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Article

The Impact of Climate Change on the Spread of Airborne Pollen in Northern Italy - The Results Of 27 Years of Monitoring in Parma

Roberto Albertini [1,2,*], Alessia Coluccia [1], Mostafa Mohieldin Mahgoub Ibrahim [1], Maria Eugenia Colucci [1], Roberta Zoni [1], Paola Affanni [1], Licia Veronesi [1] and Cesira Pasquarella [1]

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Abstract: Pollen grains play an important role in the etiopathogenesis of seasonal respiratory allergies, which are increasing in prevalence and severity worldwide. Climate change is one of the possible explanations for the increase of pollen allergies enabling plants to produce more allergenic pollen, in larger quantities and longer periods. Pollen count data can be considered the proxy for aeroallergen exposure and long pollen data sets allow to investigate the trends in seasonal characteristics over time. This study examines temporal variations in seasonality and load of airborne pollen and meteorological data recorded over 27 years in Parma (Italy). The study was performed collecting pollen by a Hirst spore trap considering the following taxa: *Betula, Corylus*, Cupressaceae-Taxaceae, *Platanus*, *Ambrosia*, Poaceae, Total pollen and *Alternaria* fungal spores. Start and end date, duration, date of peak, peak value, and Seasonal Pollen Integral (SPIn) were examined. Temporal variations in pollen seasons were displayed as the number of days from January 1 (DOY, day of the year). Daily averages temperature, relative humidity and total rainfall were considered. Linear regression analysis was carried out to investigate trends in data over time. The start date turned precocious for *Corylus* and Poaceae, but late for *Betula*. The end date was postponed for Poaceae and Total pollen, as well the duration of pollen seasons was longer for Poaceae and Total pollen, the duration became shorter for *Betula*. The peak date was anticipated for Poaceae, and the peak values were reduced for Poaceae and Total pollen. A weak positive trend was observed for SPIn of Corylus. Regarding *Ambrosia,* the duration was shorter, and the peak date was postponed. No significant differences were observed for *Platanus* and *Alternaria* spores. A significant decrease in the relative humidity and a significant increase of annual average temperature were observed. The results of our study represent a contribution to better understanding the impact on human health of environmentally changing conditions. Moreover, it should be considered that not only the seasonal respiratory allergies may be related to the variation of climate and its impact on pollen load and pollen season, but also it could be related to chronic respiratory disease and cardiovascular diseases. This highlights gaps in current knowledge and the need to quantify the impact of climate change in a One Health perspective to provide useful information to determine exposure of the allergic population to pollen and to plan public health preventive measures.

Keywords: Climate change; Pollen; Fungal spores; Season parameters; Seasonal respiratory allergies

1. Introduction

Pollen grains play an important role in the etiopathogenesis of seasonal respiratory allergies releasing the allergens they contain. The seasonal allergies are increasing in prevalence and severity worldwide [1]. Pollen allergy adversely affects the quality of life generating a substantial burden for social life, work, and school performance of several million people globally [2–7]. Nonetheless, pollen

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allergy symptoms are often trivialized and consequently sufferers frequently refrain from seeking proper treatment [8]. Climate change, altering the pollen concentrations and seasonality, influences the development of rhinitis, asthma symptoms in adults and children [9–11]. Climate change increases the concern about the relationship with pollen production. Warmer springs and autumns can cause some plants to produce pollen earlier or to extend the pollen season. An earlier start and peak of the pollen season is more pronounced in species that start flowering early in the year. Pollen-related allergies are expected to increase due to the lengthening and intensification of the pollen seasons associated with climate change [12–16]. Plants flower earlier in urban areas than in the corresponding rural areas approximately 2 to 4 days [17]. Atmospheric conditions can affect the release of anemophilous pollen, and the timing and magnitude will be altered by climate change. Present-day knowledge on the relationship between allergic respiratory diseases, asthma and environmental factors, such as meteorological variables, airborne allergens and air pollution, is taken from epidemiological studies. A 23-year observation study on Pinaceae pollen distribution showed a correlation of pollen with high temperatures during summer before the onset of the local Pinaceae flowering season [18]. As simulated with a pollen emission model and future climate data, warmer end-of-century temperatures shift the start of spring emissions 10–40 days earlier and summer/fall weeds and grasses 5–15 days later and lengthen the season duration. Phenological shifts depend on the temperature response of individual taxa, with convergence in some regions and divergence in others. Temperature and precipitation alter daily pollen emission maxima by −35 to 40% and increase the annual total pollen emission by 16–40% due to changes in phenology and temperature-driven pollen production [19]. The increased CO_2 concentrations also enable plants to produce more allergenic pollen, in larger quantities [20–23]. Production of allergenic pollen by ragweed (*Ambrosia artemisiifolia* L.) has increased in CO_2-enriched atmospheres [24]. Seven years study of increase CO_2 levels from 560 ppm to 720 ppm enhanced the production of oak pollen to 353% and 1,299%, respectively compared with ambient level [25]. As a result, it can be estimated that the increase in atmospheric CO_2 could strongly increase pollen production in conjunction with climate-altering emissions by the end of the century. Land cover change modifies the distribution of pollen emitters, yet the effects are relatively small (<10%) compared to climate or CO_2. These simulations indicate that increasing pollen and longer seasons could increase the likelihood of seasonal allergies [19]. Moreover, various studies have shown that aeroallergens can become chemically modified by pollutants and enhance allergic symptoms [20,26,27]. Climate change together with exposure to chemical air pollutants has been shown to have alarming consequences for human health and increase asthma exacerbations. Increasing atmospheric ozone is associated with an acute decrease in lung function, an increase in airway responsiveness, inflammation and systemic oxidative stress [24,28]; the number of birch catkins is influenced positively by the increase of preceding summer temperatures and negatively by the increase of O_3 [29]. Moreover, the meteorological conditions can cause the transport of pollen over long distances, depending on the pollen type and the area. Long distance transport of *Ambrosia* pollen is well documented [30,31]. It was reported that wind direction and speed, temperature, relative humidity, precipitation, air pressure and solar radiation as well as micro and macro-topography within the area can influence *Betula* pollen dispersion [32,33]. Asthma related to thunderstorms is one of the phenomena related to climate change. Thunderstorms that occur during the pollen season can induce severe asthma attacks and deaths in pollen allergic patients [10,34,35]. Asthma exacerbations and asthma epidemics related to thunderstorms have been described in several cities, mainly in Europe (Birmingham and London in the UK and Naples in Italy) and Australia (Melbourne) [36].

Some studies about airborne pollen season were carried out in Italy analysing long-term variations in airborne pollen seasons [37,38]. Other studies focused on a limit number of pollen families [39–42], while other studies examining pollen data in the Po Valley geo-climatic area in Northern Italy were over limited time periods [43–48]. This study aims at evaluating the impact that changes in some climatic parameters can have on quantity of pollen and fungal spores released into the atmosphere and their seasonality and, consequently, on human health regarding seasonal

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respiratory allergies examining a data series over 27 years (from 1997 until 2023) in the city of Parma, Northern Italy.

2. Materials and Methods

2.1. Location of the Study

This study was performed in the city of Parma (180,000 inhabitants) which lies in the Po Valley, close to the Southern bank of the Po River (Figure 1), 100 km from the Tyrrhenian coast and 200 km from the Adriatic coast, a humid subtropical climate area [49].

Figure 1. Map of Italy highlighting the city of Parma's position.

2.2. Aerobiological Data

The pollen grains were collected by a Hirst spore trap [50], placed at 18.2 m above ground level (latitude 44°48′N, longitude 10°16′E), 52 m a.s.l.

We used the rules of Italian Association of Aerobiology that in 2004 became UNI 11108:2004 [51] and afterwards EN 16868:2019 [52]. Pollen data collected over a 27-year period, from 1997 until 2023 were analysed. The following taxa were taken into consideration: *Betula*, *Corylus*, Cupressaceae-Taxaceae (hereinafter Cupressaceae), *Platanus*, *Ambrosia*, Poaceae, Total pollen and the fungal spores of *Alternaria* sp. The following characteristics of the pollen season were examined start date, end date, duration, date of peak, peak value and Seasonal Pollen Integral (SPIn) [53–55].

2.3. Meteorological Data

Daily averages of mean, minimum and maximum temperature (°C), relative humidity (%) and total rainfall (mm) transformed into annual or seasonal averages were taken into consideration. The meteorological data were obtained from the Meteorological Station (Physics Department) of the University of Parma located at the same site that the pollen data were recorded. The missing data were obtained from the OGIMET database.

2.4. Statistical Analysis

Kolmogorov–Smirnov and Shapiro-Wilk tests were used to assess the type of distribution of pollen and fungal spore's parameters. Following the methodology used in some prominent studies looking at long-term trends in pollen seasons **[56–58]**, simple linear regression analysis was carried out in order to investigate trends of selected meteorological data: a) average of relative humidity (%),

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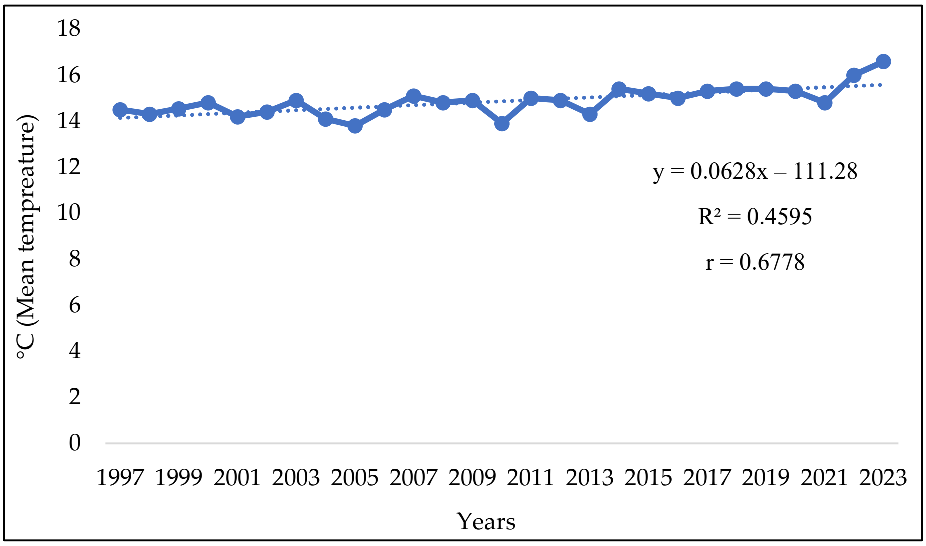
b) annual total rainfall (mm), c) and annual and seasonal temperatures. The following statistics were taken into consideration: the mean, standard deviation (SD), R^2 value, slope of the regression over time, standard error of the regression slope (SE), probability level (p) and number of years in the analysis (N). Spearman's ''q'' correlation test was used to establish any significant relationship existed between the different characteristics of the pollen and fungal spores seasons examined [59]: (a) start date/end date; (b) start date/duration; (c) start date/peak value; (d) start date/SPIn; (e) start date/date of peak; (f) end date/duration; (g) end date/peak value; (h) end date/SPIn; (i) end date/date of peak; (j) duration/SPIn; (k) duration/peak value; (l) duration/date of peak; (m) SPIn/date of peak; (n) SPIn/peak value; and (o) peak value/date of peak. Results were P-value <0.05 was considered statistically significant. Statistical analysis was performed using Microsoft Excel and IBM SPSS 28 software.

3. Results

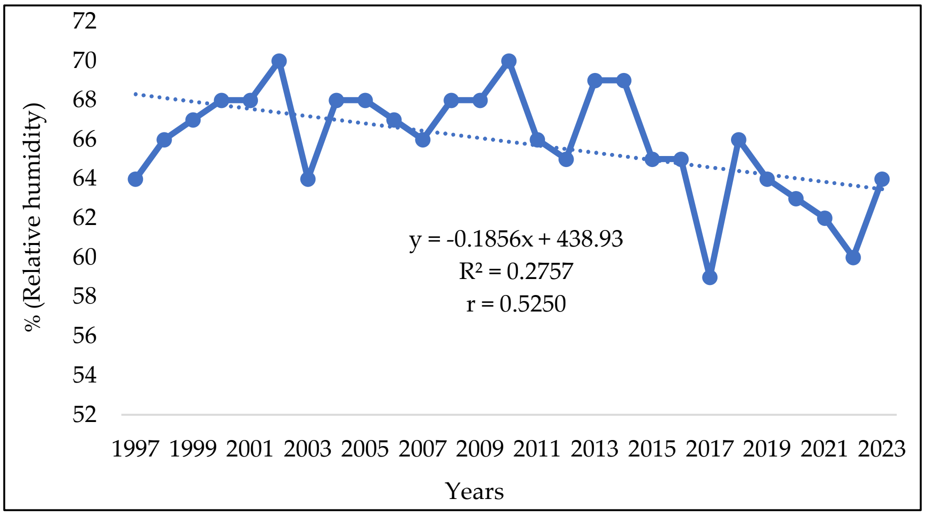
3.1. Analysis of the Meteorologic Parameters over 27 Years

Means of annual meteorological data recorded during the study period were summarized as follows (minimum and maximum values shown in parenthesis): temperature 14.9 °C (13.8–16.6 °C), relative humidity 66.0 % (59–70 %) and rainfall 776.1 mm (535.7–1113 mm), (Figure 2 a, b, c). A significant increase in the mean temperature ($p = 0.001$, $r = 0.6778$) and a significant decrease of the RH ($p = 0.005$, $r = 0.5250$) were observed (Figure 2a and 2b, respectively).

a)



b)



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c)

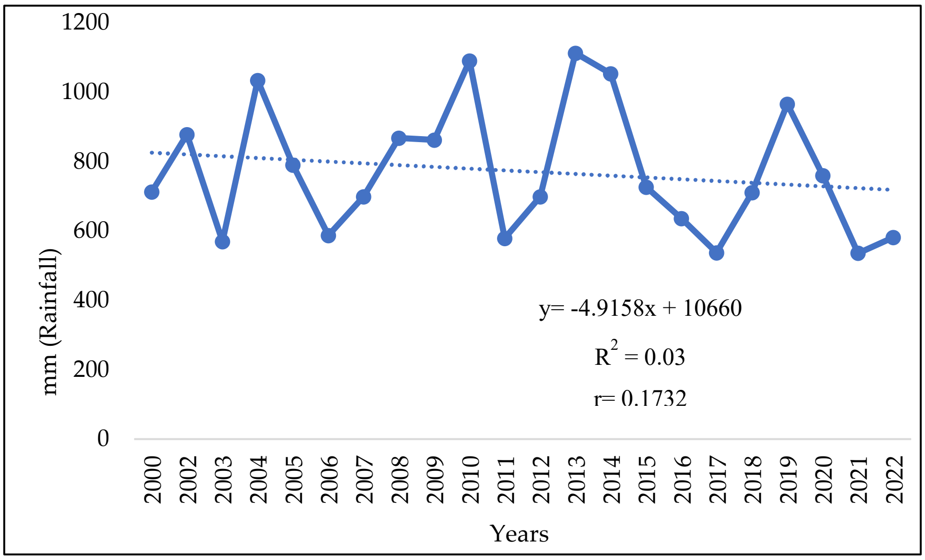
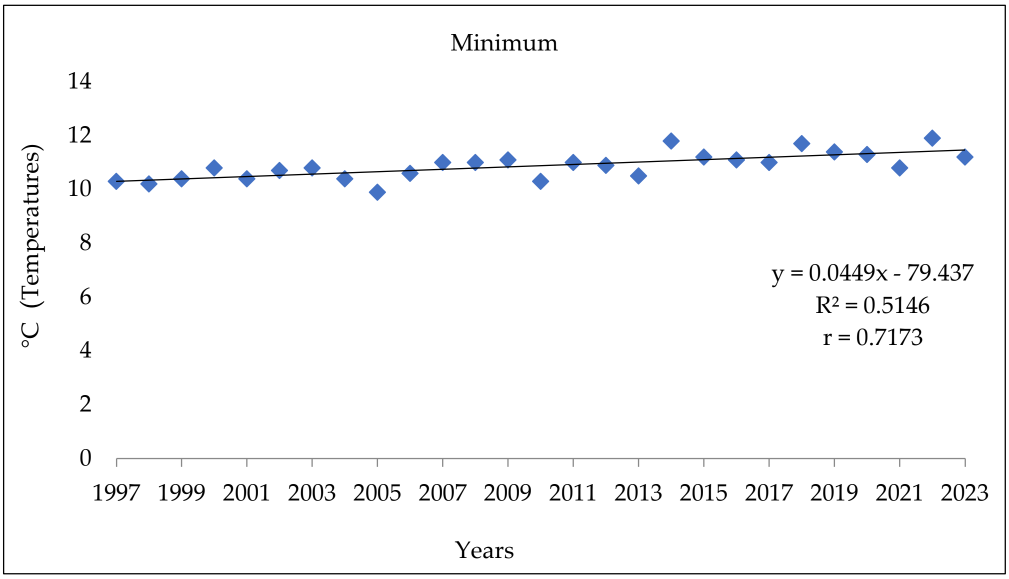


Figure 2. Annual average of mean temperatures (a), relative humidity (b) and total rainfall (c) recorded in Parma from 1997 to 2023 (for rainfall until 2022). Also, minimum (Figure 3a) ($p = 0.001$, $r = 0.7173$) and maximum (Figure 3b) ($p = 0.006$, $r = 0.5183$) temperatures significantly increased over the study period.

a)



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b)

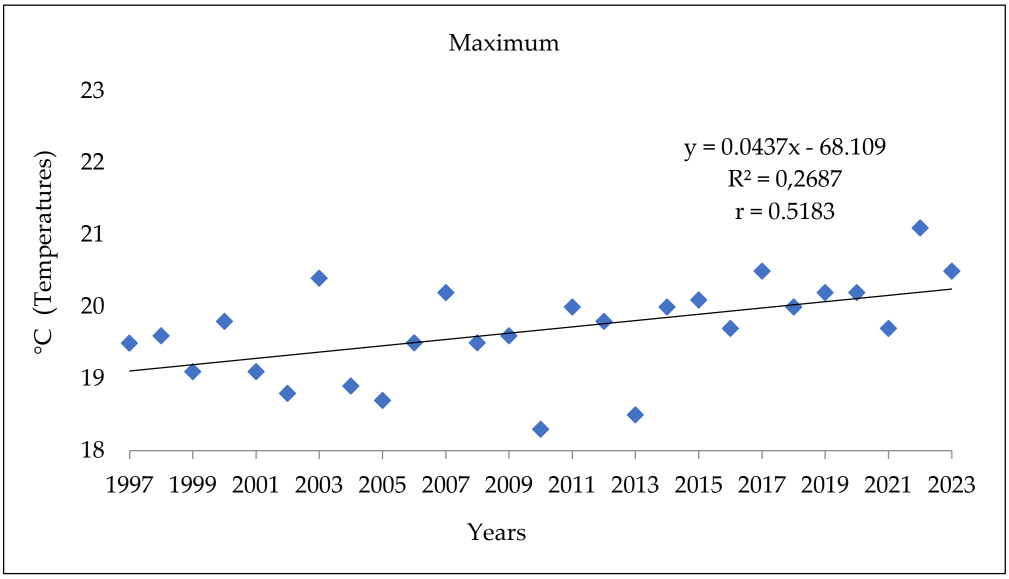

Figure 3. Minimum and maximum temperature recorded in Parma from 1997 to 2023.

Seasonal mean temperature and precipitation were analysed (Figures 4 and 5). Precipitation data were obtained from 2003 to 2022 due to lack of data.

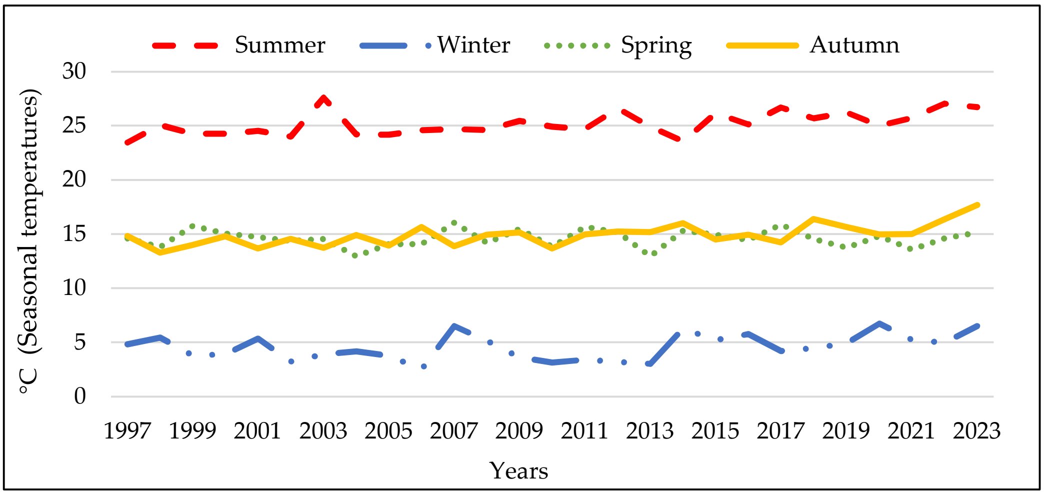

Figure 4. The mean of the seasonal temperatures recorded in Parma during from 1997 to 2023.

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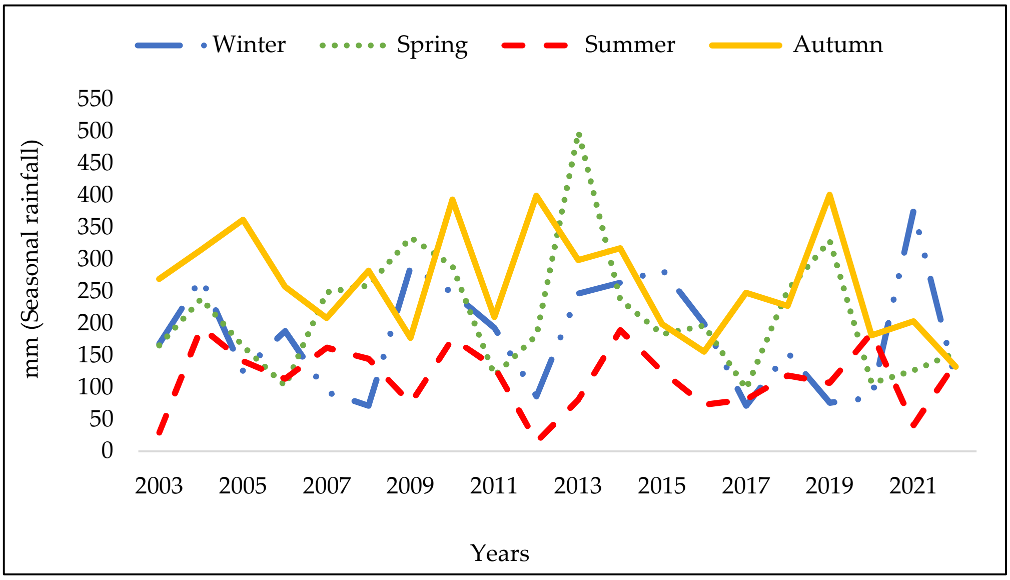
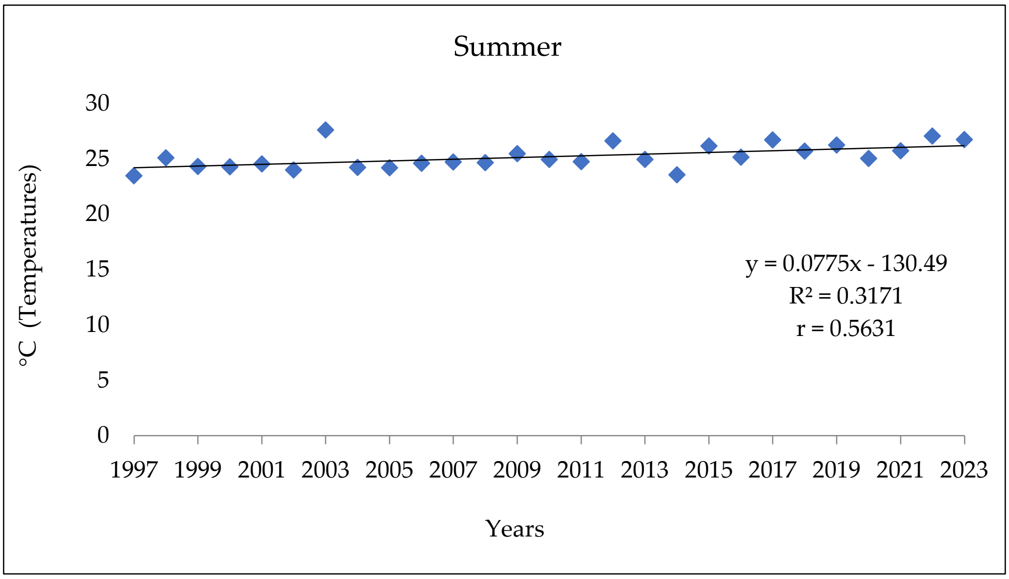


Figure 5. The mean of seasonal rainfall recorded in Parma from 2003 to 2022.

It was observed a significant increase of mean temperature for Summer (p = 0.002, r = 0.5631) and Autumn (p = 0.001, r = 0.647) during the period 1997-2023, (Figure 6a,b).

a)



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b)

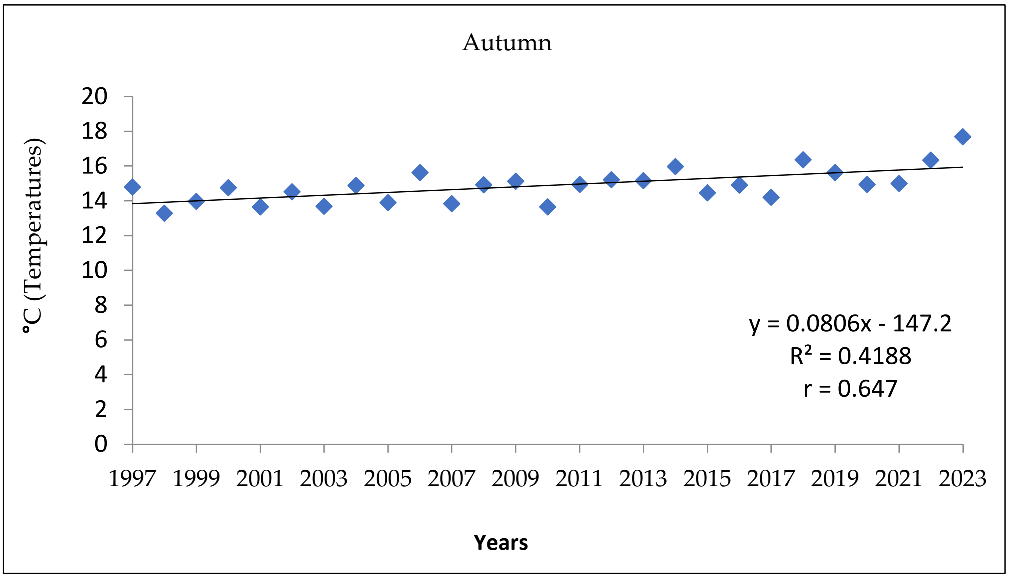

Figure 6. The mean temperatures of summer (a) and of autumn (b) seasons during the period 1997-2023.

3.2. Characteristics and Trends of Pollen Seasons over 27 Years

The analysis of data from 27 years of observations shows that, on average, the earliest pollen grains that appear in the air of Parma were arboreal taxa as *Corylus* (DOY 28), Cupressaceae (DOY 42), *Betula* (DOY 82) and *Platanus* (DOY 91). On the contrary the pollen grains that appeared later were herbaceous as Poaceae (DOY 109) and *Ambrosia* (DOY 219), Table 2a. Similarly, the pollen seasons that ended the earliest were *Corylus* (DOY 79), *Platanus* (DOY 111), *Betula* (DOY 122) and Cupressaceae (DOY167). The pollen seasons that ended later were those of Poaceae (DOY 204) and *Ambrosia* (DOY 266). Regarding season duration, the shortest pollen seasons were those of *Platanus* (20 days), *Betula* (41 days), *Corylus* (50 days),. The longest pollen seasons were those of Poaceae (95 days) and Cupressaceae (125 days), Table 2b.

Regarding trend of the pollen season, the start date for *Corylus* ($p = 0.03$) and Poaceae ($p = 0.02$) was earlier, while start date for *Betula* ($p = 0.002$) was postponed, Table 2a. The end date was delayed for Poaceae ($p = 0.04$) and Total pollen ($p = 0.03$), Table 2c. As consequence the duration was longer for Poaceae ($p = 0.011$) and Total pollen ($p = 0.05$) and shorter for *Betula* ($p = 0.04$), Table 2b.

Table 2. Seasonal characteristics (start date, duration, end date and peak date) of selected taxa recorded in Parma from 1997 to 2023. The assessed parameters over time were Mean, Standard Deviation (SD), R^2 value, Slope of the regression, Standard Error of the regression Slope (SE), p value (p) and Number of years of data (N). In bold were highlighted the significant values.

a	**Start date (DOY)**						
Grains	**Mean**	**SD**	**R^2**	**slope**	**SE**	***p***	**N**
Ambrosia	219	19.0	0.04	0.52	3.71	0.28	26
Betula	82	19.5	0.32	1.4	3.75	**0.00**	27
Corylus	28	15.7	0.16	-0.8	3.02	**0.03**	27
Cupressaceae	42	19.9	0.04	-0.11	3.83	0.82	27
Platanus	91	9.10	0.00	0.03	1.75	0.88	27
Poaceae	109	6.59	0.19	-0.37	1.26	**0.02**	27
Total pollen	69	18.8	0.01	-0.31	3.85	0.52	24

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Alternaria	168	12.6	0.00	-0.12	2.43	0.69	27

b	Duration (Days)						
Grains	**Mean**	**SD**	**R^2**	**slope**	**SE**	***p***	**N**
Ambrosia	47	19.2	0.12	-0.87	3.7	0.07	26
Betula	41	19.6	0.16	-0.99	3.7	**0.04**	27
Corylus	50	17.3	0.09	0.66	3.33	0.12	27
Cupressaceae	125	47.8	0.04	1.30	9.2	0.27	27
Platanus	20	6.68	0.00	0.00	1.28	0.96	27
Poaceae	95	20.6	0.23	1.25	3.9	**0.01**	27
Total pollen	165	24.9	0.16	1.23	5.09	**0.05**	24
Alternaria	115	20.6	0.00	0.17	3.97	0.74	27

c	End date (DOY)						
Grains	**Mean**	**SD**	**R^2**	**slope**	**SE**	***p***	**N**
Ambrosia	266	12.9	0.04	-0.36	2.54	0.28	26
Betula	122	10.3	0.01	0.38	1.99	0.13	27
Corylus	79	13.1	0.08	-0.18	2.52	0.57	27
Cupressaceae	167	41.3	0.05	1.19	7.95	0.25	27
Platanus	111	6.5	0.00	0.02	1.26	0.88	27
Poaceae	204	18	0.14	0.88	3.47	**0.04**	27
Total pollen	234	16.9	0.19	0.92	3.45	**0.03**	24
Alternaria	283	22.3	0.00	0.04	4.29	0.93	27

d	Peak date (DOY)						
Grains	**Mean**	**SD**	**R^2**	**slope**	**SE**	**p**	**N**
Ambrosia	243	8.18	0.24	0.50	1.60	**0.01**	26
Betula	102	13.00	0.07	0.43	2.50	0.18	27
Corylus	48	17.19	0.02	-0.03	3.30	0.42	27
Cupressaceae	67	12.89	0.03	-0.3	2.48	0.34	27
Platanus	99	7.51	0.01	-0.12	1.44	0.50	27
Poaceae	120	6.02	0.34	-0.44	1.15	**0.00**	27
Total pollen	109	9.92	0.31	-0.69	2.02	**0.00**	24
Alternaria	236	27.2	0.06	-0.84	5.24	0.21	27

The peak date was postponed for *Ambrosia* (p = 0.01), and precocious for Poaceae (p = 0.001) and Total pollen (p = 0.004), Table 2d. The peak value of Poaceae decreased significantly (p = 0.02), as well the SPIn of *Corylus* increased significantly (p = 0.02), Table 3a and 3b.

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The mean peak values were *Ambrosia* (44 grains/m³), *Betula* (105 grains/m³), *Corylus* (111 grains/m³), Cupressaceae (496 grains/m³), Poaceae (651 grains/m³); *Platanus* (1083 grains/m³). The pollen types with the lowest and highest average peak date were *Corylus* (48 DOY) and Cupressaceae (67 DOY); Poaceae (120 DOY) and *Ambrosia* (243 DOY), respectively. The taxa with the lowest (308 grains) and highest (8803 grains) average SPIn were *Ambrosia* and Poaceae, respectively (Table 3a and 3b).

Table 3. Seasonal characteristics (Peak value, SPIn,) of selected pollen taxa recorded in Parma from 1997 to 2023. The assessed parameters over time were Mean, Standard Deviation (SD), R^2 value, Slope of the regression, Standard Error of the regression Slope (SE), p value (p) and Number of years (N). In bold are highlighted the significant values.

a	**Peak value (grains/m³)**						
Pollen type	**Mean**	**SD**	**R^2**	**slope**	**SE**	**p**	**N**
Ambrosia	44	29	0.02	0.62	5	0.41	26
Betula	105	85	0.00	-0.26	16	0.90	27
Corylus	111	67	0.02	1.45	13	0.39	27
Cupuressaceae	496	509	0.06	16.26	98	0.20	27
Platanus	1083	757	0.02	-15.14	146	0.42	27
Poaceae	651	277	0.21	-16.03	53	**0.02**	27
Total pollen	2883	1242	0.10	-50.57	253	0.11	24
Alternaria	956	488	0.00	-3.27	93	0.79	27
b	**SPIn (grains)**						
Pollen type	**Mean**	**SD**	**R^2**	**slope**	**SE**	**p**	**N**
Ambrosia	308	192	0.07	6.49	38	0.18	26
Betula	747	523	0.00	-4.63	100	0.72	27
Corylus	902	571	0.20	31.07	110	**0.02**	27
Cupressaceae	3638	2913	0.09	113.02	561	0.11	27
Platanus	5707	3498	0.00	-37.6	673	0.67	27
Poaceae	8803	2936	0.00	14.84	565	0.84	27
Total pollen	51044	14035	0.00	-138.58	2865	0.71	24
Alternaria	24089	10472	0.00	341	2015	0.19	27

By applying the regression formulas to the parameters which were shown to be significantly modified over time, it was possible to calculate the extent of this change over time, Table 4.

Table 4. Pollen season parameters changed significantly through study period 1997 - 2023.

Pollen types	**SPIn** Pollen * day/m³	**Start date** DOY	**Duration** DAYS	**End date** DOY	**Peak date** DOY	**Peak value** Pollen/m³
Ambrosia			22.7		13.1	
Betula		36.5	-25.0			
Corylus	895.3	-12.7	17.2	4.8		
Cupressaceae		36.5				

Poaceae		-9.6	32.6	22.9	11.6	-416.8
Total pollen			32.2	24.1	18.0	

Analysing the number of days with daily pollen concentration of Poaceae > of 10, 30 and 50 pollen/m^3 respectively we observed a significant increase over the whole period excluding data of 2023 ($p= 0.050$, $p = 0.048$, $p = 0.050$, respectively).

3.3. The Meteorologic Parameters over the Three Periods 1997-2005; 2006-2014 and 2015-2023.

The data obtained by dividing the observation period into three periods of nine years each, 1997-2005; 2006-2014 and 2015-2023, mean, minimum and maximum seasonal temperature are shown in Table 5.

Table 5. The means, maximum and minimum seasonal temperatures recorded in Parma during 1997-2005, 2006-2014, 2015-2023, respectively.

Temperature	Winter			Spring			Summer			Autumn		
	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
1997-2005	4.3	8.3	1.5	14.4	20.0	9.6	24.6	30.6	19.4	14.2	18.3	11.1
2006-2014	4.1	7.4	1.7	14.8	20.1	10.2	24.9	30.9	19.7	15.0	19.2	11.7
2015-2023	5.3	9.1	2.7	14.6	19.9	9.8	26.0	31.8	20.5	15.5	20.0	12.0

Regarding temperature, Figure 7 shows the mean temperatures of the period 1997-2005 (T=14.4°C), 2006 -2014 (T=14.8°C), 2015-2023 (T=15.4°C) and over the study period (T=14.9°C). The difference was statically significant (1997-2005 *vs* 2015-2023), $p = 0.000$. Moreover, the average temperature 2006-2014 *vs* 2015-2023 was significantly different, $p = 0.001$. The comparison between 1997-2005 with 2006-2014 does not show any differences. Interestingly, the difference of average between 1997-2005 *vs* 2015-2023 and 2006-2014 *vs* 2015-2023 were (1°C and 0.6°C, respectively).

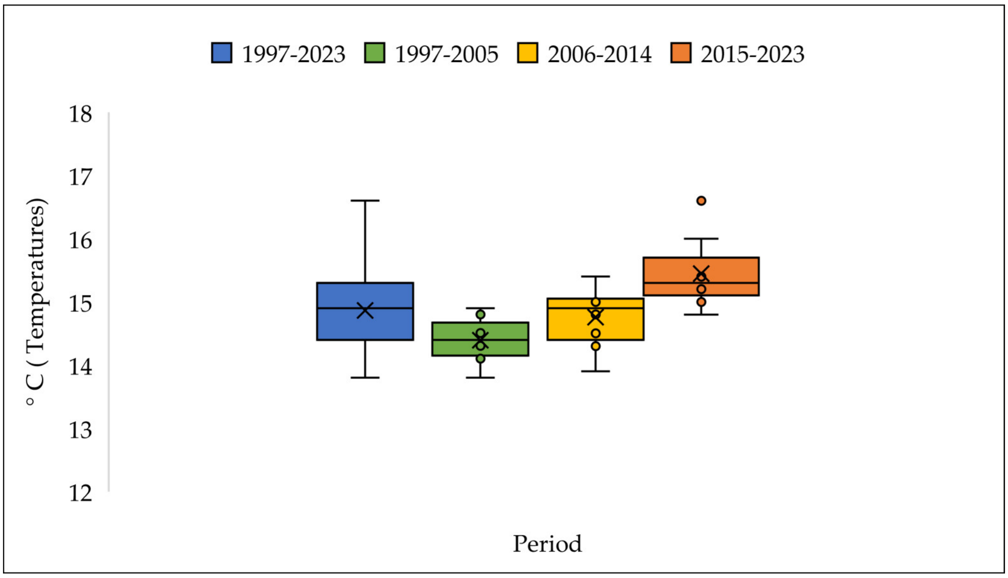

Figure 7. Mean temperature for each study period.

Figure 8 shows the mean of the relative humidity during the study period (1997-2023) RH = 66%; (1997-2005) RH = 67%; (2006-2014) RH = 68%; (2015-2023) RH = 63%.

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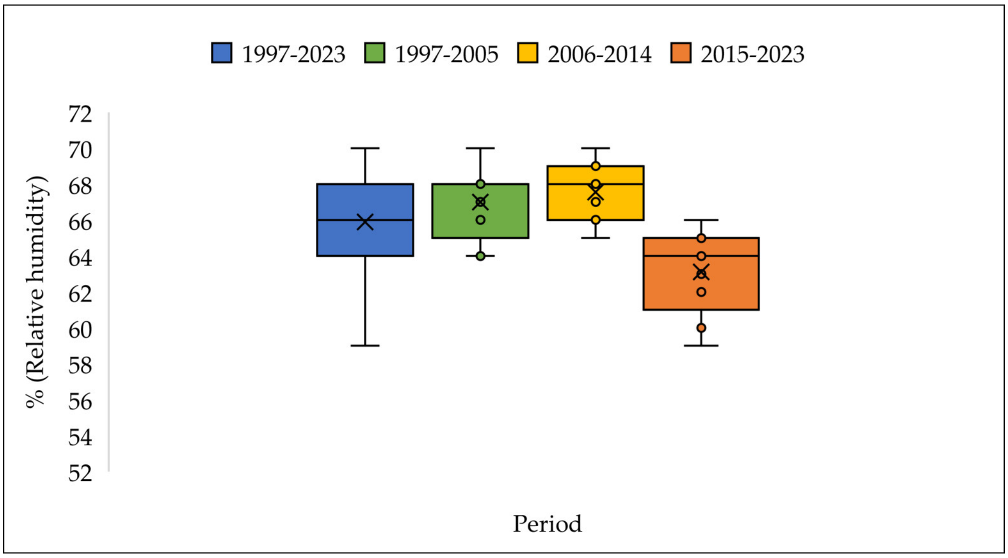


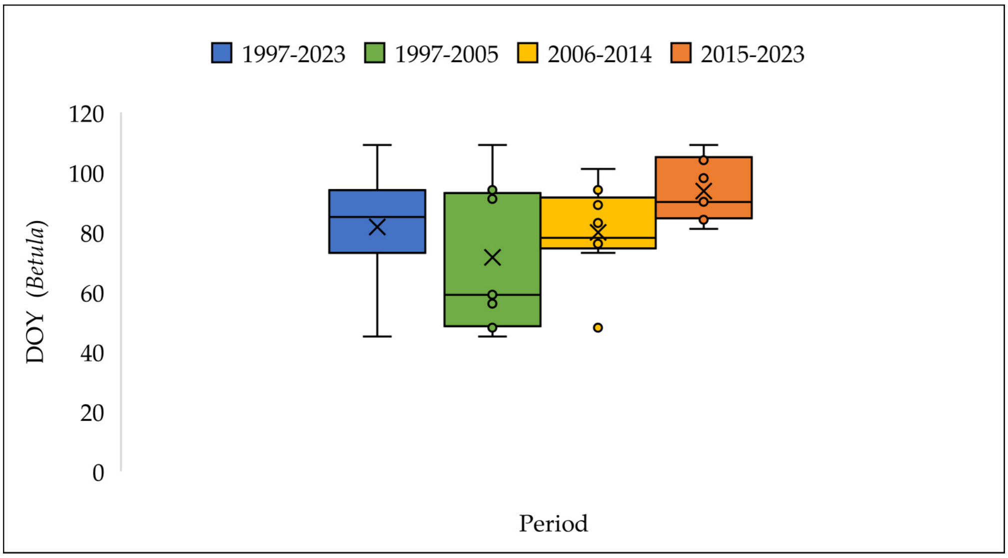
Figure 8. Mean of the relative humidity for each study period.

No significant variation in rainfall were observed (data not shown).

3.4. The Pollen Seasons Parameters over the Three Period 1997-2005; 2006-2014 and 2015-2023.

Regarding pollen seasons parameters, a significant difference in start date (1997-2005 *vs* 2015-2023) for *Betula* (p = 0.02) *Corylus* (p = 0.01), and Poaceae (p = 0.002) and the start date (1997-2005 *vs* 2006-2014) for Cupressaceae (p= 0.041) (Figure 9).9a, 9b, 9c, 9d)) was observed.

a)



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b)

c)

n)

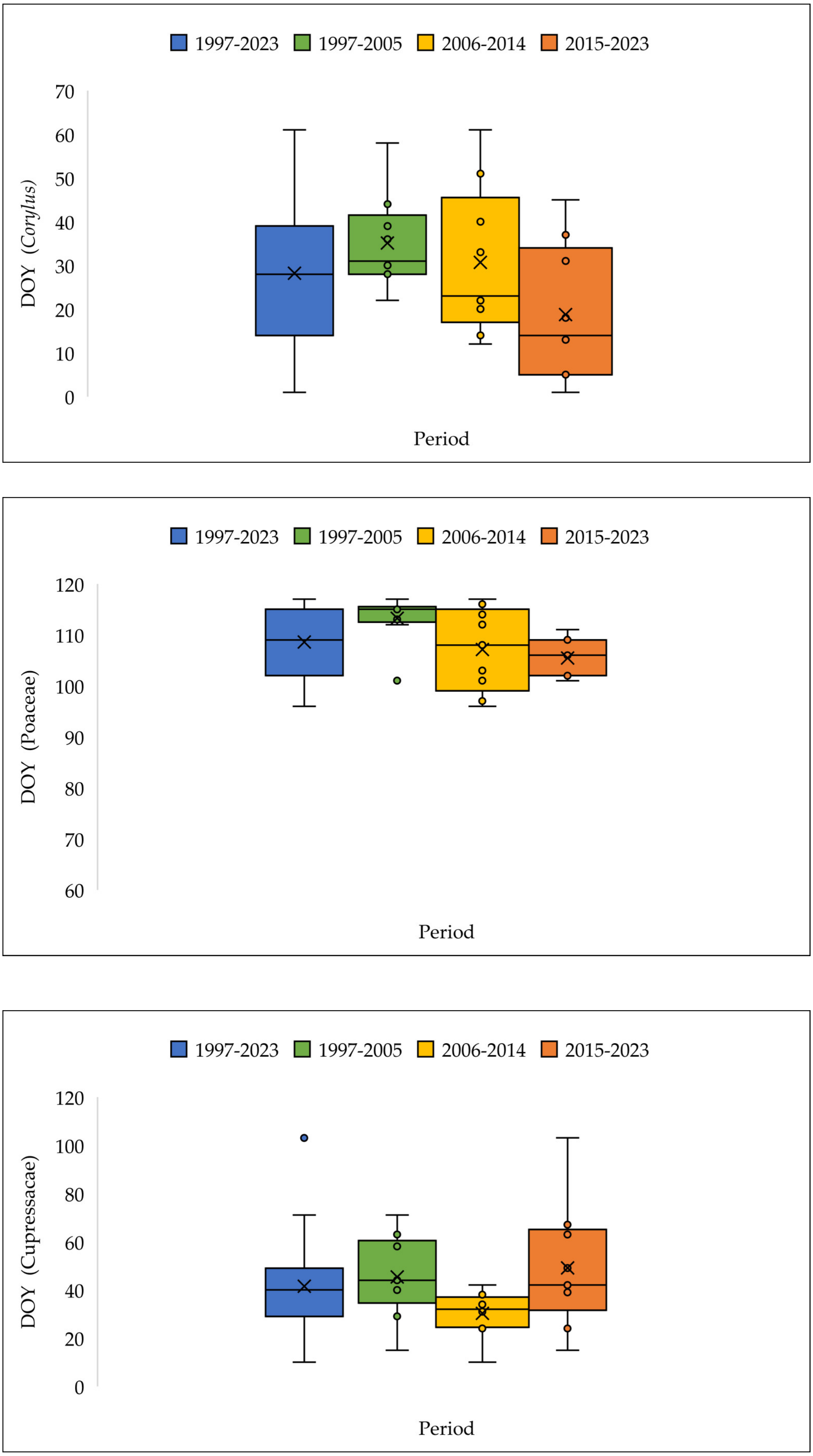

Figure 9. Start date for *Corylus* (a), *Betula* (b), Cupressaceae (c) and Poaceae (d) for each study period.

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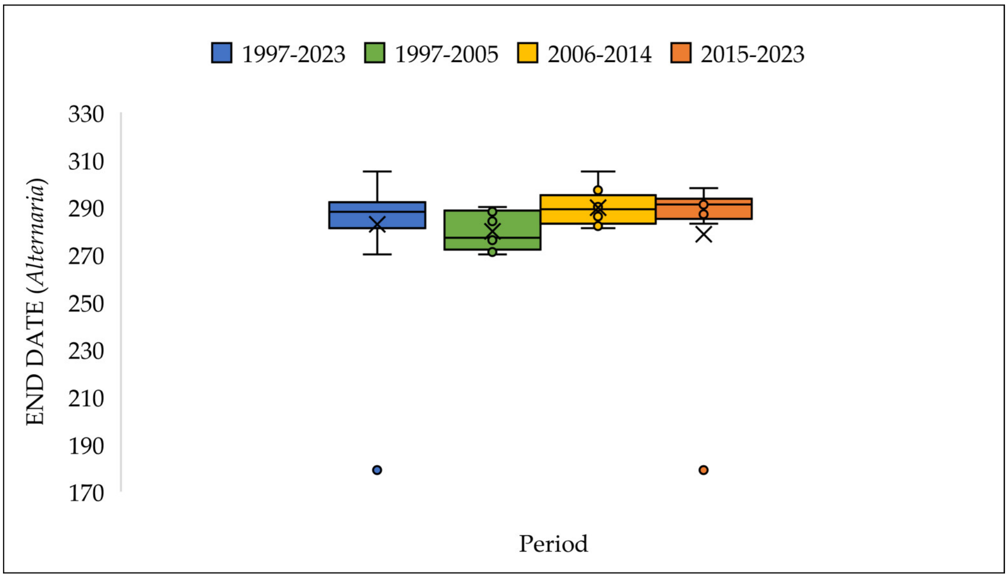
The end date for Total pollen and *Alternaria* showed a significant difference (1997-2005 *vs* 2015-2023) and (1997-2005 *vs* 2006-2014), p = 0.005, p = 0.02 respectively) respectively (Figure 10).

a)



b)

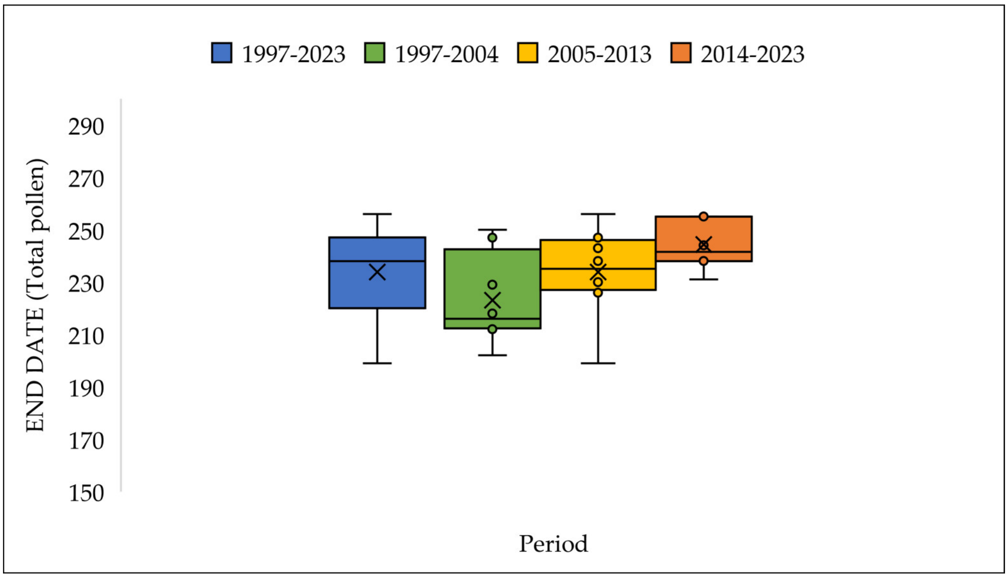


Figure 10. End date for *Alternaria* spores (a) and Total pollen (b) for each study period.

Moreover, a significant difference in duration for *Betula* (p = 0.05) was observed (1997-2005 *vs* 2015-2023); for Poaceae (p = 0.03; p = 0.02) (1997-2005 *vs* 2006-2014 and 1997-2005 *vs* 2015-2023, respectively). Total pollen showed a significant difference (p = 0.035; p = 0.038) in duration (1997-2005 *vs* 2015-2023 and 2006-2014 *vs* 2015-2023, respectively) (Figure 11).

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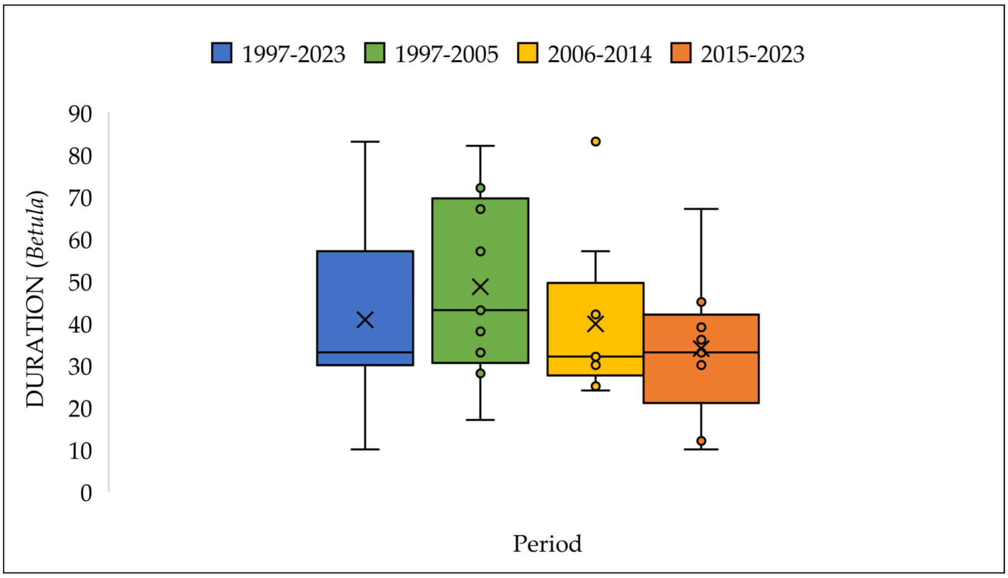
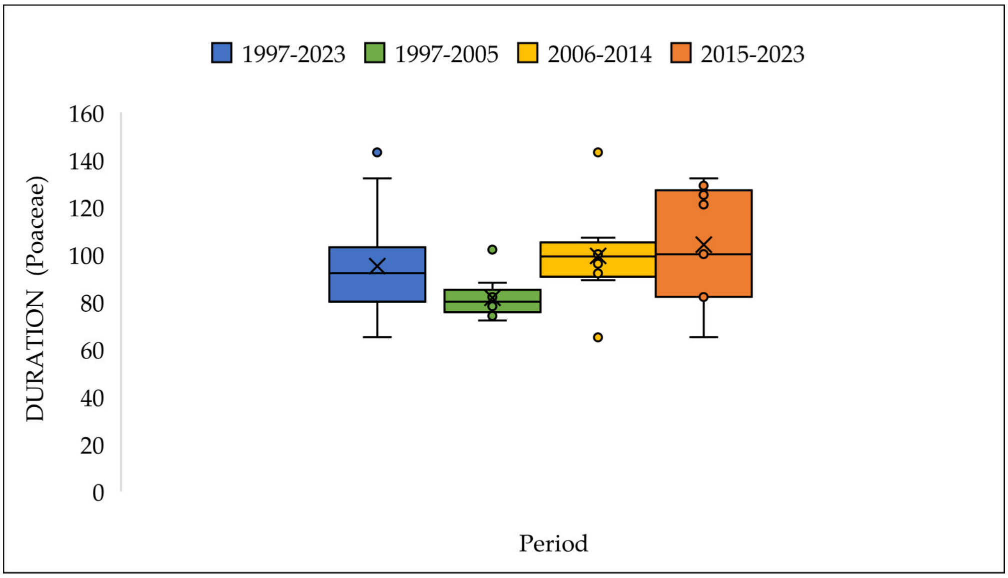
a)



b)



c)

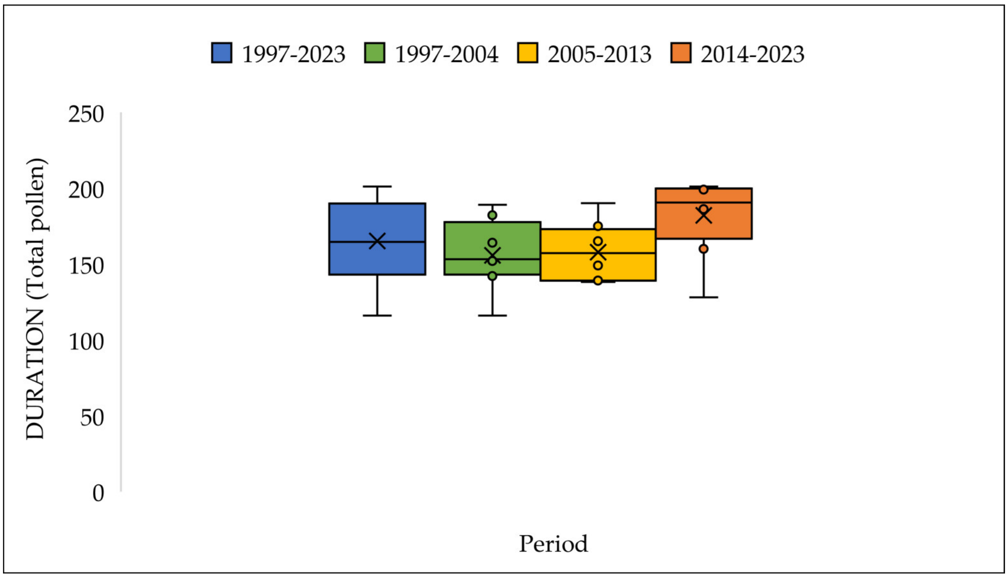


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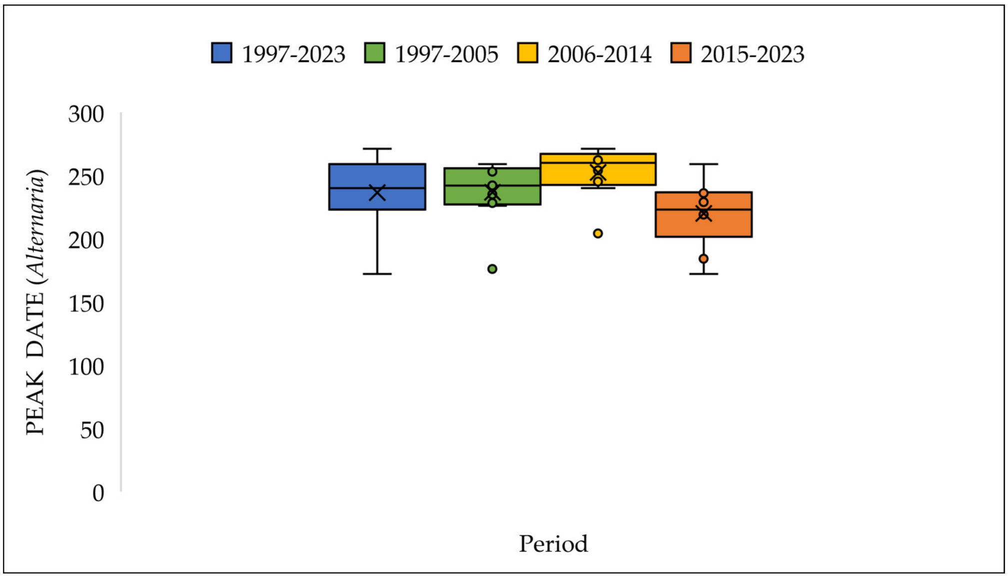
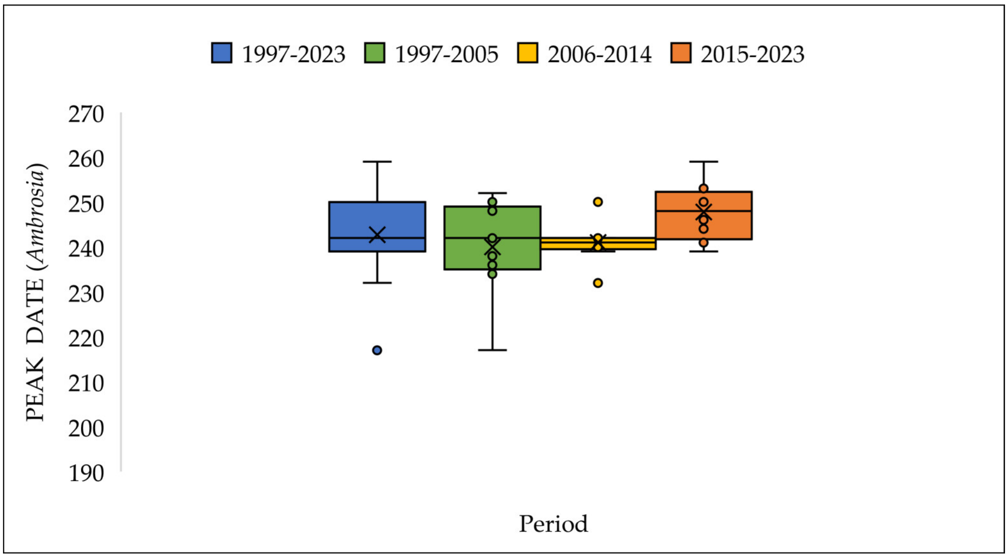
Figure 11. Duration for *Betula* (a), Poaceae (b) and Total pollen (c) for each study period.

The taxa with significant difference about peak date were *Alternaria* between period 2006-2014 *vs* 2015-2023 (p = 0.01); *Ambrosia* (p = 0.02) (2006-2014 *vs* 2015-2023; Poaceae (p = 0.01; p = 0.000) (1997-2005 *vs* 2006-2014; 1997-2005 *vs* 2015-2023, respectively. Total pollen showed significant difference (1997-2005 *vs* 2015-2023), p = 0.001, Figure 12.

a)



b)



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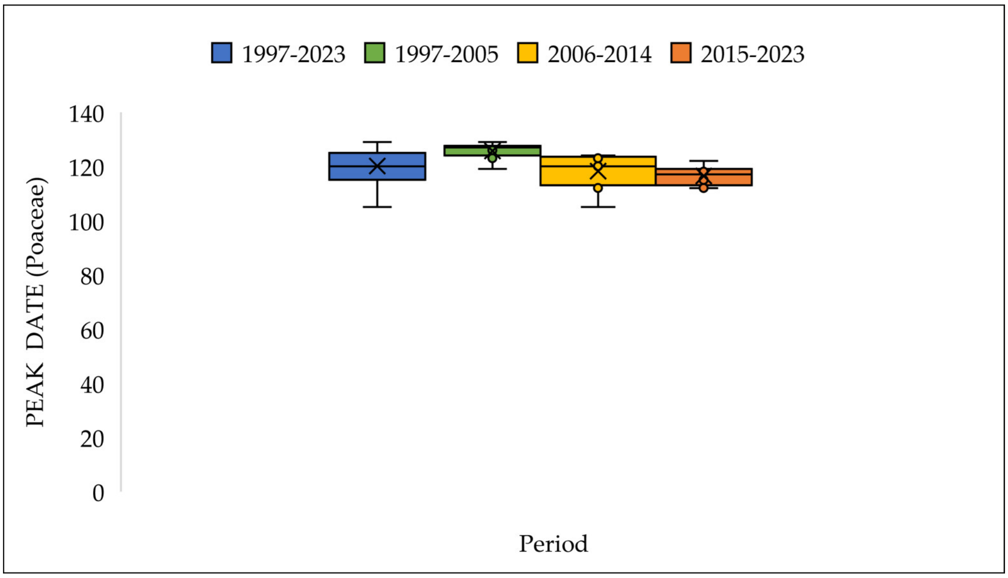
c)



d)

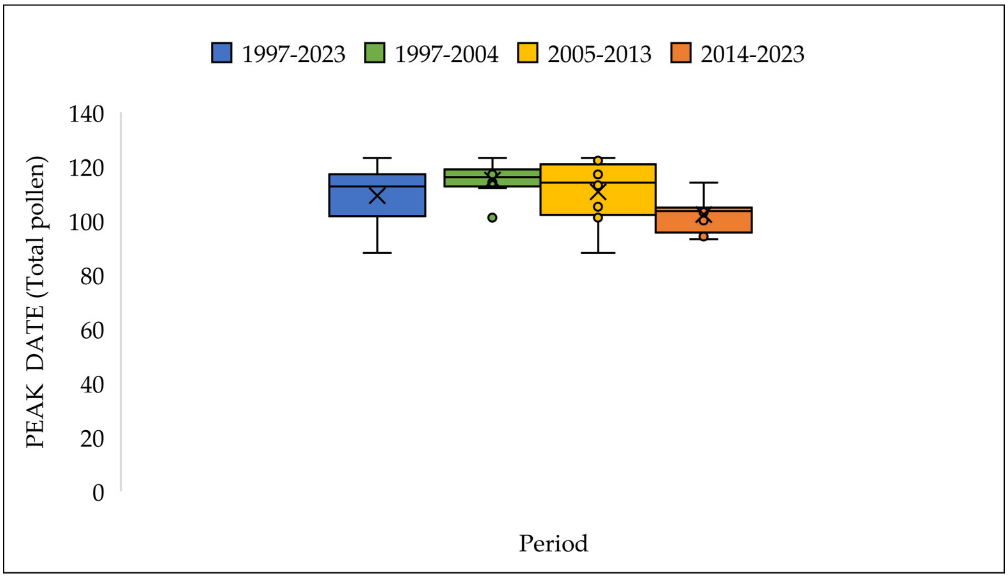


Figure 12. Peak date for *Alternaria* spores (a), *Ambrosia* (b), Poaceae (c) and Total pollen (d) for each study period.

A significant difference for SPIn for *Ambrosia* ($p = 0.01$) was observed (1997-2005 *vs* 2015-2023); for *Platanus* ($p = 0.02$) (2006-2014 *vs* 2015-2023); for *Corylus* ($p = 0.05$; $p < 0.05$) during two period 1997-2005 *vs* 2015-2023 and 2006-2014 *vs* 2015-2023, respectively. *Betula* showed a significant difference (1997-2005 *vs* 2006-2014), $p < 0.05$, Figure 13.

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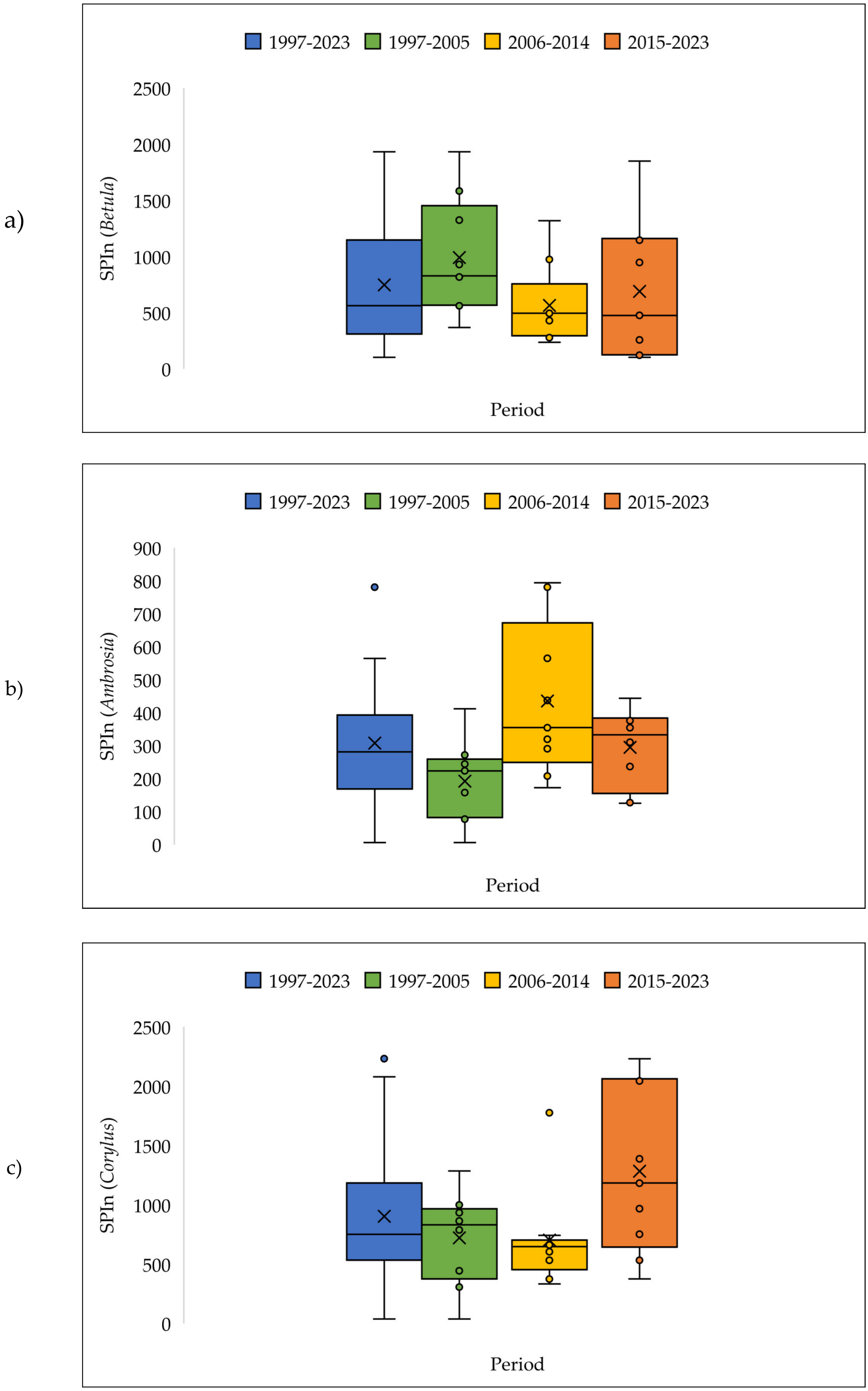

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d)

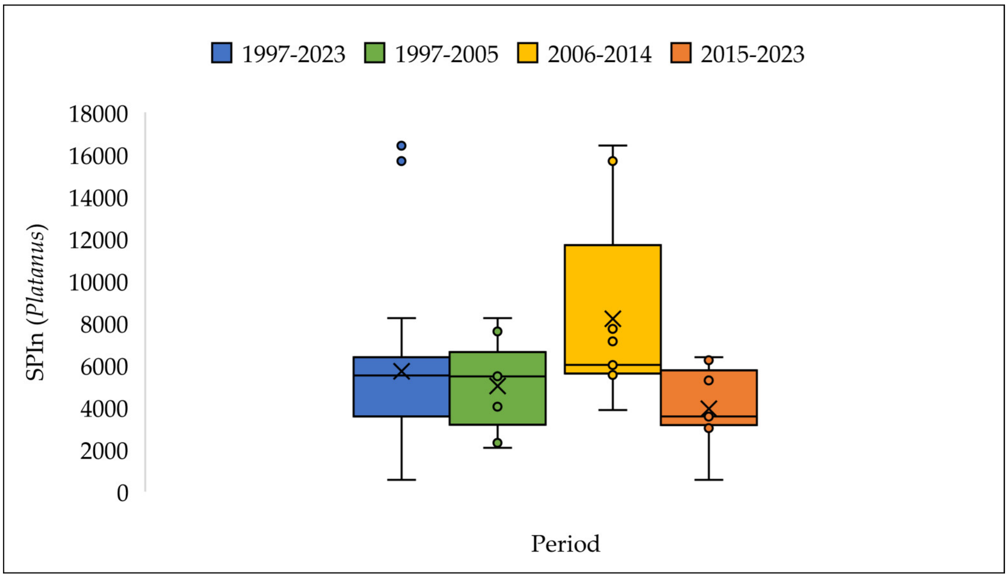
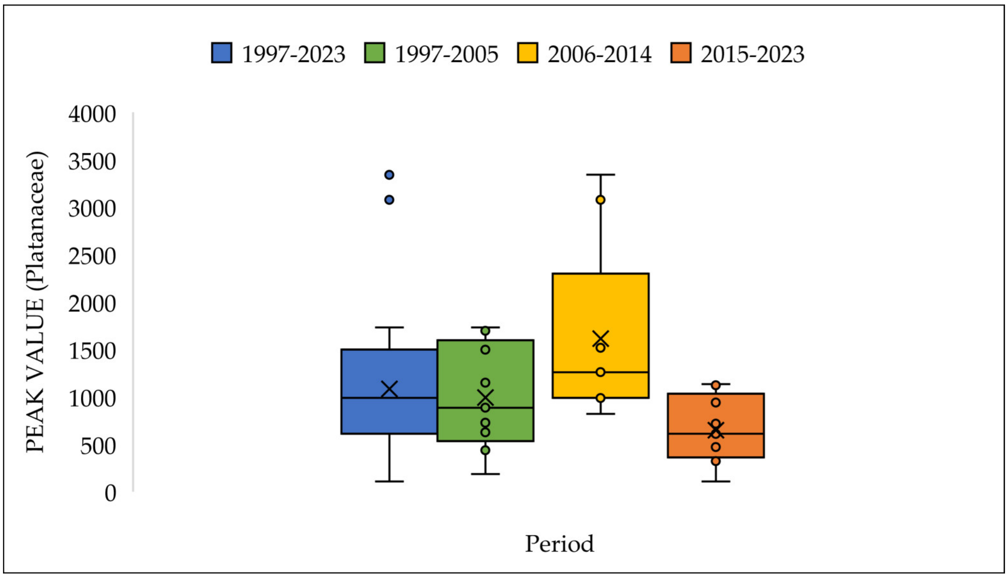


Figure 13. SPIn for *Ambrosia* (a), *Betula* (b), *Corylus* (c) and *Platanu*s for each study period.

A significant difference for peak value for *Platanus* (p = 0.010) (2006-2014 *vs* 2015-2023); for Poaceae (p = 0.041; p = 0.013) (1997-2005 *vs* 2015-2023; 2006-2014 *vs* 2015-2023, respectively) and for Total pollen (p= 0.005; p = 0.006) in the same periods (Figure 14).

a)



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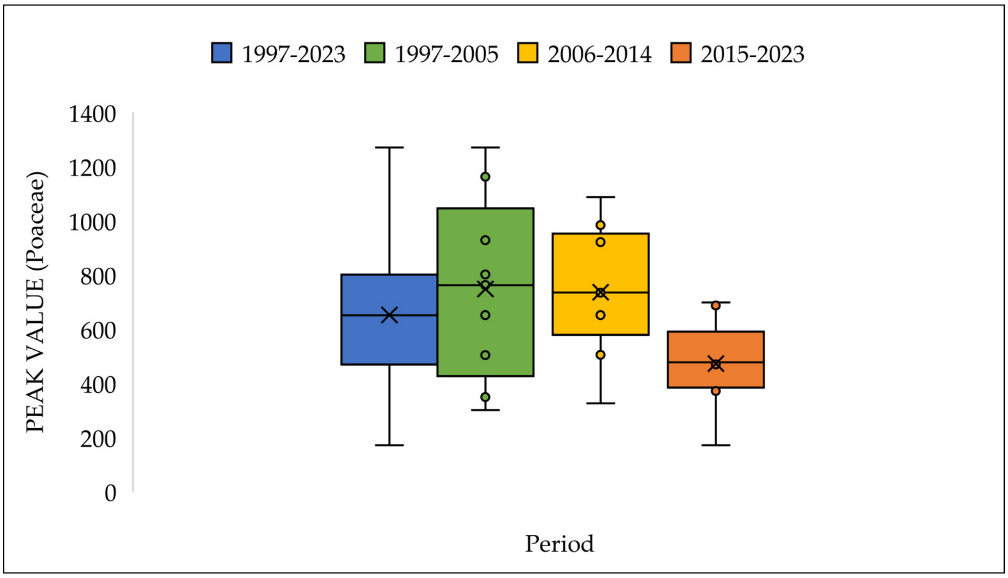
b)



c)

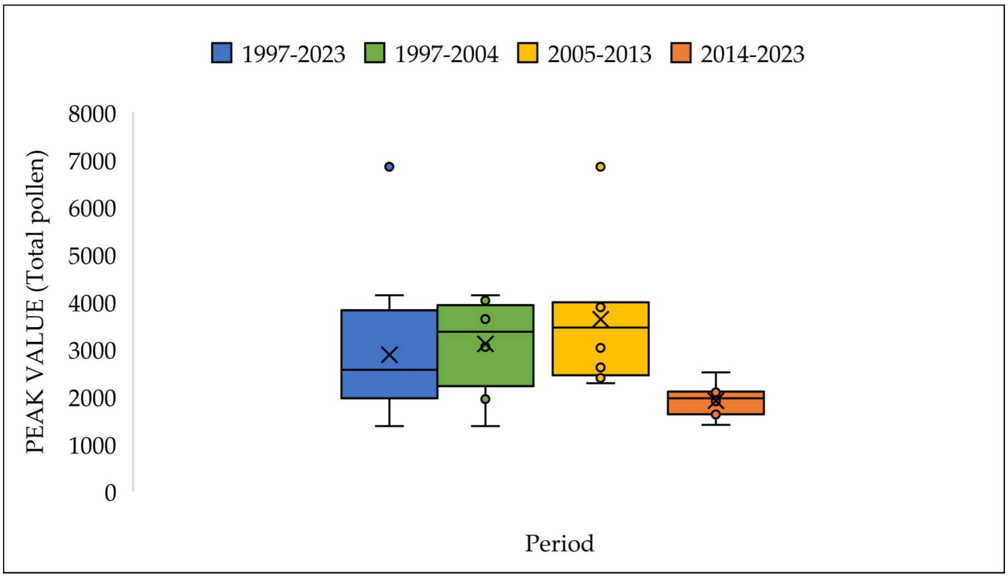


Figure 14. Peak value for *Platanus* (a), Poaceae (b) and Total pollen (c) for each study period.

3.3. Trends and Correlations Between Pollen Season Parameters

Regarding pollen season parameters Table 6 shows the significant Spearman's rank correlations between different pollen season characteristics, in particular the comparison between start date and duration (b) resulted be significant in all type of pollen analysed.

Table 6. The results of Spearman's rank correlation test etween different pollen season parameters.

Pollen type	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
Ambrosia	*ns*	** -0.54	*ns*	*ns*	*ns*	***0.61	*-0.44	*-0.44	*ns*	*-0.42	*-0.39	*ns*	*ns*	*** 0.77	*ns*
Betula	*ns*	*** -0.79	*ns*	*ns*	*0.43	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*** 0.93	*ns*
Corylus	*ns*	*** -0.66	*ns*	*ns*	***0.67	**0.53	*ns*	*ns*	*0.40	*ns*	*ns*	*ns*	*ns*	***0.90	*ns*

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Cupressaceae	*ns*	*** -0.71	*ns*	* -0.41	*ns*	***0.73	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*-0.46	***0.86	*ns*
Platanus	***0.69	***-0.66	*ns*	*ns*	***0.73	*ns*	*ns*	*ns*	***0.72	*ns*	*-0.41	*ns*	*ns*	***0.82	*ns*
Poaceae	*ns*	***-0.60	*ns*	*ns*	***0.73	***0.91	***-0.55	*ns*	*ns*	*ns*	*-0.48	*-0.44	*ns*	*ns*	*ns*
Total pollen	*ns*	***-0.68	*0.45	*ns*	**0.52	***0.67	*ns*	*ns*	*ns*	*ns*	*-0.51	**-0.52	*ns*	*ns*	*0.47
Alternaria	*ns*	**-0.53	*ns*	*ns*	*ns*	**0.52	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	***0.58	*ns*

(a) start date/end date; (b) start date/duration; (c) start date/peak value; (d) start date/SPIn; (e) start date/date of peak; (f) end date/duration; (g) end date/peak value; (h) end date/SPIn; (i) end date/date of peak; (j) duration/SPIn; (k) duration/peak value; (l) duration/date of peak; (m) SPIn/date of peak; (n) SPIn/peak value; (o) peak value/date of peak. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, *ns*: not significant.

4. Discussion

Allergies are a global public health concern, further in a context where climate change affects pollen loads and pollen seasonal parameters [60]. Allergies are expected to show a further 50% increase in prevalence every decade [61]. The severity of symptoms during pollen season poses a public health challenge considering the ongoing potency and duration of pollen season related to climate change [62]. Ragweed in the US is projected to see a 60–100% increase in pollen production by 2085 under current emissions trends [19]. Europe is experiencing similar trends, with increased allergenicity in grasses and changes in ragweed, birch and cypress trees. Greater pollen exposure is linked to poorer asthma and minimizing pollen exposure may improve asthma outcomes [8,52–65]. However, phenological changes depend on the response of individual taxa to temperature and other conditions, with convergence in some regions and divergence in others [18]; as a result, to evaluate the phenological behavior of the taxa at local level based on general considerations can lead to incorrect conclusions. In this context it is important to improve the understanding of the phenomena and if possible, the relationship with symptoms for which it is necessary to implement data and analytical tools even with artificial intelligence [15,66–68].

Our study combined a long data series of aerobiological monitoring performed in Parma from 1997 until 2023 (27 years) and allowing to show the trends of the seasonal pollen characteristic and some climatic parameters over time. This study has delved into other studies that examined trends in Parma considering more limited period of study [43–45,48].

The mean, minimum and maximum temperatures increased significantly during the period studied. Some seasonal parameters also changed significantly. For example, the significant positive trend in mean summer and autumn temperatures over the entire period 1997-2023 were observed. The relative humidity decreased significantly, while rainfall showed a decrease yet not significantly. Especially about precipitation, the patterns changed. A general trend towards decreasing precipitation could be observed, but the wide variability of the data does not yet allow for significant evidence. For example, even in a drought context, the cumulative value of 12/10/2024 was 930.9 mm, higher than the 1991-2020 median value of 642.4 mm [69]. All this represents significant data for the systemic effects it can cause.

The impact on the start and end of the pollination season, and consequently on its duration, shows a lengthening in most cases, only for *Betula* was a shortening evidenced. In both cases, however, these are marked changes and already of the magnitude of what some authors have hypothesised for the end of the century [19]. Equally evident are the changes in the peak values and dates, and for the SPIn of *Corylus*.

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The division into three periods was done to assess the continuity of any trends within the longer observation period. In fact, in some cases, the trends were not homogeneous, and it could be observed that the trend over a longer period can hide opposite trends over shorter periods, as for relative humidity. Making a comparison with our previous study which analyzed the same parameters up to 2011 we can observe that the maximum average temperature observed during that study [48] (15.7°C) is very close to what was the average of the last 9 years (15.4°C).

As regards the seasonal pollen parameters, some of them are confirmed. SPIn is increasing for *Corylus*. The start date was anticipated for *Corylus* and Poaceae and postponed for *Betula*. The end date was postponed for Poaceae and Total pollen. The duration was shorter for *Betula*, longer for Poaceae and Total pollen. The peak date was precocious for Poaceae and Total pollen, and later for *Ambrosia*. The peak value was reduced for Poaceae. As for climatic parameters, the division in three periods allows us to observe some not homogeneous behavior of the trends such as SPIn and peak value for *Platanus*, peak date for *Alternaria* or start date for Cupressaceae.

Poaceae, *Corylus* and Total pollen appear affected by climate change, while *Platanus* and *Alternaria* spores look not to be influenced at this time by climate change. No difference between tree and grasses pollen beahviour was assessed.

Regarding the correlation between different pollen season parameters, it is worth emphasizing that all the taxa considered correlate for start date and duration, and for end date/duration, start date/date of peak, SPIn/peak value, 6 out of the 8 of the taxa considered correlate, in some cases positively and in other negatively.

It is still unknown the complex interactions of pollen, meteorological variables, and air pollutants in the changing environment.

Considering the effect of climate change on the long-term trends in pollen levels and emerging viral infection, it is crucial to forecast and eliminate the associated risk for human health in future and take appropriate measures to reduce it [57].

5. Conclusions

The ongoing climate change is impacting planetary health with dangerous consequences at different levels. The latest Report of the Intergovernmental Panel for Climate Change [70] states that bioaerosols, and among which, airborne pollen and fungal spores are among the threats to human health. The World Health Organization has pointed out specific environmental diseases, emphasizing the synergy of several factors towards an unhealthy environment and their impact on human health [71].

Without wishing to enter a discussion on who or what is most responsible for climate change, it can be stated without doubt by literature and the results of our study that climate change is a reality with which needs to be faced. The repercussions are evident in many areas, including human health, which also goes hand in hand with that of animals and plants. To stay with the latter, the effects observed on them can also pose a risk to human health. However, it is also important to state that generalizations must be avoided and that expressing oneself in terms of trends, as is often the case, exposes to errors of assessment in the short and medium term. The analysis on pollen long time series compared to those obtained in other geographical areas and climatic conditions, albeit over a limited territory, could provide a useful contribution to better characterize the impact of climate change on human health with a One Health perspective.

We believe that the results of our study represent a contribution to better understanding the impact of climate change with a potential impact on human health by environmentally changing conditions. Moreover, it should be considered that not only the seasonal respiratory allergies may be related to the variation of climate and its impact on pollen load and pollen season, but also it could be related to chronic respiratory disease and cardiovascular diseases [72,73]. Long-term data sets obtained from pollen monitoring using the method developed in the 1950s are still a benchmark about this topic but new real-time bioaerosol monitoring systems based on machine learning and artificial intelligence are rapidly evolving and will soon become a reality. This could probably change our knowledge, but that will be another story.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Conceptualization, R.A.; methodology, R.A., A.C., M.M.; validation, R.A., M.M., A.C and C.P.; investigation, R.A., A.C. and M.M.; data curation, , R.A., A.C., M.M.; writing—original draft preparation, , R.A., A.C., M.M.; writing—review and editing, R.A. and C.P.; visualization, R.A., M.M., A.C. M.E.C., L.V., and C.P.; supervision, R.A., M.M., A.C. M.E.C., L.V. P.A., R.Z. and C.P. All authors have read and agreed to the published version of the manuscript."

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Informed Consent Statement: Not applicable for studies not involving humans. You might also choose to exclude this statement if the study did not involve humans.

Data Availability Statement: The data sets used in this article are not readily available because [including reason, e.g., the data are part of an ongoing study

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Savoure, M.; Bousquet, J.; Jaakkola, J.J.K.; Jaakkola, M.S.; Jacquemin, B.; Nadif, R. Worldwide prevalence of rhinitis in adults: a review of definitions and temporal evolution. *Clin Transl Allergy*, **2022,** 12:e12130.
2. Luyten, A.; Bürgler, A.; Glick, S.; Kwiatkowski, M.; Gehrig, R.; Beigi, M.; Hartmann, K.; Eeftens, M. Ambient pollen exposure and pollen allergy symptom severity in the EPOCHAL study. *Allergy*, **2024,** 79, 1908-1920.
3. Bousquet, P.; Demoly, P.; Devillier, P.; Mesbah, K.; Bousquet, J. Impact of allergic rhinitis symptoms on quality of life in primary care. *Int Arch Allergy Immunol* **2013**, 160, 393-400.
4. Vieira, R.J.; Pham-Thi, N.; Anto, J.M.; Czarlewski, W.; Sa-Sousa, A.; Amaral, R., et al. Academic Productivity of Young People With Allergic Rhinitis: A MASK-air Study. *J Allergy Clin Immunol* Pract, **2022**, 10, 3008-3017.
5. Vandenplas, O.; Vinnikov, D.; Blanc, P.D., et al. Impact of rhinitis on work productivity: a systematic review. *J Aller Cl Imm-Pract*, **2018**, 6, 1274-1286.
6. D'Amato, G.; Murrieta-Aguttes, M.; D'Amato, M.; Ansotegui, I.J. Pollen respiratory allergy: Is it really seasonal? *World Allergy Organ ,J* **2023**, 15, 100799.
7. Bousquet, J.; Anto, J.M; Bachert, C.; Baiardini, I.; Bosnic-Anticevich, S.; Canonica W.G.; Melén, E.; Palomares, O.; Scadding, G.K.; Togias, A.; Toppila-Salmi, S. Allergic rhinitis. *Nat Rev Dis Primers*, **2020**, 3, 95.
8. Muzalyova, A.; Brunner, J.O.; Traidl-Hoffmann, C.; Damialis, A. Pollen allergy and health behavior: patients trivializing their disease. *Aerobiologia*, **2019**, 35, 327-341.
9. Domingo, K.N.; Gabaldon, K.L.; Hussari, M.N.; Yap, J.M.; Valmadrid, L.C.; Robinson, K.; Leibel, S. Impact of climate change on paediatric respiratory health: pollutants and aeroallergens. *Eur Respir Rev*, **2024**, 33,
10. D'Amato, G.; Holgate, S.T.; Pawankar, R.; Ledford, D.K.; Cecchi, L.; Al-Ahmad, M.; Al-Enezi, F.; Al-Muhsen, S.; Ansotegui I.; Baena-Cagnani, C.E.; Baker, D.J.; Bayram, H.; Bergmann, K.C,.;Boulet, L.P.; Buters, J.T.; D'Amato, M.; Dorsano, S.; Douwes, J.; Finlay, S.E.; Garrasi, D.; Gómez, M.; Haahtela, T.; Halwani, R.; Hassani, Y.; Mahboub, B.; Marks, G.; Michelozzi, P.; Montagni, M.; Nunes, C.; Oh, J.J.; Popov, T.A.; Portnoy, J.; Ridolo, E.; Rosário, N.; Rottem, M.; Sánchez-Borges, M.; Sibanda, E.; Sienra-Monge, J.J.; Vitale, C.; Annesi-Maesano, I. Meteorological conditions, climate change, new emerging factors, and asthma and related allergic disorders. A statement of the World Allergy Organization. *World Allergy Organ J*, **2015**, 14, 25.
11. Lombardi, C.; Canonica, G.W.; Passalacqua, G. IGRAM, Italian Group on Respiratory Allergy in Migrants. The possible influence of the environment on respiratory allergy: a survey on immigrants to Italy. *Ann Allergy Asthma Immunol*, **2011**, 106, 407-411.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 22 January 2025 doi:10.20944/preprints202501.1624.v1

12. Ziska, L.H.; Makra, L.; Harry, S.K.; Bruffaerts, N.; Hendrickx, M.; Coates, F.; Saarto, A.; Thibaudon, M.; Oliver, G.; Damialis, A.; Charalampopoulos, A.; Vokou, D.; Heiđmarsson, S.; Guđjohnsen, E.; Bonini M, Oh JW, Sullivan K, Ford L, Brooks GD, Myszkowska D, Severova E, Gehrig R, Ramón GD, Beggs PJ, Knowlton K, Crimmins AR. Temperature-related changes in airborne allergenic pollen abundance and seasonality across the northern hemisphere: a etrospective data analysis. Lancet Planet Health. 2019 Mar;3(3):e124-e131. doi: 10.1016/S2542-5196(19)30015-4. Erratum in: Lancet Planet Health. 2019 Nov;3(11):e446. doi: 10.1016/S2542-5196(19)30219-0. PMID: 30904111. *Lancet Planet Health* **2019**, 3, e124-e131.
13. Glick, S.; Gehrig, R.; Eeftens, M. Multi-decade changes in pollen season onset, duration, and intensity: A concern for public health? *Sci Total Environ*, **2021**, 10, 781, 146382.
14. Chapman, D.S.; Makra, L.; Albertini, R.; Bonini, M.; Páldy, A.; Rodinkova, V.; Šikoparija, B.; Weryszko-Chmielewska, E.; Bullock, J.M. Modelling the introduction and spread of non-native species: international trade and climate change drive ragweed invasion. *Glob Chang Biol*, **2016,** 22, 3067-3079.
15. Makra, L.; Matyasovszky, I.; Tusnády, G.; Ziska, L.H.; Hess, J.J.; Nyúl, L.G., Chapman, D.S.; Coviello, L.; Gobbi, A.; Jurman, G.; Furlanello, C.; Brunato, M.; Damialis, A.; Charalampopoulos, A.; Müller-Schärer, H.; Schneider, N.; Szabó, B.; Sümeghy, Z.; Páldy, A.; Magyar, D.; Bergmann, K.C.; Deák, Á.J.; Mikó, E.; Thibaudon, M.; Oliver, G.; Albertini, R.; Bonini, M.; Šikoparija, B.; Radišić, P.; Josipović, M.M.; Gehrig, R.; Severova, E.; Shalaboda, V.; Stjepanović, B.; Ianovici, N.; Berger, U.; Seliger, A.K.; Rybníček, O.; Myszkowska, D.; Dąbrowska-Zapart, K.; Majkowska-Wojciechowska, B.; Weryszko-Chmielewska, E.; Grewling, Ł.; Rapiejko, P.; Malkiewicz, M.; Šaulienė, I.; Prykhodo, O.; Maleeva, A.; Rodinkova, V.; Palamarchuk, O.; Ščevková, J.; Bullock, J.M. A temporally and spatially explicit, data-driven estimation of airborne ragweed pollen concentrations across Europe. *Sci Total Environ*, **2023**, 20, 905, 167095.
16. D'Amato, G.; Akdis, C. Global warming, climate change, air pollution and allergies. *Allergy* **2020**, 75, 2158–2160.
17. Beggs, P.J. Adaptation to impacts of climate change on aeroallergens and allergic respiratory diseases. *Int J Environ Res Public Health*, **2010,** 7, 3006-3021.
18. Huusko, A.; and Hicks, S. Conifer pollen abundance provides a proxy for summer temperature: evidence from the latitudinal forest limit in Finland. *J Quaternary Sci*., **2009,** 24, 522–528.
19. Zhang, Y.; Steiner AL. Projected climate-driven changes in pollen emission season length and magnitude over the continental United States. *Nat Commun*, **2022**, 15,1234.
20. D'Amato, G.; Holgate, S.T.; Pawankar, R.; Ledford, D.K.; Cecchi, L.; Al-Ahmad, M.; Al-Enezi, F.; Al-Muhsen, S.; Ansotegui, I.; Baena-Cagnani, C.E.; Baker, D.J.; Bayram, H.; Bergmann, K.C.; Boulet, L.P.; Buters, J.T.; D'Amato, M.; Dorsano, S.; Douwes, J.; Finlay, S.E.; Garrasi, D.; Gómez, M.; Haahtela, T., Halwani, R., Hassani, Y.; Mahboub, B.; Marks, G.; Michelozzi, P.; Montagni, M.; Nunes, C.; Oh, J.J.; Popov, T.A.; Portnoy, J.; Ridolo, E.; Rosário, N.; Rottem, M.; Sánchez-Borges, M.; Sibanda, E.; Sienra-Monge, J.J.; Vitale, C.; Annesi-Maesano, I. Meteorological conditions, climate change, new emerging factors, and asthma and related allergic disorders. A statement of the World Allergy Organization. *World Allergy Organ J*, **2015,** 14, 25.
21. D'Amato, G.; Akdis, C.A. Global warming, climate change, air pollution and allergies. *Allergy*, **2020,** 75, 2158-2160.
22. Cecchi, L.; D'Amato, G.; Annesi-Maesano, I. Climate change and outdoor aeroallergens related to allergy and asthma: Taking the exposome into account. *Allergy*, **2020**, 75, 2361-2363.
23. Prescott, S.L. Allergy as a sentinel measure of planetary health and biodiversity loss. *Allergy*, **2020,** 75, 2358-2360.
24. Wayne, P.; Foster, S.; Connolly, J.; Bazzaz, F.; Epstein, P. Production of allergenic pollen by ragweed (*Ambrosia artemisiifolia* L.) is increased in CO_2-enriched atmospheres. *Ann Allergy Asthma Immunol*, **2002,** 88, 279-82.
25. Kim KR, Oh JW, Woo SY, Seo YA, Choi YJ, Kim HS, Lee WY, Kim BJ. Does the increase in ambient CO_2 concentration elevate allergy risks posed by oak pollen? *Int J Biometeorol*, 2018, 62, 1587-1594.
26. Choi, Y.J.; Lee, K.S.; Oh, J.W. The Impact of Climate Change on Pollen Season and Allergic Sensitization to Pollens. *Immunol Allergy Clin North Am*, **2021,** 41, 97-109.

27. D'Amato, G.; Pawankar, R.; Vitale, C.; Lanza, M.; Molino, A.; Stanziola, A.; Sanduzzi, A.; Vatrella, A.; D'Amato, M. Climate Change and Air Pollution: Effects on Respiratory Allergy. *Allergy Asthma Immunol Res*, **2016,** 8, 391-5.
28. Gent, J.F.; Triche, E.W.; Holford, T.R.; Belanger, K.; Bracken, M.B.; Beckett, W.S.; Leaderer, B.P. Association of low-level ozone and fine particles with respiratory symptoms in children with asthma. *JAMA*, **2003,** 290, 1859-67.
29. Smith, M.; Skjøth, C.A.; Myszkowska, D.; Uruska, A.; Puc, M.; Stach, A.; Balwierz, Z.; Chlopek, K.; Piotrowska, K.; Kasprzyk, I.; Brandt, J. Long-range transport of Ambrosia pollen to Poland, *Agric Forest Meteor*, **2008,** 148, 1402-1411.
30. Ranpal, S., von Bargen, S., Gilles, S., Luschkova, D., Landgraf, M., Bogawski, P., Traidl-Hoffmann, C., Büttner, C., Damialis, A., Fritsch, M., Jochner-Oette, S. Continental-scale evaluation of downy birch pollen production: Estimating the impacts of global change, *Environmental Research*, **2024,** 1, 252, 119114.
31. Cecchi, L.; Torrigiani Malaspina, T.; Albertini, R.; Zanca, M.; Ridolo, E.; Usberti. I.; Morabito, M.; Dall' Aglio, P.; Orlandini, S. The contribution of long-distance transport to the presence of Ambrosia pollen in central northern Italy, *Aerobiologia*, **2007**, 23, 145–151.
32. Bayr, D.; Plaza, M.P.; Gilles, S.; Kolek, F.; Leier-Wirtz, V.; Traidl-Hoffmann, C.; Damialis, A. Pollen long-distance transport associated with symptoms in pollen allergics on the German Alps: An old story with a new ending? *Sci Total Environ*, **2023,** 10, 881, 163310.
33. Hjelmroos, M. Evidence of long-distance transport of betula pollen. *Grana*, **1991**, 30, 215–228.
34. D'Amato, G.; Annesi-Maesano, I.; Urrutia-Pereira, M.; et al. Thunderstorm allergy and asthma: state of the art. *Multidiscip Respir Med*, **2021**, 16, 806–811.
35. Xu, Y.Y., Xue, T.; Li, H.R.; Guan, K. Retrospective analysis of epidemic thunderstorm asthma in children in Yulin, northwest China. *Pediatr Res,* **2021**, 89, 958-961.
36. Final Report: literature review on thunderstorm asthma and its implications for public health advice. Queensland University of Technology. Brisbane, Australia. Contracted by: Department of Health and Human Services, Victorian State Government. **2017,** 89, 958–961.
37. Ariano, R.; Canonica, G.W.; Passalacqua, G. Possible role of climate changes in variations in pollen seasons and allergic sensitizations during 27 years. *Ann Allergy Asthma Immunol* ,**2010,** 104,215-22.
38. Frenguelli, G.; Tedeschini, E.; Veronesi, F. et al. Airborne pine (Pinus spp.) pollen in the atmosphere of Perugia (Central Italy): Behaviour of pollination in the two last decades. *Aerobiologia,* **2002,** 18, 223–228.
39. Frenguelli G. Interactions between climatic changes and allergenic plants. Monaldi Arch Chest Dis. 2002 Apr;57(2):141-3.
40. Tedeschini, E., Javier RodrÍguez-Rajo, F., Caramiello, R., Jato, V., & Frenguelli, G. (2006). The influence of climate changes in Platanus spp. pollination in Spain and Italy. Grana, 45(3), 222–229.
41. Voltolini, S.; Minale, P.; Troise, C. et al. Trend of herbaceous pollen diffusion and allergic sensitisation in Genoa, Italy. *Aerobiologia,* **2000,** 16, 245–249.
42. Rodríguez-RaJo, F. J., Frenguelli, G., & Jato, V. (2003). The influence of air temperature on the starting date of Quercus pollination in the South of Europe. Grana, 42(3), 145–152.
43. Ciancianaini, P.; Albertini, R.; Pinelli, S.; Lunghi, P.; Ridolo, E.; & Dall'Aglio, P. Betulaceae, Corylacae, Cupressaceae, Fagaceae and Salicacae around Parma (Northen Italy): Pollen calendars from 1995 to 1997. *Aerobiologia*, **2000,** 16, 309-312.
44. Albertini, R.; Ciancianaini, P.; Pinelli, S.; Ridolo, E.; Dall'Aglio, P. Pollens in Parma 1995 to 2000. *Allergy,* **2001,** 56, 1232-3.
45. Ridolo, E.; Albertini, R.; Giordano, D., Soliani, L.; Usberti, I.; Dall'Aglio, PP. Airborne pollen concentrations and the incidence of allergic asthma and rhinoconjunctivitis in northern Italy from 1992 to 2003. *Int Arch Allergy Immunol,* **2007,** 142, 151-157.
46. Mercuri, A.M.; Torri, P.; Casini, E.; Olmi, L. Climate warming and the decline of Taxus airborne pollen in urban pollen rain (Emilia Romagna, northern Italy). *Plant Biol*, **2013,** 15, 70-82.
47. Mercuri, A.M.; Torri, P.; Fornaciari, R; Florenzano, A. Plant Responses to Climate Change: The Case Study of Betulaceae and Poaceae Pollen Seasons (Northern Italy, Vignola, Emilia-Romagna). *Plants*, **2016**, 5, 42.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 22 January 2025 doi:10.20944/preprints202501.1624.v1

48. Ugolotti, M.; Pasquarella, C.; Vitali, P. et al. Characteristics and trends of selected pollen seasons recorded in Parma (Northern Italy) from 1994 to 2011. *Aerobiologia,*, **2015,** 31, 341–352.
49. Köppen, W. Das geographische System der Klimate (PDF), in Handbuch der Klimatologie, vol. 1, Berlino, Borntraeger, 1936.
50. Hirst, J.M. An automatic volumetric spore trap. *Ann Appl Biol,* **1952,** 39, 257–265.
51. UNI 11108:**2004** - Qualità dell'aria - Metodo di campionamento e conteggio dei granuli pollinici e delle spore fungine aerodisperse.
52. EN 16868:**2019**. Ambient air - Sampling and analysis of airborne pollen grains and fungal spores for networks related to allergy - Volumetric Hirst method.
53. Jäger, S.; Nilsson, S.; Berggren, B.; Pessi, A.; Helander, M.; and Ramfjord, H. Trends of some airborne tree pollen in the Nordic countries and Austria, 1980-1993. *Grana*, **1996,** 35, 171-178.
54. Pfaar, O.; Bastl, K.; Berger, U.; Buters, J.; Calderon, M.A.; Clot, B.; Darsow, U.; Demoly, P.; Durham, SR.; Galán, C.; Gehrig, R.; Gerth van Wijk, R.; Jacobsen, L.; Klimek, L.; Sofiev, M.; Thibaudon, M.; Bergmann, K.C. Defining pollen exposure times for clinical trials of allergen immunotherapy for pollen-induced rhinoconjunctivitis - an EAACI position paper. *Allergy*. **2017**, 72, 713-722.
55. Galán, A.; Ariatti, M.; Bonini, B.; Clot, B.; Crouzy, A.; Dahl, D.; Fernandez-González, G.; Frenguelli, R.; Gehrig, S.; Isard, E.; Levetin, D.; W, Li, P.; Mandrioli, C. A.; Rogers, M.; Thibaudon, I.; Sauliene, C.; Skjoth, M.; Smith, M. Sofiev Recommended terminology for aerobiological studies. *Aerobiologia,* **2017,** 33, 293–295.
56. Thackeray, S. J.; Sparks, T. H.; Frederiksen, M.; Burthe, S.; Bacon, P. J.; Bell, J.; Botham, M.; Brereton, T.; Bright, P.; Carvalho, L.; Clutton-Brock, T.; Dawson, A.; Edwards, E.; Elliott, J.M.; Harrington, R.; Johns, D.; Jones, I.D.; Jones, J.T.; Leech, D.I.; Roy, D.B.; Scott, A.; Smith, M.; Smithers, R.J.; Winfield, I.J.; Wanless, S. Trophic level asynchrony in rates of phenological change for marine, freshwater and terrestrial environments. *Global Change Biology*, **2010,** 16, 3304–3313.
57. Ziello, C.; Sparks, T.H.; Estrella, N.; Belmonte, J.; Bergmann, K. C.; Bucher, E.; Brighetti, M.A.; Damialis, A.; Detandt, M.; Galán, C.; Gehrig, R.; Grewling, L.; Gutiérrez Bustillo, A.M.; Hallsdóttir, M.; Kockhans-Bieda, M.C.; De Linares, C.; Myszkowska, D.; Pàldy, A.; Sánchez, A.; Smith, M.; Thibaudon, M.; Travaglini, A.; Uruska, U.; Valencia-Barrera, R.M.; V okou, D.; Wachter, R.; de Weger, L.A.; Menzel, A. Changes to airborne pollen counts across europe. *PLoS One*, **2012**, 7(4), e34076.
58. Smith, M.; Jäger, S.; Berger, U.; Sikoparija, B.; Hallsdottir, M.; Sauliene, I.; Bergmann, K.C.; Pashley, C.H.; de Weger, L.; Majkowska-Wojciechowska, B.; Rybníček, O.; Thibaudon, M.; Gehrig, R.; Bonini, M.; Yankova, R.; Damialis, A.; Vokou, D.; Gutiérrez Bustillo, A.M.; Hoffmann-Sommergruber, K.; van Ree, R. Geographic and temporal variations in pollen exposure across Europe. *Allergy*, **2014,** 69, 913-23.
59. Zar, J. H. Biostatistical analysis, 5th ed.; Publisher: Pearson Education, Incorporated, United Kingdom, 2018; pp. 1 – 960.
60. Oh, JW. Pollen Allergy in a Changing Planetary Environment. *Allergy Asthma Immunol Res,* **2022,** 14, 168-181. doi: 10.4168/aair.2022.14.2.168.
61. Pawankar, R. Allergic diseases and asthma: a global public health concern and a call to action. *World Allergy Organ J*, **2014**, 19, 12. doi: 10.1186/1939-4551-7-12.
62. Pawankar, R.; Baena-Cagnani, C.E.; Bousquet, J.; Canonica, G.W.; Cruz, A.A.; Kaliner, M.A.; Lanier, B.Q. State of world allergy report 2008: allergy and chronic respiratory diseases. *World Allergy Organ J*, **2008**, 1, S4-S17.
63. Luyten, A.; Bürgler, A.; Glick, S.; Kwiatkowski, M.; Gehrig, R.; Beigi, M.; Hartmann, K.; Eeftens, M. Ambient pollen exposure and pollen allergy symptom severity in the EPOCHAL study. *Allergy*, **2024**, 79, 1908-1920.
64. Asthma and Allergy Foundation of America. Climate change and health. Available on line: https://aafa.org/asthma-allergy-research/our-research/climate-health/ (Accessed on 27 August 2024**)**.
65. European Climate and Health Observatory. Pollen. Available on line: https://climate-adapt.eea.europa.eu/en/observatory/evidence/health-effects/aeroallergens (Accessed on 27 August 2024).
66. Li, Z.; Xu, X.; Thompson, L.A.; Gross, H.E.; Shenkman, E.A.; DeWalt, D.A.; Huang, I.C. Longitudinal Effect of Ambient Air Pollution and Pollen Exposure on Asthma Control: The Patient-Reported Outcomes Measurement Information System (PROMIS) Pediatric Asthma Study. *Acad Pediatr*, **2019**, 19, 615-623.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 22 January 2025 doi:10.20944/preprints202501.1624.v1

67. Sofia Papadogiannaki * , Serafeim Kontos , Daphne Parliari andDimitriosMelas. Machine Learning Regression to Predict Pollen Concentrations of Oleaceae and Quercus Taxa in Thessaloniki, Greece. Environ. Sci. Proc. 2023, 26, 2-6.
68. Goktas P, Karakaya G, Kalyoncu AF, Damadoglu E. Artificial Intelligence Chatbots in Allergy and Immunology Practice: Where Have We Been and Where Are We Going? J Allergy Clin Immunol Pract. 2023 Sep;11(9):2697-2700.
69. Agenzia regionale per la prevenzione, l'ambiente e l'energia dell'Emilia-Romagna (Arpae). Precipitazioni giornaliere cumulate in Emilia-Romagna (anno 2024) https://www.arpae.it/it/temi-ambientali/clima, accessed on October 14, 2024.
70. Intergovernmental Panel on Climate Change (IPCC), AR6 Synthesis Report: Climate Change 2023. https://www.ipcc.ch/assessment-report/ar6/ accessed October 14, 2024.
71. WHO, Preventing disease through healthy environments: a global assessment of the burden of disease from environmental risks. Meeting report. 13 September 2018.
72. Idrose NS, Lodge CJ, Erbas B, Douglass JA, Bui DS, Dharmage SC. A Review of the Respiratory Health Burden Attributable to Short-Term Exposure to Pollen. Int J Environ Res Public Health. 2022 Jun 20;19(12):7541. doi: 10.3390/ijerph19127541..
73. Lappe BL, Scovronick N, D'Souza RR, Manangan A, Chang HH, Ebelt S. Associations of pollen and cardiovascular disease morbidity in Atlanta during 1993-2018. Environ Epidemiol. 2024 Feb 29;8(2):e296. doi: 10.1097/EE9.0000000000000296..

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