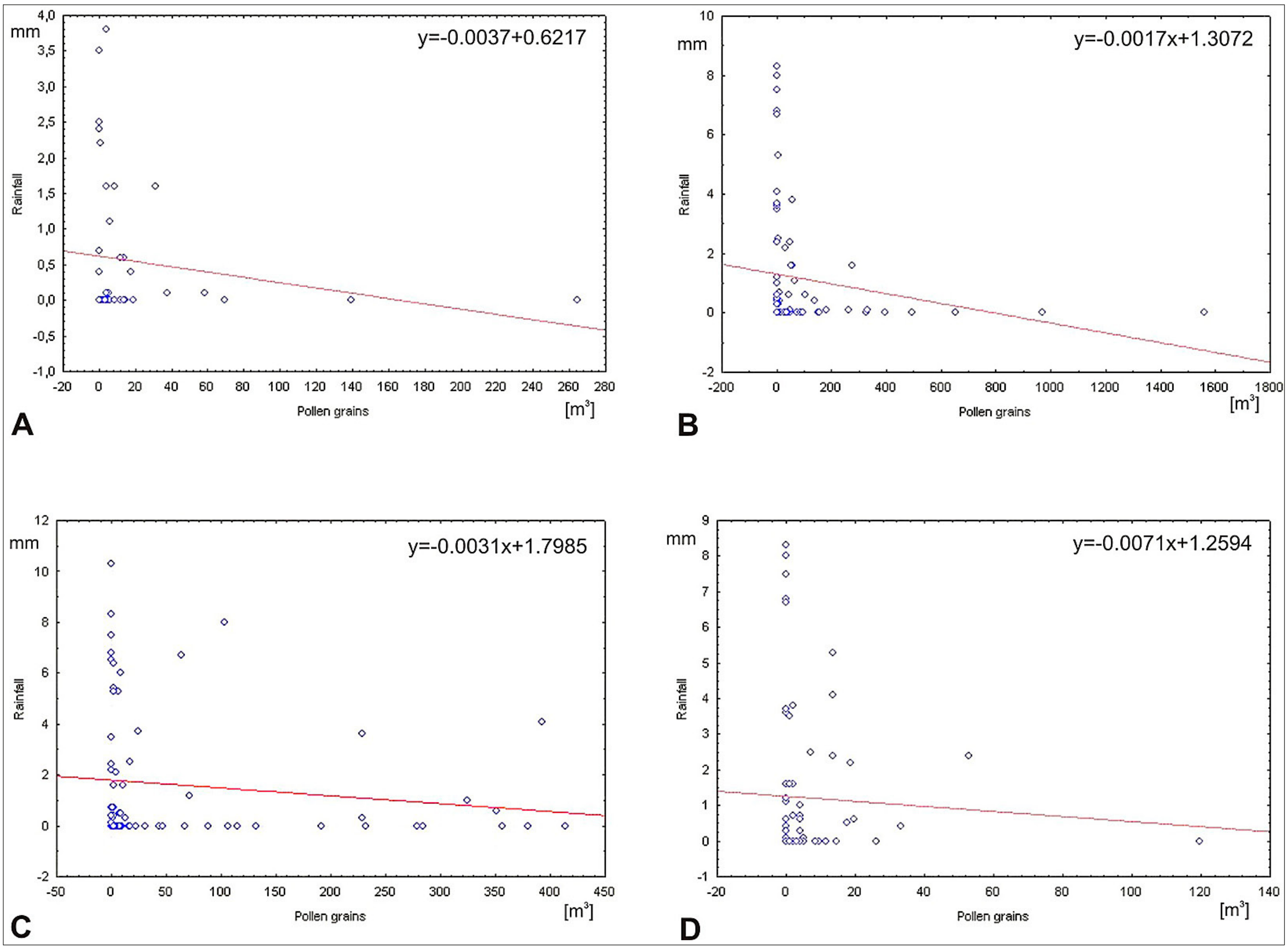


Figure 6. Relationship between the daily rainfall sum and total count of hazel (A), alder (B), birch (C), and poplar (D) pollen in the bioaerosol in Kielce

9. Aalberse RC, Akkeerdaas JH, van Ree R. Cross-reactivity of IgE antibodies to allergens. Allergy. 2001; 56(6): 478–490. https://doi.org/10.1034/j.1398–9995.2001.056006478.x.
10. Biedermann T, Winther L, Till SJ, et al. Birch pollen allergy in Europe. Allergy. 2019; 74(7): 1237–1248. https://doi.org/10.1111/all.13758.
11. Rapiejko P. Alergeny pyłku olszy. Alergoprofil. 2007; 3(3): 28–33.
12. Rapiejko P, Stankiewicz W, Szczygielski K, et al. Progowe stężenie pyłku roślin niezbędne do wywołania objawów alergicznych. Otolaryngol Pol. 2007; 61(4): 591–594. https://doi.org/10.1016/S0030–6657(07)70491–2.
13. Asam C, Batista AL, Moraes AH, et al. Bet v 1 – a Trojan horse for small ligands boosting allergic sensitization? Clin Exp Allergy. 2014; 44(8): 1083–1093. https://doi.org/10.1111/cea.12361.
14. Wölbing F, Kunz J, Kempf WE, et al. The clinical relevance of birch pollen profilin cross-reactivity in sensitized patients. Allergy. 2017; 72(4): 562- 569. https://doi.org/10.1111/all.13040.
15. Dyakowska J. Podręcznik palynologii. Metody i problemy. Wyd. Geologiczne, Warszawa, 1959.
16. Rapiejko P. Alergeny pyłku topoli. Alergoprofil. 2008; 4(2): 30–32.
17. Celik G, Mungan D, Pinar M, et al. Poplar pollenrelated allergy in Ankara, Turkey: how important for patients living in a city with high pollen load? Allergy Asthma Proc. 2005; 26(2): 113–119.
18. Weryszko-Chmielewska E. Aerobiologia. Wydawnictwo Akademii Rolniczej w Lublinie, Lublin, 2007: 108–110.
19. Lin RY, Clauss AE, Bennett ES. Hypersensitivity to common tree pollen in New York City patients. Allergy Asthma Proc. 2002; 23(4): 253–258.
20. Guilbert A, Cox B, Bruffaerts N, et al. Relationships between aeroallergen levels and hospital admissions for asthma in the Brussels-Capital Region: a daily time series analysis. Environ Health. 2018; 17(1): 35. https://doi.org/10.1186/s12940–018–0378-x.
21. Chłopek K, Malkiewicz M, Weryszko-Chmielewska E, et al. Pyłek topoli w powietrzu wybranych miast Polski w 2014 r. Alergoprofil. 2014; 10(3): 31–35.
22. Zemmer F, Dahl Å, Galán C. The duration and severity of the allergenic pollen season in Istanbul, and the role of meteorological factors. Aerobiologia. 2022; 38: 195–215. https://doi.org/10.1007/s10453–022–09742-x.
23. Rahman A, Khan MHR, Luo C, et al. Variations in airborne pollen and spores in urban Guangzhou and their relationships with meteorological variables. Heliyon. 2021; 7(11): e08379. https://doi.org/10.1016/j.heliyon.2021.e08379.
24. Kasprzyk I, Uruska A, Szczepanek K, et al. Regional differentiation in the dynamics of the pollen seasons of Alnus, Corylus and Fraxinus in Poland (preliminary results). Aerobiologia. 2004; 20(2): 141–151. https://doi.org/10.1023/B:AERO.0000032951.25974.c9.
25. Nowosad J. Spatiotemporal models for predicting high pollen concentration level of Corylus, Alnus, and Betula. Int J Biometeorol. 2016; 60: 843–855. https://doi.org/10.1007/s00484–015–1077–8.
26. Yagami A, Ebisawa M. New Findings, Pathophysiology, and Antigen Analysis in Pollen-Food Allergy Syndrome. Curr Opin Allergy Clin Immunol. 2019; 19(3): 218–223. https://doi.org/10.1097/ACI.0000000000000533.
27. Emberlin J, Savage M, Jones S. Annual variations in grass pollen seasons in London 1961–1990: trends and forecast models. Clin Exp Allergy. 1993; 23(11): 911–918. https://doi.org/10.1111/j.1365–2222.1993.tb00275.x.
28. Instytut Meteorologii i Gospodarki Wodnej – Państwowy Instytut Badawczy. www.meteomodel.pl (access: 27.07.2021).
29. Buters JTM, Antunes C, Galveias A, et al. Pollen and spore monitoring in the world. Clin Transl Allergy. 2018; 8: 9. https://doi.org/10.1186/s13601–018–0197–8.
30. Camacho IC. Airborne pollen in Funchal city, (Madeira Island, Portugal) – First pollinic calendar and allergic risk assessment. Ann Agric Environ Med. 2015; 22(4): 608–613. https://doi.org/10.5604/12321966.1185762.
31. Kafashan HA, Khosravi AR, Alyasin S, et al. Airborne Pollens and Their Association with Meteorological Parameters in the Atmosphere of Shiraz, Southwest Iran. Iran J Allergy Asthma Immunol. 2021; 20(3): 294–302. https://doi.org/10.18502/ijaai.v20i3.6332.
32. Aboulaich N, Achmakh L, Bouziane H, et al. Effect of meteorological parameters on Poaceae pollen in the atmosphere of Tetouan (NW

Morocco). Int J Biometeorol. 2013; 57(2): 197–205. https://doi.org/10.1007/s00484–012–0566–2.
33. Malkiewicz M, Piotrowska-Weryszko K, Puc M, et al. Alder pollen season in selected cities of Poland in 2020. Alergoprofil. 2020; 16(2): 25–30. https://doi.org/10.24292/01.AP.162250420.
34. Rapiejko A, Malkiewicz M, Wolski T, et al. The analysis of alder pollen season in selected cities of Poland in 2021. Alergoprofil. 2021; 17(4), 38–43. https://doi.org/10.24292/01.AP.174171121.
35. Stępalska D, Myszkowska D, Piotrowicz K, et al. The phenological phases of flowering and pollen seasons of spring flowering tree taxa against a background of meteorological conditions in Kraków, Poland. Acta Agrobot. 2016; 65(2): 1678. https://doi.org/0.5586/aa.1678.
36. Puc M, Wolski T, Camacho IC, et al. Fluctuation of birch (Betula L.) pollen seasons in Poland. Acta Agrobot. 2015; 68(4): 303–313. https://doi.org/10.5586/aa.2015.041.
37. Malkiewicz M, Lipiec A, Dąbrowska-Zapart K, et al. Birch pollen season in southern Poland in 2017. Alergoprofil, 2017; 13(3): 118–123. https://doi.org/10.24292/01.ap.200917.
38. Rapiejko P. Pyłek roślin jako źródło alergenów. Przegląd Alergiczny. 2004: 7–12.
39. Piotrowska-Weryszko K, Weryszko-Chmielewska E, Dmitruk M, et al. The analysis of Betula pollen season in Poland in 2019. Alergoprofil. 2019; 15(3): 10–15. https://doi.org/10.24292/01.AP.153300919.
40. Rapiejko J, Puc M, Malkiewicz M, et al. The analysis of birch pollen season in selected cities of Poland in 2021. Alergoprofil. 2022; 18(1): 29–34. https://doi.org/10.24292/01.AP.181040322.
41. Malkiewicz M, Lipiec A, Puc M, et al. Populus pollen in the air of selected Polish cities in 2018. Alergoprofil. 2018; 14(2): 54–58. https://doi.org/10.24292/01.AP.21429161.
42. Puc M, Kasprzyk I. The patterns of Corylus and Alnus pollen seasons and pollination periods in two Polish cities located in different climatic regions. Aerobiologia. 2013; 29(4): 495–511. https://doi.org/10.1007/s10453–013–9299-x.
43. Majeed HT, Periago C, Alarcón M, et al. Airborne pollen parameters and their relationship with meteorological variables in NE Iberian Peninsula. Aerobiologia. 2018; 34: 375–388. https://doi.org/10.1007/s10453–018–9520-z.
44. Ślusarczyk J, Kopacz-Bednarska A, Posłowska J. Characteristics of ash, maple, yew/ juniper, and willow pollen seasons in the air of Kielce in 2021 in correlation with weather conditions. Alergoprofil. 2021; 17(4): 44–51. https://doi.org/10.24292/01.AP.174181021.