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Global warming contributes to reduction in the intensity of *Artemisia* pollen seasons in Lublin, central-eastern Poland

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Abstract

Introduction and Objective. Species of the genus *Artemisia* (Asteraceae) are weeds and ruderal plants growing in northern temperate regions of the world. Many of them are used in medicine and the cosmetic industry and for culinary purposes. Pollen grains of plants of this genus contain the most important aeroallergens.
Materials and Method. An aerobiological study conducted with the volumetric method in Lublin in 2001–2022. Trend lines for the season parameters were established. Spearman's correlation and stepwise regression analyses were carried out to determine relationships between various parameters of the pollen season and meteorological factors. PCA analysis was also carried out to visually compare the pollen seasons.
Results. In Lublin, central-eastern Poland, the *Artemisia* pollen season lasted on average from the second ten days of July to the end of August, with its beginning depending on the temperature in April and May. The highest pollen concentrations were mainly recorded in the first half of August and were largely dependent on the mean temperature in June and July. The second peak in the pollen season recorded in September was associated with the presence of *Artemisia annua* pollen. Intense sunshine in June and the higher temperatures in June and July resulted in significant reduction in the Artemisia annual pollen sum (by 65%) over 22 years. *Artemisia vulgaris* is abundant in the Lublin region and contributes substantially to the amount of *Artemisia* pollen in the aeroplankton.
Conclusions. The downward trend in the amount of *Artemisia* pollen was a result of the increase in temperatures observed in the summer months, and the declining rainfall rates. The global warming effect is extremely unfavourable for plants of Artemisia vulgaris, as they require moist soil substrates for growth.

Key words

mugwort, airborne pollen concentrations, downward trend, season parameters, meteorological factors, climate warming, aeroallergens

INTRODUCTION

The genus *Artemisia* L. has recently undergone rapid evolutionary radiation [1]. It is the largest in the tribe *Anthemideae* belonging to the Asteraceae family which comprises over 500 species. The genus is circumboreal in distribution and is mainly found in northern temperate regions in the world [2]. In Europe, the range of this taxon extends from central Scandinavia to southern Spain and Italy [3].

The representatives of the genus *Artemisia* differ widely in their distribution, abundance, ecology, and growth form. They are typically evergreen shrubs, subshrubs, and herbaceous perennials [4]. The members of this genus have a distinctive scent or taste. Many of them are used in folk and modern medicine, with *Artemisia* species being used in the treatment of cancer, hepatitis, malaria, inflammation, and infections caused by viruses (including COVID-19), fungi, and bacteria [4–9]. They also exhibit neuroprotective and anti-epileptic potential [10]. Some species provide components for the cosmetic industry [11–13] and some are used for culinary purposes [8, 11, 14–16]. Mugwort herb and extracted essential oil is used for the production of vermouths, herbal vodkas (e.g. absinthe), and liqueurs [11, 17]. Some species exhibit allergic and toxic properties [4, 17].

In Europe, the most popular *Artemisia* species is *A. vulgaris*; additionally, *A. annua* and *A. verlotiorum* are common in the southern part of the continent [18]. In Poland, the genus *Artemisia* is represented by 14 species, with *A. vulgaris*, *A. campestris*, *A. annua*, and *A. absinthium* being the most common species. They mainly grow in ruderal places, at roadsides, in dry areas, on sandy soils, and in well-sunlit habitats [19]; *A. vulgaris* is the only species that prefers wetter localities [20]. The *Artemisia* representatives in Poland flower in July-September [21]. Their flowers are adapted to anemophily, but they are often visited by bees forming light-coloured pollen loads from pollen [22–24]. The size of *A. vulgaris* pollen grains is 18.1–24.2 µm, whereas a substantially smaller pollen size of 15.6–21.1 µm is produced by *A. annua* [25].

Artemisia vulgaris is classified as a nitrophilic ruderal plant growing in wastelands, railway areas, landfills, field margins, roadsides, arable fields, ditches, and near rivers. Its 0.5–2.2 m stems are grooved, highly branched, bare at the bottom and tomentose in the apical part [19, 26].

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Pollen grains of *Artemisia* are one of the most important aeroallergens [27, 28]. The sensitization rate against pollen of these taxa is compared to that of grass pollen and is expected to increase due to plant migration across Europe [29]. In Europe, the highest amounts of pollen grains of this taxon are recorded in Poland, Lithuania, Latvia, and Ukraine [3]. In Bavaria (Germany), it was found that at the beginning of the season that 33.3% of *Artemisia* pollen grains originated from atmospheric transport [30]. In Europe and Asia, these grains cause allergic disease in 10–14% of pollinosis patients [31]. In Central Europe, the sensitisation rate ranges from 10.6 % in Austria to 44.3 % in Hungary [32]. In Poland, the first symptoms of *Artemisia* pollen allergy were detected at a concentration of 30 grains/m^3 in 24 h [18, 33], while in Lithuania they were recorded at the level of 15 grains/m^3 in 24 h [34]. *Artemisia* pollen release was detected in the early morning, with higher concentrations at street level than on the roof [18].

Studies on *Artemisia* pollen deposition in nasal cavities revealed that the greatest amount of pollen accumulated in the nasal vestibule and in the nasal septum [35]. Defensin-polyproline-linked proteins are allergens in *Artemisia* pollen. Defensin-related food allergies are associated with the consumption of celery, horse chestnut, mango, and sunflower seeds [36]. Mugwort pollen is also known to cross-react with some other fruits (peach, apple) and vegetables belonging to the Brassicaceae family, e.g. cauliflower, cabbage, and broccoli [37].

It has been shown that, in comparison with pollen grains of other plant species collected from 100 locations across Europe, *Artemisia vulgaris* pollen was characterised by the highest levels of endotoxin released by Gram-negative bacteria, causing strong immunological and inflammatory effects [38]. As shown by Bashiri et al. [39], *Artemisia* pollen extracts showed significant activity against *Enterococcus faecalis*, *Staphylococcus aureus*, and *Klebsiella pneumoniae*.

Although the most important source of *Artemisia* pollen in Poland is *A. vulgaris*, the roles of other *Artemisia* species (mainly *A. absinthium* and *A. campestris*) cannot be ignored. In particular, *A. campestris* pollen grains may trigger allergic reactions during late summer [40].

OBJECTIVE

The aim of the study was to examine the intensity of *Artemisia* pollen seasons in Lublin, central-eastern Poland, in 2001–2022. To assess the impact of climate change on seasonal features, correlations were calculated between season parameters and some meteorological factors. The research results were compared with the effects of similar studies conducted in other parts of Poland and various European countries differing in their climatic and geobotanical conditions. Given the high allergenicity of *Artemisia* pollen, the results obtained may be essential for assessment of the risk of inhalation allergy caused by the pollen of this taxon.

MATERIALS AND METHOD

Measurements of the *Artemisia* pollen concentration in the air of Lublin were carried out in 2001–2022 using a Hirst-type volumetric apparatus (Lanzoni VPPS 2000). The device was located on the roof of the Rectorate building of the University of Life Sciences in Lublin (51°14'37'' N and 22°32'25'' E; 197 a.s.l.) at a height of 18 m above ground level. The pollen sampler operated on a 24-hour basis in a 7-day cycle. Quantitative pollen analysis was performed in accordance with the recommendations of the European Aerobiology Society [41] and the European Standard [42]. For adequate identification of pollen grains, microscopic preparations containing pollen tapes were stained with basic fuchsin. Pollen grain concentrations were expressed as the number of pollen grains in 1 m^3 of air (P/m^3) per day [43].

The duration of the pollen season was determined with the 98% method [40]. The start of the season was defined as the date when 1% of the seasonal cumulative pollen concentration was trapped, and the end of the season was determined when the cumulative pollen sum reached 99%. The total pollen sum was calculated and the maximum pollen concentration and the peak date were determined.

The relationships between the different parameters (6 parameters) of the *Artemisia* pollen season and between the course of the season and selected meteorological factors (minimum, mean, and maximum temperature, cloud cover, sunshine, humidity, rainfall), were determined using Spearman's correlation analysis.

The Principal Component Analysis (PCA) was performed to visually compare the analysed pollen seasons in terms of their characteristics. This is as a valuable dimensionality reduction technique commonly applied to large datasets. By transforming an extensive array of variables into a more concise set, PCA effectively reduces dimensionality while retaining the essential information from the original dataset. The overarching goal of PCA is to enhance data interpretability and visualisation capabilities [44].

The outcomes are displayed in a factor loading table illustrating the correlations between the season parameters and the derived factors (PC1, PC2, PC3). Additionally, factor score scatterplots are provided in the PC1-PC2 and PC1-PC3 coordinate systems. The factor loadings were acquired following VARIMAX rotation, a technique that maximises the sum of variances of squared loadings. The number of designated principal components was determined based on Kaiser's criterion, in which principal components with eigenvalues not exceeding one are eliminated [45].

An attempt was also made to find a linear relationship between the analysed weather data and the pollen season parameters. For this purpose, a stepwise regression analysis was performed.

RESULTS

Characteristics of *Artemisia* pollen seasons. In Lublin, the mugwort pollen season started, on average, on 17 July and ended on 24 September (Tab. 1; Fig. 1). In all the study years, the mugwort pollen season began in July, i.e. between 8 July – 24 July. The earliest beginning of the season was recorded in 2018 and its latest beginning was noted in 2022. The difference between the extreme season onset dates reached 17 days. The date of the season onset was characterised by the lowest variability, compared to the other season parameters (Tab. 1). Slightly higher variability was found in the case of the end of the season, which was recorded between 6 September – 12 October. The latest end of the mugwort pollen season (in 2005) was preceded by lower pollen concentrations in September than in October.

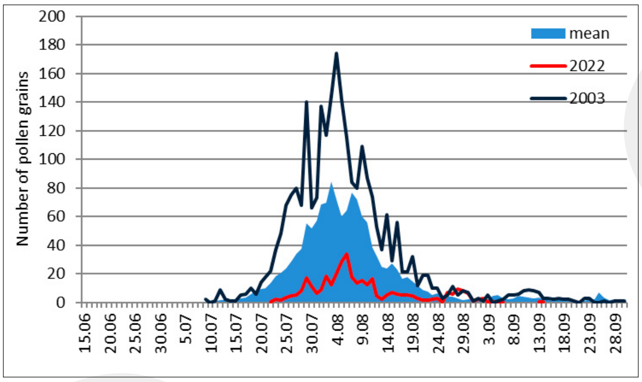

Figure 1. Daily pollen concentrations of *Artemisia* in years with the highest (2003) and lowest (2022) annual pollen sum, compared with the mean of 22 years

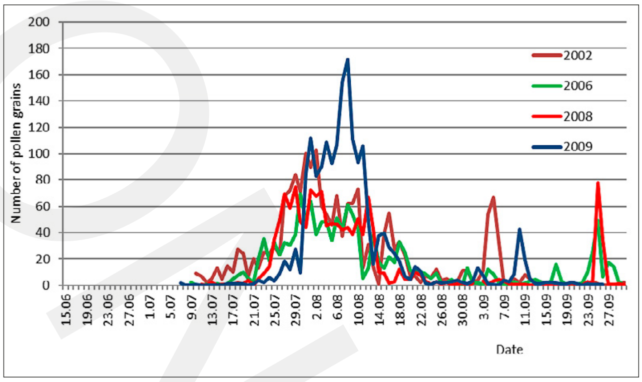

Figure 2. Course of *Artemisia* pollen seasons in years with high pollen concentrations recorded in September

The mugwort pollen season lasted, on average, over two months (Tab. 1) and was the shortest in 2022 (44 days) and the longest in 2002 (90 days). Statistical analysis showed the strongest positive correlation between the end date and the season duration. A statistically significant negative correlation was also found between the start date and the duration of the season (Tab. 2), which indicates that an earlier beginning of the season is associated with its longer duration. The duration of the *Artemisia* season showed no significant trend in the 22-year study period.

Table 1. Statistics of the *Artemisia* pollen season parameters in Lublin in 2001–2022

Statistics	Pollen season (98%)		Duration	Peak		Pollen
	Start	End	(days)	P/m³	Date	sum
Mean	17.07	24.09	69.2	121.5	7.08	1442.6
Min	8.07 *(2018)*	6.09 *(2022)*	44 *(2022)*	34 *(2022)*	30.07 *(2006)*	356 *(2022)*
Max	24.07 *(2022)*	12.10 *(2005)*	90 *(2002)*	268 *(2012)*	25.09 *(2008)*	2533 *(2003)*
SD	4.4	9.1	11.2	59.7	11.3	532.4
V (%)	2.2	3.4	16.3	49.1	5.2	36.9

Table 2. Significant Spearman's correlations between the parameters of the *Artemisia* pollen season in Lublin (2001–2022)

Parameters of pollen season	Spearman coefficient
Start & peak date	0.5697
Start & duration	-0.5566
End & duration	0.9247
Peak value & total pollen sum	0.8193
Peak value & pollen sum in VII	0.8554
Total pollen sum & pollen sum in VII	0.6228
Total pollen sum & pollen sum in VIII	0.8972

Level of significance <0.01

In many years, the course of the *Artemisia* season in Lublin was characterised by the presence of two peaks, i.e. it was bimodal (Fig. 2). In addition to the first peak noted in the first ten days of August, the second peak was recorded on various dates in September. The additional peak was related to the maximum pollen release by species flowering in September.

The highest concentrations of *Artemisia* pollen were recorded between 30 July – 8 August, except for 2008, when the season peak was recorded on 25 September (Fig. 2). In 2008, the maximum daily pollen concentration in the air was 78 P/m³, which was slightly higher than the daily pollen concentration recorded between 27 July 27 – 3 August, which ranged from 70–75 P/m³ for four days. The highest maximum pollen concentration was recorded in 2012 and was almost 8-fold higher than the lowest pollen concentration noted in 2022. The highest variability of the pollen season parameters was exhibited by the peak value (V=49.1%), whereas the season peak date was characterised by relatively low variability (V = 5.2%). After exclusion of the outlier year 2008, this value declined to 1.3%. The pollen grain sums recorded in the individual pollen seasons in Lublin were less variable than the peak value (Tab. 1). The lowest amount of pollen grains was recorded in 2022, and the largest concentration (approximately 7-fold higher) was noted in 2003. Comparison of the mean annual sums during the first 11 years of the study (2001–2011) and the subsequent 11 years (2012–2022) indicated a 34% decrease in this value in the latter period, with 1,142 pollen grains versus 1,730 in the former period. Additionally, a significant downward trend ($b=-66.24$, $p<0.01$) in the annual total sum was demonstrated in the 22-year period, with a 65% decrease in the amount of pollen calculated on the basis of the trend line (Fig. 3). There was no significant deviation of the distribution of regression model residuals from the normal distribution (Shapiro-Wilk $W=0.94$; $p=0.24$)

A statistically significant positive correlation was found between the beginning of the season and the date of its peak. The maximum values and the total pollen sums were strongly positively correlated (Tab. 2). The 2022 season was specific, as it was the shortest, started the latest, ended the earliest, and was characterised by the lowest peak and pollen sum values (Tab. 2).

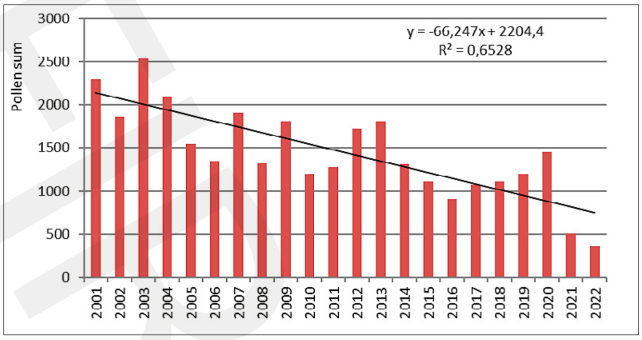

Figure 3. Comparison of annual *Artemisia* pollen sums in Lublin in 2001–2022 and the trend line

In most of the years (except 2008), the mean number of pollen season days in the pre-peak period was substantially lower than in the post-peak period. The highest pollen concentration was recorded between the 12th and 26th day of the season, i.e. on average, at day 18 after the beginning. The period between the peak date and the end of the season lasted 51 days, on average.

The greatest amounts of airborne pollen grains were recorded in August (mean: 966) and in July (almost 2.5-fold less than in August), whereas, on average, 72 and 12 pollen grains were recorded in September and October, respectively (Fig. 4). In seven different years, the pollen sums were higher in September than the mean value for that month (>72 grains). In the other years, from 11–65 pollen grains were recorded in September.

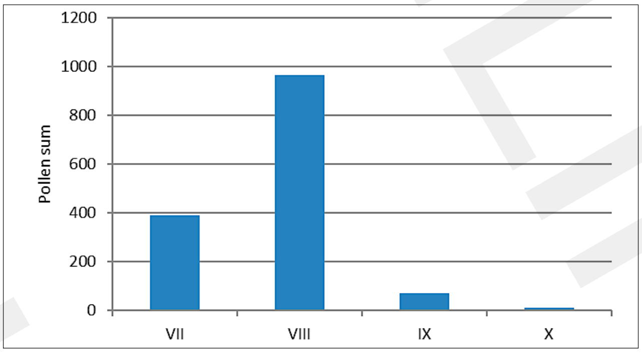

Figure 4. Mean sums of *Artemisia* pollen grains in the individual months of the pollen season

To visualise the data, the mugwort pollen seasons were compared using PCA analysis.

The newly-determined PC1 variable was strongly positively correlated with the peak value and with the pollen sum; therefore, it is interpreted as the abundance of the pollen season. The second variable (PC2) exhibited the strongest positive correlation with the peak date and a weaker correlation with the start parameter. Variable PC3 was strongly negatively correlated with the end of the season and less strongly but positively correlated with the start parameter (Tab. 3). The new variables explain over 85% of the variability of the entire system.

Table 3. Factor loadings after VARIMAX rotation. Correlations above 0.7 are marked in red. Correlations between 0.5–0.7 are marked in blue

Variable	PC1	PC2	PC3
Start	0.23	0.60	0.58
End	0.07	0.07	-0.93
Peak value	0.94	-0.03	0.10
Peak date	-0.10	0.93	-0.09
Pollen sum	0.93	0.01	-0.08

Based on the PC1-PC2 plot, it can be concluded that there is a very high variability of pollen abundance in the mugwort pollen seasons. 2021 and 2022 were the least abundant seasons, while 2001, 2003, 2004, and 2012 were characterised by high abundance. Special attention should be paid to 2008, which is located extremely high in the plot and is characterised by a late peak. Simultaneously, this season was less abundant (Fig. 5).

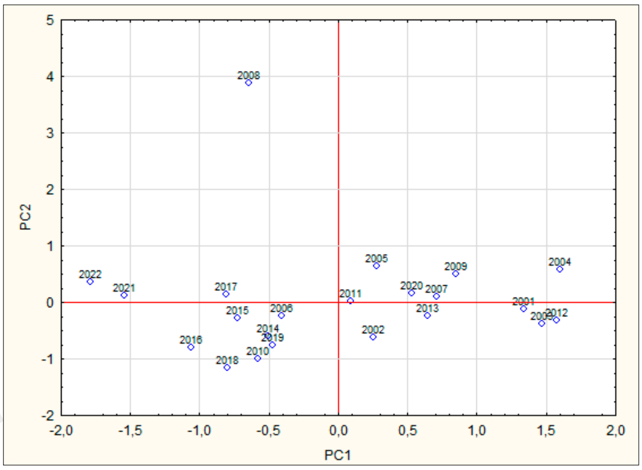

Figure 5. Factor scores of seasons 2001–2022 in the PC1-PC2 coordinate system

The PC1-PC3 plot provides additional information. It shows that the pollen season in 2022 was not only not highly abundant, but also ended early. The seasons 2002 and 2005, located at the lowest position along the PC3 axis, were characterised by the latest end of the season (Fig. 6).

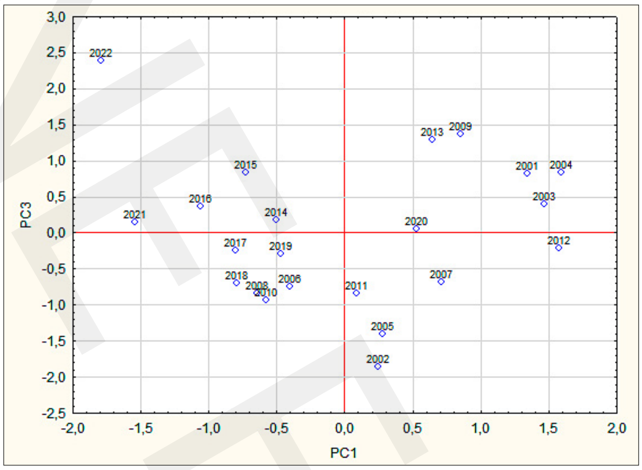

Figure 6. Factor scores of seasons 2001–2022 in the PC1-PC3 coordinate system

Impact of meteorological factors on parameters of mugwort pollen seasons. Analysis of Spearman's rank correlations between the season parameters and the meteorological factors revealed the greatest impact of temperature on the mugwort pollen seasons, as indicated by the highest correlation coefficients (Tab. 4). The beginning of the mugwort pollen season was correlated with the temperature in April and May, as the higher temperatures in these months promoted an earlier start of the season. The high temperature in June and July and the intense sunshine in June resulted in lower peak values, total pollen sum, and pollen sum in August (negative correlation). In turn, the cloud cover in June and humidity in June contributed to the greater abundance of the pollen seasons (positive correlation). The peak date depended mainly on the weather conditions in July, as the high temperature accelerated the peak date, and the rainfall delayed the peak. The pollen sum in July was positively correlated with the temperature in April and May, and negatively correlated with the temperature in June. A positive relationship was found between the pollen sum in September and the minimum temperature in April.

Table 4. Significant Spearman's correlations between pollen season parameters and meteorological factors in Lublin (2001–2022)

Season parameter vs. meteorological factor	Spearman's coefficient
Dependent variable: season start	
mean daily maximum temperature in V	-0.459491*
mean daily minimum temperature in V	-0.792899**
highest daily average temperature in IV	-0.444831*
Dependent variable: duration	
mean daily minimum temperature in V	0.428814*
Dependent variable: peak value	
mean daily average temperature in VI	-0.524322**
mean daily average temperature in VII	-0.655747**
mean daily maximum temperature in VI	-0.436847*
highest daily average temperature in VI	-0.592593**
cloud cover in VI	0.640786**
sunshine in VI	-0.702993**
humidity in VI	0.485739*
rainfall in VI	0.558442**
Dependent variable: peak date	
mean daily average temperature in VII	-0.532519**
mean daily maximum temperature in VII	-0.564356**
mean daily minimum temperature in V	-0.439102*
mean daily minimum temperature in VII	-0.443507*
rainfall in VII	0.457260*
Dependent variable: total pollen sum	
mean daily average temperature in VI	-0.544118**
mean daily average temperature in VII	-0.556905**
mean daily maximum temperature in VI	-0.584911**
highest daily average temperature in VI	-0.754878**
highest daily minimum temperature in VI	-0.553516**
cloud cover in VI	0.478705*
sunshine in VI	-0.565217**
humidity in VI	0.423044*
Dependent variable: pollen sum in VII	
mean daily maximum temperature in V	0.493785*
mean daily minimum temperature in V	0.768231**
highest daily average temperature in IV	0.528398**
highest daily average temperature in VI	-0.489116*
highest daily minimum temperature in V	0.430552*
Dependent variable: pollen sum in VIII	
mean daily average temperature in VI	-0.633485**
mean daily average temperature in VII	-0.704321**
mean daily maximum temperature in VI	-0.583216**
highest daily average temperature in VI	-0.692678**
highest daily minimum temperature in VI	-0.513414*
cloud cover in VI	0.540522*
sunshine in VI	-0.604743**
humidity in VI	0.436035*
Dependent variable: pollen sum in IX	
mean daily minimum temperature in IV	0.452798*

Level of significance * 0.05; ** 0.01

The regression results showed a significant increase in temperature in June during the analysed years (Fig. 7). 2019, with an average June temperature of 22.7 °C, was a specific year, and this observation was excluded by the analysis of residuals as an outlier. A significantly increasing linear trend was found ($b=0.123$; $p=0.012$) for the other years. There was no significant deviation of the distribution of regression model residuals from the normal distribution (Shapiro-Wilk $W=0.96$; $p=0.49$).

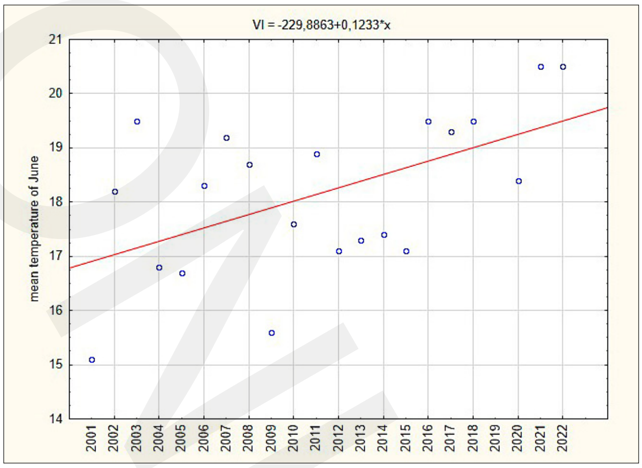

Figure 7. Scatterplot of the temperature in June during the study period, together with the plot of the linear trend

Due to the small amount of data required for a multivariate analysis, predictors with coefficients that were not statistically significantly different from zero were omitted in the construction of the regression model. This was intended to limit the number of predictors in the model and avoid over-parameterization of the model. This resulted in a lower degree of fit of the model to the data. Therefore, a satisfactory regression model was obtained only in the case of the pollen sum in August. The dependence of this parameter on meteorological factors can be described by the following equation:

$$y=7065.827-130.294x_1-184.078x_2$$

x_1 – mean temperature in June
x_2 – mean temperature in July

Regression analysis showed that the pollen abundance in August was influenced primarily by the mean temperature in June and July. The corrected coefficient of determination for the regression equation was almost 0.6. The model explains approximately 60% of the variability in pollen sums in August. The curves showing values predicted from the regression equation and observed values indicate a clear fit (Fig. 8).

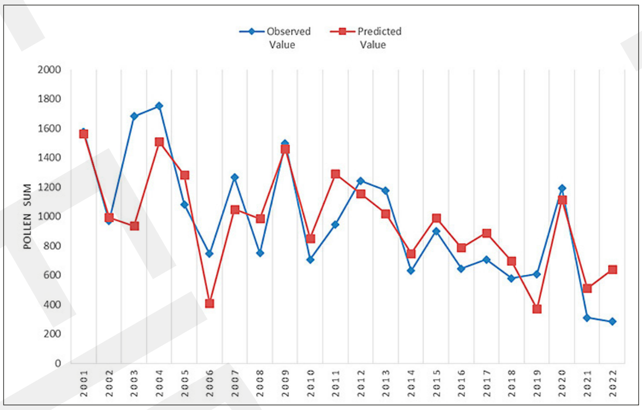

Figure 8. *Artemisia* pollen sums in August; observed and predicted values calculated in the regression model

The assumptions of the distribution of model residuals were checked. The Shapiro-Wilk test indicated no grounds for rejecting the null hypothesis of the normal distribution (p=0.08). The assumption that the residuals have a distribution close to normal confirmed that a reliable description was obtained of the relationship between the mean temperature in the months preceding pollen release, and the abundance of pollen released in August.

DISCUSSION

The *Artemisia* pollen seasons in Lublin in 2001–2022 were characterised by a high variability of the peak value (v=49.1%) and the annual total sum (v=36.9%). Even greater variability in these season parameters was observed in Poznań in 1996–2011, where the variability of the peak value was v=75.9% and SPI v=56.9% [46].

The annual pollen sums in Lublin in the analysed years (2001–2022) ranged from 356–2533. The lowest values were recorded in the last two years. In turn, many previous comparative studies conducted in Poland have demonstrated the highest annual pollen sums in this city located in the central-eastern part of the country. Analyses of 5-year (2001–2005) mean sums of *Artemisia* pollen grains performed in eight cities indicated the highest value recorded in Lublin (2065), while the sums in the other cities were in the range of 622–1,756 [47]. Similarly, research conducted in 12 and 11 cities in Poland in 2018 and 2019, respectively, indicated that the highest pollen sums of 1,085 and 1,193, respectively, were recorded in Lublin. The values noted in the other cities were 296–1,055 in 2018 and 509–1,077 in 2019 [48, 49]. In 2020, compared to other regions in Poland, the highest number of *Artemisia* pollen grains was recorded in Lublin, where the highest number of days with concentrations above the threshold value was also recorded. This indicates the highest risk of development of *Artemisia* pollen allergy symptoms in this city [50]. These large differences were probably related to the biogeographical conditions, the variable occurrence of *Artemisia* species throughout the country, and differences in land use.

In 2022, the *Artemisia* pollen season in Lublin was characterised not only by the lowest annual pollen sum, but also by the lowest peak value and the shortest duration. However, statistical analyses did not indicate a significant downward trend in the duration of the *Artemisia* pollen season in the 22-year period. In turn in Poznań in 1996–2011, it was reported by other researchers that the pollen season of this taxon was extended, which was associated with the delay in the season end date [46]. Similarly, an increase in the length of the *Artemisia* pollen season was recorded between 1980–2015 in Belgium [51].

The present study has demonstrated a significant downward trend in the *Artemisia* annual pollen sums recorded in Lublin in 2001–2022. This is probably attributable to global warming, as indicated by the authors' data on the increase in the temperature in June in 2001–2022, and by research results reported by other authors. Kaszewski and Bilik [52] found that the mean air temperature in Lublin in 1981–2010 was 8.7 °C – 0.8 °C higher than the mean temperature in 1951–1980. Similarly, Sachindra et al. [53] provided evidence of climate warming in Lublin, as it was found that the maximum temperature in summer in 1998–2020 increased by 0.083 °C/year, compared to the temperature recorded in 1974–1997. As shown by these authors, the temperature also increased in the other seasons. Moreover, an increase in the number of heat waves in Lublin was reported by Sachindra et al. [53]. An 11-year study conducted in Northern Italy showed a significantly lower downward trend in the seasonal pollen index (SPI) and peak values of *Artemisia* pollen grains [54]. Similar results of pollen monitoring were obtained in the Benelux countries [55], Bavaria (Germany) [8], and Slovakia [56].

The present study indicates the greatest impact of the temperature on *Artemisia* pollen seasons of all the meteorological factors. The beginning of the pollen season was significantly correlated with the temperature in April and May, with higher temperatures accelerating the beginning of the season. In turn, other researchers found that the start of *Artemisia* pollen seasons were largely dependent on the temperature in June and July [57].

The impact of meteorological factors in the months preceding the pollen season start is of great important for the production of *Artemisia* pollen. The current study demonstrated a strong influence of the mean temperature in June and July on the abundance of pollen released in August. The high temperatures in June and July and the intense sunshine in June resulted in lower peak values, as well as the total pollen and pollen sum values in Lublin in 2001–2022. In turn, the cloud cover and humidity recorded in June contributed to a greater abundance of pollen during the season.

Other authors have demonstrated a positive impact of intensive rainfall before *Artemisia* flowering on pollen production [46, 57]. Similar results to those presented for Lublin and showing that high summer temperatures delay *Artemisia* flowering, were obtained in 13 different locations of Central and Eastern Europe [57]. A significant positive impact of maximum relative humidity and rainfall, and a negative impact of radiation and maximum temperatures on the *Artemisia* pollen concentration, were reported from Belgium [51]. In China, relative humidity, rainfall, and minimum daily temperatures were the most essential factors exerting a positive effect on daily *Artemisia* pollen concentrations [58].

The most common species of the genus *Artemisia* in Lublin and its surroundings is *A. vulgaris*, whose pollen probably dominates in the air during the pollen season of this taxon. The positive effect of lower temperatures, cloud cover, and humidity on the abundance of pollen produced by the flowers of this species can be explained by its environmental preferences. In contrast to other species of this genus, *A. vulgaris* prefers moist localities rather than dry and intensely sunlit areas [20]. The downward trend in the *Artemisia* annual pollen sum may also be related to the lower rainfall rates caused by climate change. Rainfall deficits in June and July were demonstrated in the Lublin area already in 1951–2000 [59]. In 1981–2010, the area of arid regions in Poland increased to 30% *versus* only 5% in 1971–2000 [60]. Data in the current study show that the increasing temperatures and lower rainfalls contributed to a significant reduction in the *Artemisia* annual pollen sum.

The *Artemisia* pollen season in Lublin started, on average, in the second ten days of July and lasted until the third ten days of September. As indicated by pollen monitoring carried out in 20 European countries, pollen of *Artemisia* plants and other Asteraceae representatives was recorded in the atmosphere at the same time of the year [61]. Similar dates of the pollen seasons of this taxon were recorded in Italy (August-September) [62] and China (July-September) [58]. The course of the season in Lublin was characterised by two peaks. The first peak, usually reaching higher values, was most often recorded in the first ten days of August and was probably associated with pollen production by *A. vulgaris*. Similarly, the *Artemisia* pollen peak concentration was reported in the first week of August in Ukraine [63]. The second peak was noted in Lublin in September and may have been related to the pollen release by *A. annua*, which blooms at the end of summer [62]. At that time, the pollen found in the preparations had a smaller size. As reported by Beug [25] and Cristofori et al. [62], *A. annua* pollen is smaller than that of other *Artemisia* species. Analysis of the map of *A. annua* occurrence in Poland shows that this is the most abundant *Artemisia* species in the Lublin region [19]. *A. annua* has the status of a kenophyte in Poland and an epecophyte in the Lublin region [20].

Grewling et al. [64] recorded a bimodal *Artemisia* pollen season in the Morasko suburb of Poznań in central Poland, and suggested that the second peak occurring in the late pollen season was associated with *A. campestris* pollen. Two peaks in the *Artemisia* pollen season have also been observed in Northern Italy in recent years [62]. Analyses of the morphology of pollen grains carried out by these authors revealed that the second peak was associated with pollen release by *A. annua* and *A. verlotiorum*, which are invasive plants in Italy.

The results of the present study confirm the negative impact of global warming on the intensity of *Artemisia* pollen seasons, which was also reported by other authors [30, 46, 54–57]. Previously, a downward trend in annual airborne pollen sums caused by an increase in summer temperature was also exhibited by weeds. This was reported, e.g. in grasses (Poaceae) [65] and Amaranthaceae plants [66], which produce allergenic pollen.

CONCLUSIONS

This study presents a detailed description and analysis of mugwort pollen seasons in 2001–2022. A simple comparison of parameter values between the individual seasons is shown in graphs facilitating the identification of seasons with outstanding values. Additionally, the following conclusions have been formulated based on the results:

- The higher temperatures in April and May resulted in an earlier start of the *Artemisia* pollen season.
- The intense sunshine in June and the higher temperatures in June and July reduced the intensity of the mugwort pollen seasons. The annual pollen sum decreased by 65% over 22 years.
- The highest concentrations of mugwort pollen were recorded in August and were largely dependent on the mean temperature in June and July.
- The downward trend in the annual pollen sum demonstrated in the 22-year study of the concentration of *Artemisia* pollen in the air of Lublin is associated with global warming, accompanied by lower rainfall rates. Since *A. vulgaris*, i.e. the most common species in Poland, requires a moist substrate for optimal flowering, environmental changes have a negative impact on the airborne concentration of pollen of this taxon recorded in the present study.
- The second late peak of the bimodal *Artemisia* pollen season noted in September is probably associated with the presence of pollen of *A. annua* flowering during this period.

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