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Exposure to pollen allergens in allergic rhinitis expressed by diurnal variation of airborne tree pollen in urban and rural area

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ABSTRACT: Exposure to airborne pollen allergens results in allergic symptoms in subjects who are sensitized. The paper presents diurnal variation in the counts of airborne allergenic pollen of selected trees (*Betula L., Alnus Mill., Corylus L., Fagus L. and Ulmus L.*) in two localities differing in the degree of urbanization: the city of Szczecin (urban) and the village of Gudowo, West Pomerania in northwest Poland (rural) in the years 2012–2014. The measurements were made by the volumetric method using a Burkard-type sampler operating in a continuous mode. The greatest similarities in the beginning of the main pollen season between the two sites studied were observed for birch and elm trees, while in the length of the main pollen season, for birch and alder trees. Pollen counts of alder and hazel reached higher levels in the rural area, while the levels of ash tree pollen counts were higher in the urban area. The level of birch tree pollen counts was similar in the two sites studied. For the majority of taxons observed in the urban and rural areas the dynamics of hourly changes in tree pollen counts were similar. The pollination peak was noted in the daytime, usually in the afternoon. For ash and elm trees increased pollen counts were observed at nighttime, while the birch tree pollen counts were at a high level for most of the 24 h cycle. The knowledge of seasonal and diurnal variations in tree pollen counts is crucial for prevention in patients with allergic rhinitis, sensitized to tree pollen allergens.

KEYWORDS: allergic rhinitis, diurnal pollen counts, rural, tree pollen, urban

INTRODUCTION

Allergic rhinitis affects between 10% and 30% of the global population as WAO White Book on Allergy: Update 2013 indicates [1]. In Poland 22.5% of the population suffer from allergic rhinitis as shown by the Epidemiology of Allergic Diseases in Poland (ECAP) study [2]. The prevalence of the disease is higher in populations living in urban areas in comparison with those living in rural areas [3, 4].

Exposure to airborne pollen allergens results in allergic symptoms in subjects who are sensitized [5, 6, 7]. In Poland tree pollen allergens can induce symptoms of allergic rhinitis from January/February until May. Pollen counts display not only substantial seasonal but also diurnal variations. The rhythmic variations in pollen counts are related to the rhythm of anther opening and characteristics of a given species. This biological rhythm is modified by meteorological factors and partly by biogeographic conditions, i.e. local habitat conditions and land sculpture.

The knowledge of diurnal variation in pollen counts, besides the knowledge of seasonal variation, is important for preventive measures and therapy monitoring in pollen allergy. Unfortunately there are not many analyses of diurnal variations in airborne pollen counts published [8–11]. Comparative analyses of the pollen counts in industrialized urban areas and in unpolluted rural areas are also rare while comparative studies of hourly dynamics of pollen counts in areas of different degree of urbanization are even rarer.

AIM

The main aim of the study was the analysis of hourly changes in airborne pollen counts, produced by a selected allergenic species of trees and bushes, in urban and rural areas.

MATERIAL AND METHODS

The subject of the study was the allergenic pollen produced by a selected species of trees and bushes. Taxons with very high clinical significance; *Betula L, Alnus Mill., Corylus L*, as well as taxons of lesser clinical significance (*Fagus L., Ulmus L., Fraxinus L.*) were monitored [12–15].

The pollen count measurements were carried out in the years 2012–2014. Pollen concentrations were recorded, in line with international standards, by volumetric method using a Burkard-type sampler operating in a continuous volumetric mode. Concentrations were recorded over 7 days and microscopic analysis was

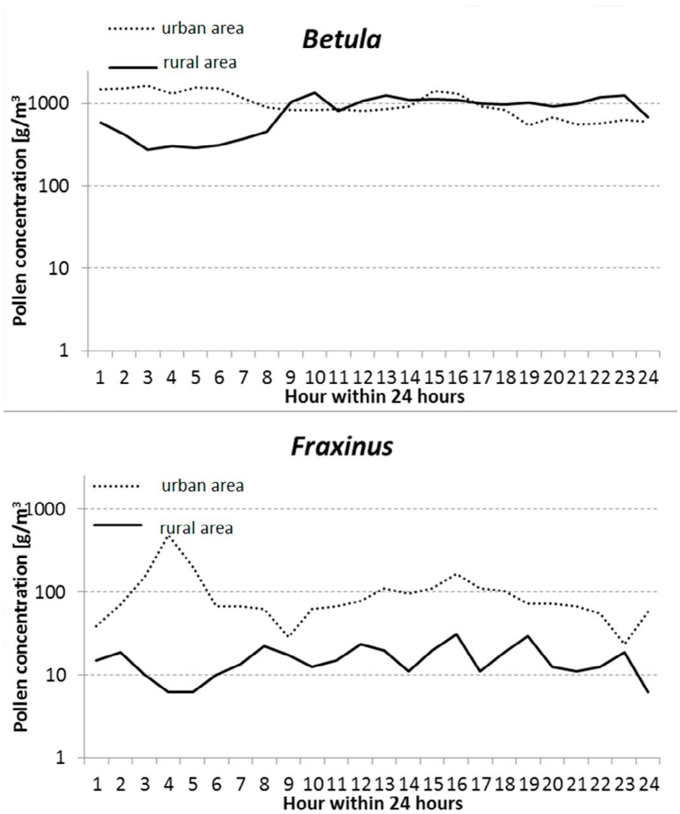

Fig. 1. Diurnal fluctuations of birch tree (*Betula*) and ash tree (*Fraxinus*) pollen concentration.

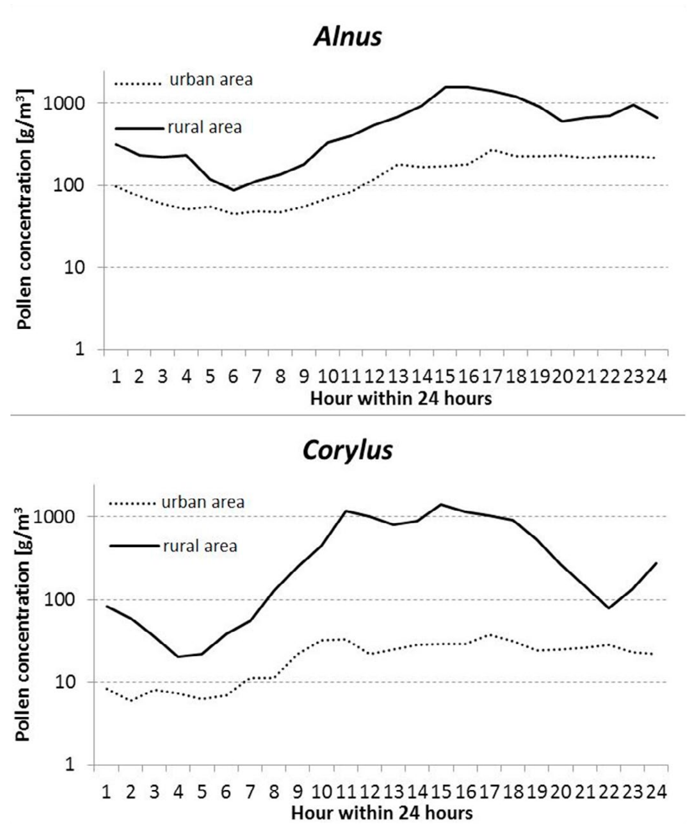

Fig. 2. Diurnal fluctuations of alder tree (*Alnus*) and hazel (*Corylus*) pollen concentration.

performed for each 1-hour period separately, with pollen counts expressed per 1 m^3 of air [16]. For each taxon the main pollen season was determined as the period in which 25–75% of annual pollen sum (of SPI seasonal pollen index) is airborne. Measurements of diurnal dynamic changes in pollen counts (Fig. 1.–3.) for each plant were made on the days from the main pollen season with no precipitations. With this method the days with unusually low pollen counts were excluded and the impact of precipitations on pollen count fluctuations could be disregarded, while the set of data was still large enough for a reliable analysis. As the pollen count distribution checked by the Shapiro-Wilk test was divergent from the normal distribution, the correlation analyses were made by the Spearman test in Statistica 12, at the level of significance of $p < 0.05$ [17].

Pollen monitoring was carried out in Szczecin, a large urban agglomeration, representing urban areas and in Gudowo village in West Pomerania, representing rural areas. The measuring site in Szczecin was in the Śródmieście district (53°26'23" N and 14°32'53" E), at 21 meters above the ground level. The closest area was loosely covered with apartment blocks and tenement houses. The vicinity of the measuring site comprises trees of poplar, birch, linden and plane species. In a distance of about half kilometer there is one of the largest forest parks in Szczecin. More than half of the forested area in Szczecin is occupied by urban forests, which are parts of three wild forests growing in the lower section of the river Oder [18]. The measuring site in Gudowo was in the center of the village, at a distance of about 100 km SW of Szczecin, (53°29'34" N, 15°51'44" E). Pollen sampler was mounted on the roof of a farm building, at about 4.5 m above the ground level. The surrounding area is covered with single-family housing with farm buildings, arable fields and greenery. The vicinity of the measuring site was covered with numerous willow, hazel, linden, birch, yew, maple and pine trees.

RESULTS

At both measuring sites, the main pollen season of birch tree (*Betula*) fell on April and lasted 9 days on average, the longest in 2014 (14 days in Szczecin and 13 days in Gudowo). From among the species whose pollen was measured, birch pollen occurs at the highest diurnal and hourly counts, similar at both measuring sites. The hourly birch pollen count distribution curve in the urban area (Fig. 1.) reveals two peaks. The first falls at night, between 1:00 a.m. and 6:00 a.m., the highest pollen count of over 1660 grains per 1 m^3 per hour was noted at 3:00 a.m. The second peak was in the afternoon, between 3:00 p.m. and 4:00 p.m. The birch tree pollen count decreased in late evening.

The hourly birch pollen count was very high, i.e. of 560–680 grains per 1 m^3 per hour even in the period of diurnal decrease, between 7:00 p.m. and 12:00 a.m. The analogous curve for the rural area (Fig. 1.) shows two periods: that of lower pollen count at night and that of higher pollen count between 9:00 a.m. and midnight and three peaks, the first at 10:00 a.m., which was the diurnal maximum and two lower ones at 12:00 p.m. and 11:00 p.m. The lowest diurnal birch pollen count in the rural area, of 274 grains per 1 m^3 per hour, was noted at 3:00 a.m.

The main pollen season of alder tree (*Alnus*) at both measuring sites lasted 8 days on average. The dates of the beginning of the main season varied from February 21 in Szczecin (2014) to April 13 in Gudowo (2013). The diurnal pollen counts at both sites were very high, although the values were higher in the rural area. According to hourly measurements, the Alnus pollen count (Fig. 2.) in Szczecin was low from 1:00 at night to midday, then it gradually grew reaching maximum at 5:00 p.m., then it remained high till midnight. The lowest pollen counts were noted between 6:00 a.m. and 8:00 a.m. The curve illustrating hourly changes in *Alnus* pollen count in Gudowo has two peaks, the first was higher and was noted in the afternoon, between 1:00 and 7:00, while the second – between 10:00 p.m. and 12:00 a.m. The lowest pollen count was recorded between 5:00 and 9:00 a.m. The absolute minimum in this three-year period was at 6:00 a.m.

Hazel was the first to pollinate in all the years studied; the main pollen season began as early as January 30 in 2012 in the rural area and February 15 in 2014 in the urban area. The range of dates of the beginning of hazel (*Corylus*) main pollen season in Gudowo was 7 weeks, which was much longer than in Szczecin – 3 weeks. Also the duration of pollen seasons showed much variation, lasting 8 days on average in Szczecin, the longest in 2014 (14 days) and 12 days on average in Gudowo, the longest in 2013 (24 days). The airborne hazel pollen count in the rural area reached very high values, much higher than in the urban area, in the top pollen season. In Szczecin the hazel pollen count (Fig. 2.) at night, between 1:00–6:00 did not exceed 10 grains /m^3 of air. Two peaks were noted in the hourly diagram of pollen count in Szczecin, between 10:00 and 11:00 a.m. and in the afternoon between 5:00 and 6:00, with the maximum value at 5:00 p.m. The corresponding peaks of the hourly hazel pollen count in Gudowo were between 11:00 a.m. and 12:00 p.m. and between 3:00 and 5:00 p.m., the latter was of higher values. The diurnal maximum of hazel pollen count was noted at 3:00 p.m., while the lowest pollen count was measured between 1:00 a.m. and 7:00 a.m. For hazel, the negative correlation of pollen counts and precipitation occurrence was found in Gudowo (Tab. I.).

The main pollen season of beech tree (*Fagus*) in Gudowo started in April and lasted 14 days on average, while in Szczecin at the end of April and the beginning of May and lasted 8 days on average. At both sites the beech pollen counts were low, at similar levels. The curve of hourly variation of beech pollen counts recorded in Szczecin (Fig. 3.) shows two peaks, the first between 4:00 p.m. and 5:00 p.m. and the second – of almost the same height – between 8:00 p.m. and 9:00 p.m. Apart from the peaks the diurnal pollen counts were very low. The analogous curve for the rural area was very similar as that for the urban, with two peaks being noted between 2:00 p.m. and 3:00 p.m. and between 10:00 p.m. and 11:00 p.m., corresponding to pollen counts of about 20 grains per 1 m^3 per hour. For beech tree, negative correlation of pollen counts and precipitation occurrence was found in Szczecin (Tab. I.).

The dates of the beginning of the pollen season of elm tree (*Ulmus*) were similar, at the end of March in 2012 and 2015 and in the middle of April in 2014. The pollen season in Szczecin lasted for a maximum of 10 days, while in Gudowo – 20 days and was more abundant than in the urban area. The curve of hourly changes in elm pollen count in Szczecin (Fig. 3.) had a single peak at 2:00 p.m. Besides this peak,

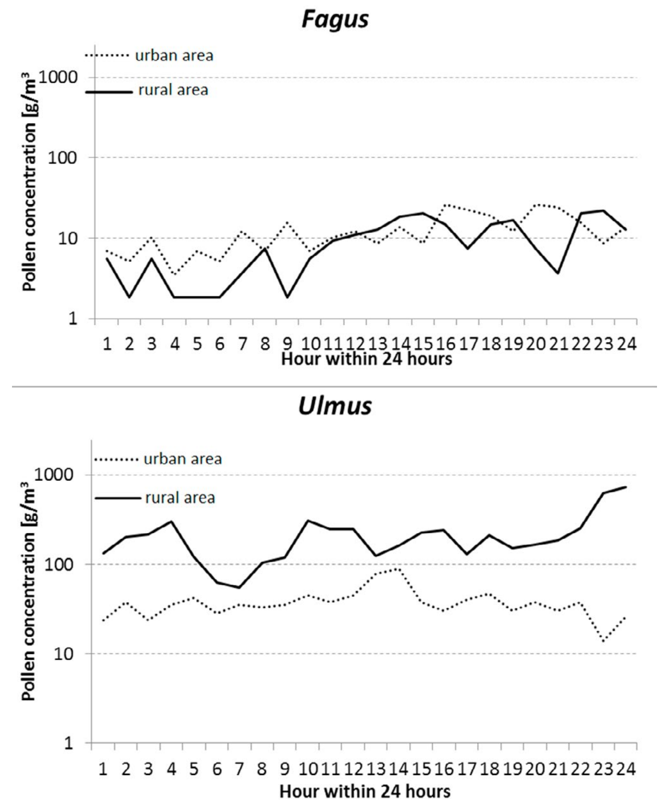

Fig. 3. Diurnal fluctuations of beech tree (*Fagus*) and elm tree (*Ulmus*) pollen concentration.

the pollen count was at a similar level. The lowest pollen count was measured near midnight. In Gudowo the elm pollen count varied rhythmically for the whole day, with a maximum at midnight and the lowest pollen counts between 6:00 and 7:00 a.m.

The main pollen season of ash tree (Fraxinus) in Szczecin lasted for 2–6 days. The season started from the end of April to the beginning of May. In Gudowo the pollen season was by 10–13 days longer than in Szczecin and started in April. Moreover, it was characterized by many times lower pollen counts than in Szczecin. The curve illustrating the hourly pollen counts in the urban area (Fig. 1.) revealed two peaks, the first much higher than the second, between 3:00 and 5:00 a.m., while the second at 4:00 p.m. The diurnal maximum was at 4:00 a.m., while the minimum occurred at 9:00 a.m. and 11:00 p.m. In the rural area the hourly pollen count distribution also showed two peaks, the first at 4:00 p.m.– the diurnal maximum, and the second at 7:00 p.m. Apart from these two peaks the pollen count showed no variation.

DISCUSSION

As follows from our observations, the curves of hourly distribution of pollen counts for different species do not have the same shapes. For birch tree (*Betula*) the character of the curve is significantly different from other taxons. A comparison of the diagrams for Szczecin (urban) and Gudowo (rural) shows that despite differences in the pollen counts, the majority of taxons studied show a similar dynamics of the hourly pollen count distribution.

Tab. I. Spearman's correlation coefficients between pollen concentration and precipitation in Szczecin (urban) and in Gudowo (rural), 2012–2014.

PRECIPITATION /TAXON	URBAN AREA	RURAL AREA
Betula	- 0.018	0.047
Alnus	- 0.167	- 0.185
Corylus	- 0.071	***- 0.213**
Fraxinus	- 0.167	- 0.068
Fagus	***- 0.149**	0.108
Ulmus	- 0.124	- 0.081

* Statistically significant at $p < 0.05$

The airborne variations of pollen counts in diurnal cycles are different, which confirmed the earlier studies [19, 20]. The values and variations of pollen counts depend on many factors that influence the release of pollen grains from the anther and its dispersal [21]. Galan et al. [22] have distinguished two types of diurnal patterns of airborne pollen counts. The first type is characterized by small differences between the maximum and minimum hourly pollen counts, while the second type – great differences. The first type pattern is found for birch tree pollen in both our measuring sites, while the pollen counts variations for the other species represent the second pattern. The diurnal rhythms of pollen counts can change in subsequent seasons or in different areas [10], which has also been observed in the urban and rural area of Poland.

The diurnal rhythms of anther opening are genetically determined, but the hourly dynamics of airborne pollen count depend on other factors, in particular meteorological [19, 23]. For some species growing in Szczecin (beech trees) and in Gudowo (hazel), a negative correlation of pollen counts and precipitation occurrence was found. During precipitations, high air humidity restricts the opening of anthers and pollen release, which reduces the airborne pollen count [24]. Precipitates lead to agglomeration of pollen grains in the air followed by their falling on the ground [25]. When the pollen grains that fell on the grounds dry out, they can be airborne again thanks to the wind, which is called redeposition. At the first moments of intensive precipitation the airborne pollen count may increase, which is probably a result of strong winds accompanying the precipitations [24]. Of particular significance in allergology are the drizzles as water suspended in the air is then absorbed by pollen grains which swell and break releasing cytoplasm with allergenic proteins [24, 26, 27].

In our study the measurements were made on days without precipitates, a similar procedure has been reported [21, 28, 29, 30, 31]. The maximum airborne pollen count has been observed during the day at the time of maximum air temperature and minimum relative humidity [10, 32, 33]. In the urban and rural areas that were studied, the pollen counts of the majority of the taxons studied were higher during the daytime than at nighttime. The character of the curves of hourly variations in pollen counts can be disturbed by the grains coming from far long-range transport and redeposition [34, 35]. Airborne pollen grains observed during the day do not always come from the original source of emission (anthers), sometimes higher pollen counts can be a result of temporary break in temperature fluctuations, which permits falling on the ground of the suspended pollen [36]. An increase in pollen count at night, noted e.g. for elm trees (*Ulmus*) (Gudowo) or ash tree (Fraxinus) (Szczecin), may indicate that the pollen comes from long-range transport. The release of pollen from anthers in the evening or at night is unlikely because of the unfavorable weather conditions. The maximum pollen count in the evening or at night can be a consequence of a far distance of the pollen source and the high pollen count is read off because the pollen from this far source has just reached the measuring site [21, 37, 38].

The diurnal variations of airborne pollen count coming from particular species measured in Szczecin and Gudowo were compared with the data reported by other authors. In the main pollen season of birch tree (*Betula*) the pollen counts at our measuring sites were very high for all 24 h, also at night. In Rzeszów over 50% of the total birch pollen count have been recorded in the evening and at night, with a maximum between 9:00 and 11:00 p.m. [39]. The curve of hourly distribution of birch pollen count in Szczecin has two peaks, one in the afternoon and the other at night. Norris-Hill and Emberlin [40] have explained their similar results obtained in London by the effect of the wind and different distances of pollinating trees from the measuring points. According to their interpretation, the pollen coming from local sources of emission gives the daytime peak, while the nighttime peak is a result of long-range transportation. Perhaps a similar situation took place in Szczecin. Two diurnal peaks have also been reported by Toth et al [11]. In Sweden, Berggren et al. [28] have reported many differences between the hourly distributions of pollen counts recorded in two cities. In Gudowo the diurnal maxima were noted before noon, while other authors from other localities report peak observations at noon, in the afternoon and even at night. This high diversity of results hinders the recommendation for prophylaxis in allergy to birch pollen allergy.

The data collected from a number of measuring sites illustrate the diversity of the hourly rhythms of pollen counts from alder tree (*Alnus*). The results obtained in our study are the most similar to those reported by Rodriguez-Rajo et al. [41]. Galan et al. [22] have reported the highest pollen count from this species between 4:00 and 5:00 a.m. as well as at 1:00 p.m. The results of other authors revealed maximum pollen counts in the evening [11, 35, 42].

The peak pollen counts for hazel (*Corylus*) noted at our measuring sites were a bit later than those reported from Lublin [35] and Zagreb [11]. The elevated levels of hazel pollen count were observed in Szczecin from 10:00 to 11:00 a.m. and in Gudowo from 11:00 a.m. to 12:00 p.m., besides the afternoon maxima. The occurrence of an additional peak in the morning hours was reported in Rzeszow [39]. Many anemophilous species start pollen release in the morning to make use of the uplifting convection currents [23, 43].

The diurnal dynamics of elm tree pollen count (*Ulmus*) in different localities were different. In Szczecin the diurnal period of elevated level of pollen count was noted at a similar time as in Cordoba [22]. In Toledo and Turku the hourly maximum of pollen count was noted at about 5:00 p.m., while in Gudowo at midnight [10, 20].

As far as ash tree (Fraxinus) pollen count diurnal variations are concerned, in Szczecin two diurnal periods of high pollen counts were noted, at night and in the afternoon. Similar results have been presented by Perez-Badia et al. [20]. Yang et al. [44] recorded the diurnal maximum in early morning, while Borycka [39] at noon. In Gudowo the highest pollen counts from ash tree were found in the afternoon, similarly as in the majority of other localities for which the data have been reported.

Pollen monitoring data allow to assess pollen allergen exposure of allergic rhinitis sufferers. The pollen produced by anemophilus plants can occur at high counts [45–46]. Of particular concern in this respect are the species that produce flowers prior to leaves, which facilitates dispersal of their pollen [47]. Exposure to tree pollen allergens changes not only seasonally, but also on a daily basis. Increased exposure can be caused by the specificity of hourly variability of pollen concentration and the hourly pollen count during 24 hours exceeds even several dozen times the average daily concentrations of pollen. As follows from our observations, in the evaluated period, the exposure to alder, hazel and elm pollen allergens was more intense in the rural than in the urban area. However, an individual exposure, resulting from local vegetation sources, can be multiplied. What is more, microclimate of the city, increased turbulences, the presence of high buildings restrict the aeroplankton spreading, that is why high levels of pollen count can remain longer in the cities than in open air areas [48]. The so-called "effect of urban heat island" caused by a combination of heat accumulation e.g. in asphalt and concrete, reduced level of relative humidity and specific winds, may extend the vegetation periods [49, 50]. Furthermore, in the urban area pollutants can play an adjuvant role by modifying allergenicity and enhancing the allergic response to allergens [51].

The knowledge of the above is essential in order to reduce the exposure to sensitizing allergens. Thus, education of the patient with allergic rhinitis is crucial. The first-line management in respiratory allergy is allergen avoidance. Effectiveness of pollen allergen avoidance will depend on the time spent outdoors, and the efficiency with which the indoor environment is isolated from the outdoors [1, 5, 52]. Sensitive individuals should optimally plan their activities when the pollen count is expected to be high, such as staying in low-exposure environments [53]. Pollen warnings are a part of self-management which allows the allergic rhinitis sufferers take control of the disease.

CONCLUSIONS

- The greatest similarities in the beginning of the main pollen season between the two sites studied were observed for birch and elm trees, while in the length of the main pollen season, for birch and alder trees. Pollen counts of alder and hazel reached higher levels in the rural area, while the levels of ash tree pollen counts were higher in the urban area. The level of birch tree pollen counts was similar in the two sites studied.
- For the majority of taxons observed in the urban and rural areas the dynamics of hourly changes in tree pollen counts were similar. The pollination peak was noted in the daytime, usually in the afternoon. For ash and elm trees, increased pollen counts were observed at nighttime, while the birch tree pollen counts were at a high level for most of the 24-h cycle.
- The knowledge of seasonal and diurnal variations in tree pollen counts is crucial for prevention in patients with allergic rhinitis, sensitized to tree pollen allergens.

REFERENCES

1. Pawankar R., Canonica G.W., Holgate S.T., Lockey R.F., Blaiss M.S.: World Allergy Organization (WAO) White Book on Allergy: Update 2013. Resource document. World Allergy Organization 2013.
2. Samoliński B., Sybilski A.J., Raciborski F. et al.: Prevalence of rhinitis in Polish population according to the ECAP (Epidemiology of Allergic Disorders in Poland) study. Otolaryngol Pol., 2009; 63(4): 324−330.
3. Tomaszewska A., Raciborski F., Samel-Kowalik P. et al.: Częstotliwość występowania alergicznego nieżytu nosa w wybranych regionach Polski. Analiza miasto – wieś. Otolaryngol Pol, 2007; 61(4): 550–553.
4. Nicolaou N., Siddique N., Custovic A.: Allergic disease in urban and rural populations: increasing prevalence with increasing urbanization. Allergy, 2005; 60(11): 1357−1360.
5. Bousquet J., Van Cauwenberge P., Khaltaev N., ARIA Workshop Group: World Health Organization. Allergic rhinitis and its impact on asthma. J Allergy Clin Immunol., 2001; 108(5 Suppl): S147–334.
6. Rapiejko P., Stankiewicz W., Szczygielski K., Jurkiewicz D.: Threshold pollen count necessary to evoke allergic symptoms. Otolaryngol Pol., 2007; 61(4): 591–594.
7. Caillaud D., Martin S., Segala C. et al.: Effects of airborne birch pollen levels on clinical symptoms of seasonal allergic rhinoconjunctivitis. International Archives of Allergy and Immunology, 2014; 163(1), 43–50.
8. Puc M: Influence of meteorological parameters and air pollution on hourly fluctuation of birch (Betula L.) and ash (Fraxinus L.) airborne pollen. Annals of Agricultural and Environmental Medicine, 2012; 19: 660–665.
9. Perez-Badia R., Vaquero C., Sardinero S. et al.: Intradiurnal variations of allergenic tree pollen in the atmosphere of Toledo (Central Spain). Annals of Agricultural and Environmental Medicine, 2010; 17: 269–275.
10. Kapyla M.: Diurnal variation of tree pollen in the air in Finland. Grana, 1984; 23: 167–176.
11. Toth I., Peternel R., Srnec L. et al.: Diurnal Variation in Airborne Pollen Concentrations of the Selected Taxa in Zagreb, Croatia. Collegium Antropologicum, 2004; 35: 43–50.
12. Biedermann T., Winther L., Till S.J. et al. Birch Pollen Allergy in Europe. Allergy. 2019. doi: 10.1111/all.13758.
13. Imhof K., Probst E., Seifert B. et al.: Ash pollen allergy: reliable detection of sensitization on the basis of IgE to Ole e 1. Allergo J, 2014; 23 (3): 78–83.
14. Niederberger V., Purohit A., Oster J.P. et al.: The allergen profile of Ash (Fraxinus excelsior) pollen: cross-reactivity with allergens from various plant species. Clin Exp Allergy, 2002; 32: 933–941.
15. Asam C., Hofer H., Wolf M.: Tree pollen allergens—an update from a molecular perspective. Allergy, 2015; 70: 1201–1211.
16. Mandrioli P., Comtois P., Dominguez-Vilches E. et al.: Sampling: Principles and Techniques. W: Methods in Aerobiology, red.: P. Mandrioli, P. Comtois, V. Levizzani, Bologna: Pitagora Editrice, 1998: 47–112.
17. Trigo Del Mar M., Toro F.J., Recio M. et al.: A statistical approach to comparing the results from different aerobiological stations. Grana, 2000; 39: 252–258.
18. Stachak A., Grinn U., Haas-Nogal M. et al: Zieleń Szczecina. Ilustrowany przewodnik dendrologiczny. Szczecin 2000; Oficyna In PLUS.
19. Nitiu D.S., Mallo A.C.: Incidence of allergenic pollen of Acer spp., Fraxinus spp. and Platanus spp. in the city of La Plata, Argentina: preliminary results. Aerobiologia, 2002; 18: 65–72.
20. Perez-Badia R., Rapp A., Vaquero C. et al: Aerobiological study in east-central Iberian Peninsula: Pollen diversity and dynamics for major taxa. Annals of Agricultural and Environmental Medicine, 2011; 18: 99–111.

21. Ščevkova J., Dušička J., Mičieta K. et al: Diurnal variation in airborne pollen concentration of six allergenic tree taxa and its relationship with meteorological parameters. Aerobiologia, 2015; 31(4): 457–468.

22. Galan C., Tormo R., Cuevas J. et al.: Theoretical daily variation patterns of airborne pollen in the South-West of Spain. Grana., 1991; 30: 201–209.

23. Gassmann M.I., Perez C.F., Gardiol J.M.: Sea-land breeze in a coastal city and its effect on pollen transport. International Journal of Biometeorology, 2002; 46: 118–125.

24. Puc M.: Wpływ pogody na przebieg sezonow pyłkowych. W: Aerobiologia, red. E. Weryszko-Chmielewska, Lublin 2007; Akademia Rolnicza w Lublinie; 68–74.

25. Palacios I., Molina R., Rodriguez A.: The importance of interactions between meteorogical conditions when interpreting their effect on the dispersal of pollen from homogeneously distributed sources, Aerobiologia., 2007; 23: 17–26.

26. Grote M., Vrtala S., Niederberger V. et al.: Release of allergen-bearing cytoplasm from hydrated pollen: A mechanism common to a variety of grass (Poaceae) species revealed by electron microscopy. Journal of Allergy and Clinical Immunology, 2001; 108: 109–115.

27. Grote M., Valenta R., Reichelt R.: Abortive pollen germination: A mechanism of alergen release in birch, alder, and hazel revealed by immunogolg electron microscopy. Journal of Allergy and Clinical Immunology., 2003; 111: 1017–1023.

28. Berggren B., Nilsson S., Boethius G.: Diurnal variation of airborne birch pollen in some sites in Sweden. Grana, 1995; 31: 251–259.

29. Latałowa M., Uruska A., Pędziszewska et al.: Diurnal patterns of airborne pollen concentration of the selected tree and herb taxa in Gdańsk (northern Poland). Grana, 2005; 44: 192–201.

30. Peel R.G., Orby P.V., Skjoth C.A. et al.: Seasonal variation in diurnal atmospheric grass pollen concentration profiles. Biogeosciences, 2014; 11: 821–832.

31. Puc M.: Influence of meteorological parameters and air pollution on hourly fluctuation of birch (Betula L.) and ash (Fraxinus L.) airborne pollen. Annals of Agricultural and Environmental Medicine, 2012; 19: 660–665.

32. Latorre F., Caccavari M.A.: Airborne pollen patterns in Mar del Plata atmosphere (Argentina) and its relationship with meteorological conditions. Aerobiologia, 2009; 25: 297–312.

33. Noh Y.M., Lee H., Mueller D. et al.: Investigation of the diurnal pattern of the vertical distribution of pollen in the lower troposphere using LIDAR. Atmospheric Chemistry and Physics., 2013; 13: 7619–7629.

34. Peeters A.: Ambrosia sp. pollen in Switzerland. Aerobiologia, 2000; 16: 295–297.

35. Piotrowska-Weryszko K., Weryszko-Chmielewska E.: Spatial differentiation of airborne arboreal pollen in Lublin (Poland). Acta Agrobotanica., 2015; 68: 333–341.

36. Norris-Hill J.: The influence of ambient temperature on the abundance of Poaceae pollen., Aerobiologia, 1997; 13: 91–97.

37. Smith M., Skjoth C.A., Myszkowska D. et al.: Long-range transport of Ambrosia pollen to Poland. Agricultural and Forest Meteorology., 2008; 148: 1402–1411.

38. Skjoth C.A., Smith M., Brandt J., Emberlin J.: Are the birch trees in Southern England a source of Betula pollen for North London? International Journal of Biometeorology, 2009; 53: 75–86.

39. Borycka K., Kasprzyk I.: Przestrzenne zróżnicowanie stężeń pyłku roślin drzewiastych w Rzeszowie w przebiegu sezonowym i dobowym. Sympozjum Aerobiologiczne Pyłek Roślin Wśród Nas, Szczecin 2015; Polska, 35–37.

40. Norris-Hill J., Emberlin J.: Diurnal variation of pollen concentration in the air of North-Central London. Grana, 1991; 30: 229–234.

41. Rodriguez-Rajo F.J., Dopazo A., Jato V.: Environmental factors affecting the start of pollen season and concentrations of airborne *Alnus* pollen in two localities of Galicia (NW Spain). Annals of Agricultural and Environmental Medicine, 2004; 11: 35–44.

42. Calderon-Ezquerro M.C., Guerrero-Guerra C., Martinez-Lopez B. et al.: First airborne pollen calendar for Mexico City and its relationship with bioclimatic factors. Aerobiologia, 2015; 32(2): 225–244.

43. Clot B.: Airborne birch pollen in Neuchatel (Switzerland): onset, peak and daily patterns. Aerobiologia, 2001; 17: 25–29.

44. Yang Y., Huang T., Chen S.: Diurnal Variations of Airborne Pollen and Spores in Taipei City, Taiwan. Taiwania, 2003; 48: 168–179.

45. Rapiejko P., Puc M., Malkiewicz M. et al.: Hazel pollen in the air of selected Polish cities in 2015. Alergoprofil, 2015; 11(3): 40–44.

46. Malkiewicz M., Lipiec A., Dąbrowska-Zapart K. et al.: Birch pollen season in southern Poland in 2017. Alergoprofil, 2017; 13(3): 118–123.

47. Rapiejko P.: Aerobiologia medyczna. Alergia Astma Immunologia, 2006; 11: 76–82.

48. Sudnik-Wojcikowska B.: Flora miasta – chaos i przypadek czy prawidłowości w różnorodności? Kosmos., 2002; 51: 213–219.

49. Mimet A., Pellsier V., Quenol H. et al.: Urbanisation induces early flowering: evidence from Platanus acerifolia and Prunus cerasus. International Journal of Biometeorology, 2009; 53: 287–298.

50. Rodriguez-Rajo F.J., Fdez-Sevilla D., Stach A., Jato V.: Assessment between pollen seasons in areas with different urbanization level related to local vegetation sources and differences in allergen exposure. Aerobiologia, 2010; 26: 1–14.

51. D'Amato G., Vitale C., Lanza M. et al.: Climate change, air pollution, and allergic respiratory diseases. Current Opinion in Allergy and Clinical Immunology, 2016; 16(5): 434–440.

52. Portnoy J., Barnes C.: Clinical relevance of spore and pollen counts. Immunol Allergy Clin N Am, 2003; 23: 389–410.

53. Samoliński B., Rapiejko P., Lipiec A., Kurzawa R.: Metody ograniczania narażenia na alergen. W: Standardy w alergologii. Cz. 1. Stanowisko Panelów Eksperckich Polskiego Towarzystwa Alergologicznego, red.: J. Kruszewski, M.L. Kowalski M.L., wyd. 2., Kraków, Medycyna Praktyczna, 2010: 143–149.

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