



Correspondence between tree pollen emissions sources and pollen content of the ambient air

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Abstract The article presents the findings, regarding the comparison between the pollen spectrum of the atmosphere in the area and the species composition of pollen emitting trees within the operating range of a Hirst-type volumetric air sampler. The research has revealed how local and transported pollen influence the pollen content of the atmospheric bioaerosol. Even though only a small number of birch trees grow in the area, its pollen proved to be prevalent in the pollen spectrum, while only an insignificant amount of *Quercus* pollen was detected due to the remoteness of its emission sources from the air sampler. Despite the fact that the highest number of trees in the immediate vicinity of the air sampler belong to the genus *Tilia* (linden), its pollen made up less than 1% of the pollen spectrum due to entomophily of these trees.

Locations of tree pollen emission sources in the immediate vicinity of the Burkard spore and pollen trap were mapped out.

Keywords Airborne pollen spectrum · Woody plants · Pollen inventories · Seasonal allergy

1 Introduction

Urban greenery plays an important role in creating a microclimate of a city, produces phytoncides, and determines the quality of atmosphere in a metropolitan area (Muzyka and Grabovj 2014; Carter et al. 2015; Trlica et al. 2017). Planting trees and shrubs in towns

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and cities is beneficial for people's health; it reduces pollution of the air with dust and toxic substances, lowers noise levels, and enhances the esthetics of the townscape (Wilmsers 2008; Glukhov and Volodarez 2010; Pitman et al. 2015).

However, the use of plants that produce allergenic pollen may heighten the risk of developing the symptoms of seasonal allergy among city residents (Celenk and Malyer 2017; Werchan et al. 2017). This risk is added to the existing background risk level which is mainly determined by pollen of indigenous anemophilous flora of the area (Sofiev and Bergmann 2013).

Over the last decade, ecologists and aerobiologists have become increasingly interested in identification and inventory of pollen emission land sources in a given region (Chapman et al. 2016; Makra et al. 2016). This interest was prompted by the need to determine trajectories of airborne allergenic pollen transport and, consequently, to pinpoint its sources in order to facilitate better prediction and modeling of allergy risks for people for the following days (Veriankaite et al. 2010; Weger et al. 2016; Flonard et al. 2018).

Today two independently created pollen transport model systems operate in Europe; they enable researchers to trace pollen movement in the atmosphere as well as to forecast pollen concentration levels of main allergens across Europe. One of the systems—COSMO-ART—was developed in the Institute for Meteorology and Climate Research in Karlsruhe, Germany (Baklanov et al. 2014; Glassmeier et al. 2017); the other—SILAM—was designed by specialists working at the Finnish Meteorological Institute (Helsinki, Finland) (Prank et al. 2016).

These models provide the means to anticipate variations in allergenic plant pollen concentrations mainly at the continental scale. Average target consumers of the information regarding potential pollinosis risks, however, are more interested in a detailed report about possible emergence of allergic conditions in their locality (Kukkonen et al. 2012; Berger et al. 2013).

Furthermore, one of the drawbacks of the models that attempt to predict allergy risks over a considerable territory is that they are fraught with uncertainty and imprecision when applied for a concrete, small, localized area. Moreover, current aerobiological practice is of limited or no use in creating a dynamic forecast in real time. This is due to the fact that pollen

is mainly collected by the volumetric method that requires continuous sampling of air content for 1 week; as a result, the information becomes available with a 7-day delay (Sofiev et al. 2013). Even if a 24-h head is used, it still causes a 1-day delay. Thus, phenological observations and detailed inventory of emission sources of allergenic pollen within a certain region become of practical importance, in particular for urban areas.

This often requires a detailed study of the local flora to determine taxonomic identity of plants that populate a certain territory. Nowadays such “natural” data are used to create various apps for mobile phones that inform users about the presence of allergenic pollen sources nearby and current exposure risk (Javier et al. 2010). In particular, a user can find out whether there are allergenic pollen emitters along the chosen route, whether at the moment they are generating allergenic pollen and in what amount.

Vinnytsia region commonly has forest-steppe landscapes. The forests are dominated by broadleaf trees composed of hornbeam (*Carpinus* spp.), maple (*Acer* spp.), linden (*Tilia* spp.), oak (*Quercus* spp.) and ash (*Fraxinus* spp.). Herb vegetation is characterized by a great variety.

The climate of the Vinnytsia region is moderately continental, characterized by long, warm and fairly humid summers, early spring, dry autumn, moderate frost and heavy snow cover in winter. The coldest month is January and the warmest month is July. Average amplitudes of temperature' fluctuations during the year do not exceed 25 °C. The highest temperatures are observed in July–August. The average annual amount of precipitation in the region is 440–590 mm. The winter months are the least wet, they account for 25% of annual precipitation. The beginning of spring corresponds with the transition of the daily temperature through the 0 °C and occurs most often in the second fortnight of March. Spring lasts about 2 months. Summer runs from the second fortnight of May to the first fortnight of September. The daytime temperatures in May are + 18... + 20 °C, in July – + 21... + 25 °C. The highest levels of precipitation, mainly showers, occur in this season. The number of days with precipitation decreases gradually, when the autumn approaches. The autumn begins with the downward transition of the average daily temperature through + 10 °C. The onset of autumn occurs in the first fortnight of October. A

characteristic feature of the autumn in Vinnytsia is the occurrence of warm sunny days. The autumn ends at the end of November, when the average daily temperatures drops below 0 °C (Report about the condition of the natural environment of the Vinnytsia region in 2016).

In Ukraine, two waves of pollination are normally observed and, as a result, two peaks of pollinosis exacerbation are registered. During the first wave (spring–summer), airborne pollen is produced by wind pollinated trees and grasses, and during the second wave (summer–autumn) by grasses and weeds (Rodinkova 2015). The period of active pollination of plants, mainly herbal, may last up to 180 days. The duration of exacerbation of pollinosis is on average 60–180 days. (Kuchma 2010; Pryhod'ko 2010; Pukhlyk 2013).

A significant part of wind pollinated plants flower in the early spring before trees break into leaf (hazel, alder, birch etc.) It is these plants that are the first seasonal cause of pollinosis symptoms among the afflicted people. Our previous studies show that pollen of birch, alder, hazel, oak is an important causal agent for the spring hay fever for Ukrainian population and the birch pollen solely may contribute as much as one-third of annual pollen index of Vinnytsia city (Rodinkova 2015). Due to the fact that pollen is generated in copious amounts as well as the sudden effect that tree pollen has on the bodies of sensitized people after the winter respite, members of the tree taxa that emit allergenic pollen take up a special place among all potential seasonal allergens (Pukhlyk 2009; Sofiev and Bergmann 2013; Rodinkova et al. 2013). Monitoring pollen constituents of the air enables researchers to determine the quantity and identity of potentially allergenic pollen content in the ambient air and how it changes over time (Werchan et al. 2017). The area of the operating range of a Burkard trap lies within a 40-km radius (Haberle et al. 2014; Skjoth et al. 2010). This coverage means that the pollen content registered where the air sampler is set up is formed by various emission sources. These sources are usually unevenly spaced at different distances from the pollen trap and demonstrate unequal quantitative representation of diverse tree taxa in the observed area. The most consistent and active pollen emitters, at least, in Vinnytsia area, are mainly woody plants (Rodinkova et al. 2018), whose exact positions on the ground are usually easy to identify. What is more, the herbaceous cover may change from year to year, especially, in the

cities, where mainly brightly flowering plants are planted that have large and showy perianth. They usually produce pollen which is transmitted by insects. On the other hand, trees are perennial plants, their location is permanent and it is possible to depict them on the ground as the sources of potentially allergenic pollen.

Thus, the *aim* of our study was to inventory the spatial distribution of airborne tree pollen sources at the trap location and to determine how it compares with the corresponding pollen spectrum composition in the atmospheric air.

2 Materials and methods

The study was conducted at the Laboratory of the Aeroallergenic Studies at the National Pirogov Memorial Medical University, Vinnytsia, Ukraine (VNMU).

Air sampling was performed by the standard volumetric method (Myszkowska et al. 2011; Thibaudon 2013) on a continuous 7-day basis using a Hirst-type suction slit impactor (a Burkard spore and pollen trap) in 2013–2015. The trap was set up on the roof of the Chemistry Department of VNMU in accordance with the requirements of the European Aerobiology Society (Lanzoni 2009; Galan 2011).

A 345-mm-long strip of Melinex tape was fixed onto a clock-controlled drum that made a complete revolution in 1 week. Before sampling, the Melinex tape was coated with an adhesive (a solution of pure silicon and carbon tetrachloride). After the tape was removed from the drum, it was cut into seven even pieces representing the 7 days of sampling. Each daily segment was made into a microscope sample which was mounted on a slide using glycerin and gelatin mixture. For better pollen identification, the samples were stained with the same solution containing basic fuchsin.

The study of the tree pollen content and concentration in the samples of atmospheric air was conducted at 400 × magnification using a Zeiss Axioskop microscope (Germany) by the method of 12 vertical transects so that the area of analyzed surface was 11,25%, which fits to the minimum requirements of pollen monitoring (Galan et al. 2014).

To determine taxonomic identity of the collected pollen, the identification key (Sulmont 2008) and reference sources were employed (Kuprijanova and Aleshina 1972, 1978).

To compare the data obtained by monitoring and quantify pollen emitters in the immediate vicinity of the Burkard trap, the number of trees growing within a 2-km radius around VNMU was counted. This territory covered the hospital grounds of the Vinnitsa Regional Clinical Hospital named after M. I. Pirogov, in M. Pirogov Boulevard and Vasyi Stus Square. The records of tree species composition in the Gorky Central City Park were studied. The data about main tree types that are currently planted in the Vinnitsa urban area by City Municipal Enterprise “Vinnytsyazelenbud” was obtained too.

The identified trees were placed on the electronic map of the city of Vinnytsia using the GIS Toolkit Panorama. For mapping purpose the name of a map feature, a unique identifier, types of symbols corresponding to a feature were determined. Specific symbols for the following tree taxa were created (Fig. 1): linden tree (*Tilia*), conifers (or Gymnosperms, *Pinus*, *Piceae*, *Abies* genera), birch (*Betula pendula*), horse chestnut (*Aesculus hippocastanum*), walnut (*Juglans regia*), maple (*Acer*), Rosaceae (cherry, apple tree, cherry plum, apricot).

In addition, the data provided by the Vinnytsia Regional Department of Forestry about the species composition of tree taxa in the woodland within a 40-km radius around Vinnytsia was used.

Spearman rank correlation was used to establish the correspondence between pollen index and territory occupied by certain taxa.

3 Results and discussion

A great number of trees that produce airborne pollen grow on the campus of VNMU. Also, one of the main

pollen generators is Gorky Park located at a distance of 1 km from the VNMU campus (Fig. 2).

On the territory adjacent to the Medical University buildings 605 trees have been located, the majority of which constitute 155 linden trees (*Tilia cordata*) (25.6%), followed by fir (*Abies*) (17.7%), maple (*Acer*) (10.4%), pine (*Pinus*) (9.6%), walnut (*Juglans regia*) (9.6%), horse chestnut (*Aesculus hippocastanum*) (8.8%) and common birch (*Betula pendula*) (6.8%) trees. Other woody plants have also been identified in this location in smaller quantities; these are black locust (*Robinia pseudoacacia*), willow (*Salix*), hazel tree (*Corylus*), poplar (*Populus*), alder (*Alnus*), oak (*Quercus*) as well as members of the families Rosaceae and Cupressaceae.

In the surrounding green zones situated in close proximity to VNMU further 2002 trees have been identified, the majority of which make up *Tilia cordata* (667) and *Aesculus hippocastanum* (187).

On the both previously described sites, the most frequently occurring woody plants belong to the genera *Tilia* (33%) and *Abies* (10%), *Aesculus hippocastanum* species (9%), the genus *Acer* (8%), the families Rosaceae (7%) and Cupressaceae as well as the genera *Betula* and *Pinus*—6% each (Table 1). (Pinaceae 16%)

Spearman's rank correlation between the percentage of area occupied by certain pollen producers and their pollen index was expectedly low ($r = -0.094$) but reliable ($p < 0.05$). Correlation between the pollen index and the territory of anemophilous species (*Betula*, *Alnus*, *Juglans*, *Salix*, *Ulmus*, Pinaceae, *Populus*, *Ostrya*, *Quercus*, *Corylus*, *Fraxinus*, *Carpinus*, *Acer*, *Fagus*, Cupressaceae, *Morus*) is better: $r = 0.27$ ($p < 0.05$).

To visualize the collected data, we have mapped the location of pollen emission sources in the area at various scales (Fig. 3a, b).

The Gorky Central City Park is a part of City Municipal Enterprise “Vinnytsyazelenbud.” The plantations of *Quercus robur* comprise 13.3% of the total area of the green zones of the park. No single species is predominant over most of the park territory. Here, grow hornbeam (*Carpinus betulus*), maples (*Acer campestre* and *A. platanoides*), ash tree (*Fraxinus excelsior*), *Tilia cordata* etc. (Klimenko 2010). Thus, the main pollen emitters in the park are trees of the genera *Quercus*, *Carpinus*, *Acer*, *Fraxinus* and *Tilia*.

- MAP LEGEND:**
- ▲ – Burkard trap
 - ① – Linden tree (*Tilia*)
 - ② – Gymnosperms (*Pinus*, *Piceae*)
 - ③ – Birch (*Betula*)
 - ④ – Horse chestnut (*Aesculus*)
 - ⑤ – Walnut (*Juglans regia*)
 - ⑥ – Maple (*Acer*)
 - ⑦ – Rosaceae (Cherry, apple tree, cherry-plum, apricot)

Fig. 1 Legend for the mapped trees of the investigated area

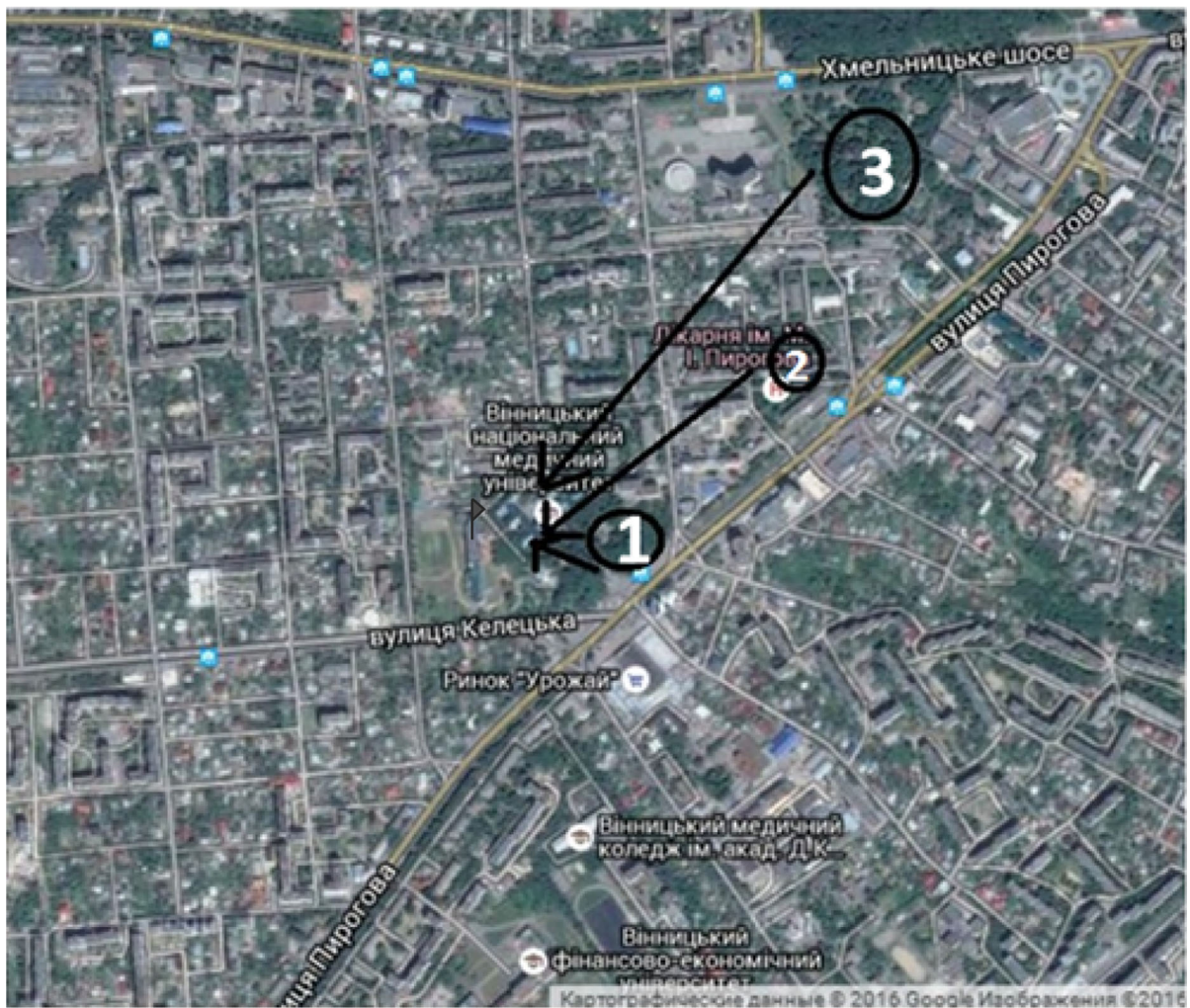


Fig. 2 The localized green spaces in close vicinity to the Burkard trap: 1. The public garden on the campus of VNMU. 2. The grounds of the Pirogov Hospital 3. The territory of the

Gorky Park. The arrows toward the trap indicate the location of the pollen inventory in relation to the pollen sampling site

According to the statistical data provided by the Vinnytsia Regional Department of Forestry, the main forest-forming category in the Vinnytsia Region is genus *Quercus* (79%). Plants of the genus *Fraxinus* occupy 7% of the woodland, *Pinus* and *Carpinus*—4% each. *Robinia*, *Betula*, *Alnus*, *Abies*, *Acer* and *Tilia* are represented in lower quantities (Fig. 4).

While investigating the tree pollen spectrum in 2013, it was established that the main pollen producer was *Betula* spp. Their contribution to the pollen spectrum was 26.2% of the annual tree pollen index. *Fraxinus* and *Alnus* produced 15.6% and 11.1%, respectively. The pollen of the main constituent

species of the Vinnytsia Region forests, *Quercus robur*, made up a mere 4% (Table 1).

The analysis of the pollen spectrum of the Vinnytsia atmosphere in 2014 revealed that the largest amount of pollen in the air was emitted by *Betula* (71.9%) and *Alnus* (7%). The percentage contributed to the annual tree pollen index by other tree taxa was low and reached 3% or less. *Quercus* pollen made up only 1.2% of that year's index.

In 2015, the highest amount of pollen was produced by trees of the genera *Alnus* (23.0%), *Betula* (16.8%), *Fraxinus* (15.1%) and *Juglans* 7.1%. The pollen spectrum also included tree pollen of the genera *Abies*, *Larix*, *Populus*, *Tilia*, *Siringa*, *Ulmus*, *Acer*,

Aesculus, *Betula*, *Carpinus*, *Corylus* as well as pollen of the Rosaceae family members. The percentage of *Quercus* pollen registered that year was 1.9%, which is a low number, just as it was in the previous years of observation (Table 1).

The collected data reveals that the pollen spectrum throughout the 3 years of observation qualitatively corresponds with the spectrum of tree plantations growing within the radius of the operating range of the Burkard trap, including the areas in its immediate vicinity. However, the composition of the tree species and the percentage of their pollen identified in the atmospheric bioaerosol differ significantly.

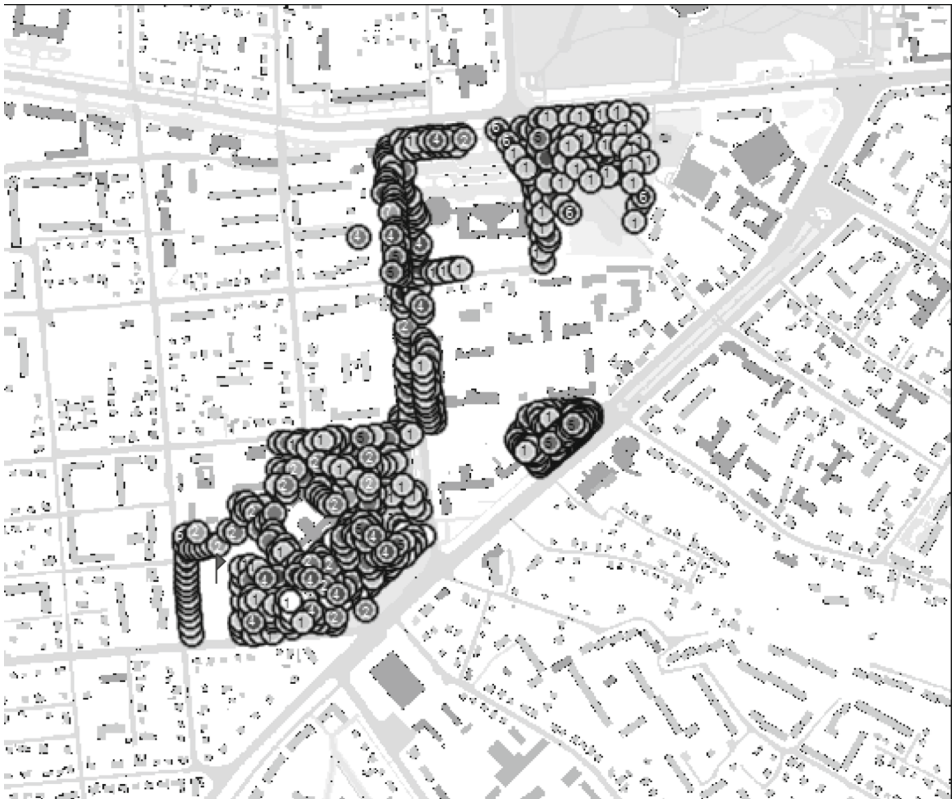
Such discrepancy may be caused by different strategies of pollen dispersion employed by trees. Thus, *Betula*, which pollen count in the air was one of the highest over all the years of observation, and

Fig. 3 The spatial distribution of tree pollen emission sources in close proximity to the Burkard trap: **a** scale 1: 70,000, **b** scale 1: 30,000 with the table reflecting the territory occupied by plants of different genera and families and their indexes on the map

Fraxinus, which pollen count was high in the years 2013 and 2015, being anemophilous plants, are well adapted their pollen dispersed by wind. Thus, they produce copious amounts of pollen grains and, as a result, both genera are important aeroallergens in central and northern Europe (Sofiev et al. 2015; Vara et al. 2016). Even though plants of the genus *Betula* were identified in close proximity to the Burkard trap as well as in the parks of Vinnytsia and in the green belt around the city, they account only for about 7% of trees mapped. *Fraxinus* trees were not identified

Table 1 Airborne tree pollen spectrum in Vinnytsia, years 2013–2015

Tree pollen producers	2013		2014		2015		$M \pm \sigma$	% of total, mean	% of territory
	Pollen index		Pollen index		Pollen index				
	Pollen grains-m ⁻³	% of total	Pollen grains-m ⁻³	% of total	Pollen grains-m ⁻³	% of total			
<i>Betula</i>	2421.6	26.2	22,832.7	71.9	1392.5	16.8	8882.3 ± 9873.4	54.1	6
<i>Alnus</i>	1027.8	11.1	2236.4	7.0	1898.7	23.0	1721.0 ± 509.2	10.5	0.1
<i>Juglans</i>	889.5	9.6	969.8	3.1	589.6	7.1	816.3 ± 163.6	5.0	5
<i>Salix</i>	172.8	1.9	535.1	1.7	24.1	0.3	244 ± 214.6	1.5	1
<i>Ulmus</i>	137	1.5	555.6	1.7	56.2	0.7	249.6 ± 218.9	1.5	0
Pinaceae	234.7	2.5	581	1.8	426.7	5.2	414.1 ± 141.7	2.5	16
<i>Populus</i>	535.2	5.8	678.9	2.1	209.9	2.5	474.7 ± 196.2	2.9	1
<i>Ostrya</i>	118.5	1.3	727.8	2.3	245.1	3.0	363.8 ± 262.6	2.2	0
<i>Quercus</i>	318.5	3.4	366	1.2	161.1	1.9	281.9 ± 87.57	1.7	0
<i>Corylus</i>	57.5	0.6	126.5	0.4	101.3	1.2	95.1 ± 28.5	0.6	0.2
Rosaceae	146.2	1.6	170.4	0.5	97.6	1.2	138.1 ± 30.3	0.8	7
<i>Fraxinus</i>	1439.5	15.6	391.4	1.2	1251.3	15.1	1027.4 ± 456.2	6.3	0
Oleaceae	38.9	0.4	129.6	0.4	48.7	0.6	72.4 ± 40.6	0.4	2
<i>Aesculus</i>	41.4	0.4	71	0.2	14.2	0.2	42.2 ± 23.2	0.3	9
<i>Carpinus</i>	958	10.4	300.6	0.9	485.9	5.9	581.5 ± 276.8	3.5	2
<i>Acer</i>	294.4	3.2	638.9	2.0	1147.3	13.9	693.5 ± 350.3	4.2	8
<i>Tilia</i>	90.2	1.0	89.5	0.3	5	0.1	61.6 ± 40.0	0.4	33
<i>Fagus</i>	85.8	0.9	12.4	0.0	21	0.3	39.7 ± 32.8	0.2	0
Cupressaceae	118.7	1.3	151.2	0.5	34.6	0.4	101.5 ± 49.1	0.6	6
<i>Morus</i>	117.3	1.3	199.4	0.6	56.2	0.7	124.3 ± 58.7	0.8	0.1
Others									3.6
Total	9243.5	100	31,764.2	100	8267	100	16,424.9	100	



Index on the map	Tree pollen producers	% of territory
1	<i>Tilia</i>	33
2	Pinaceae	16
3	<i>Betula</i>	6
4	<i>Aesculus</i>	9
5	<i>Juglans</i>	5
6	<i>Acer</i>	8
7	Rosaceae	7

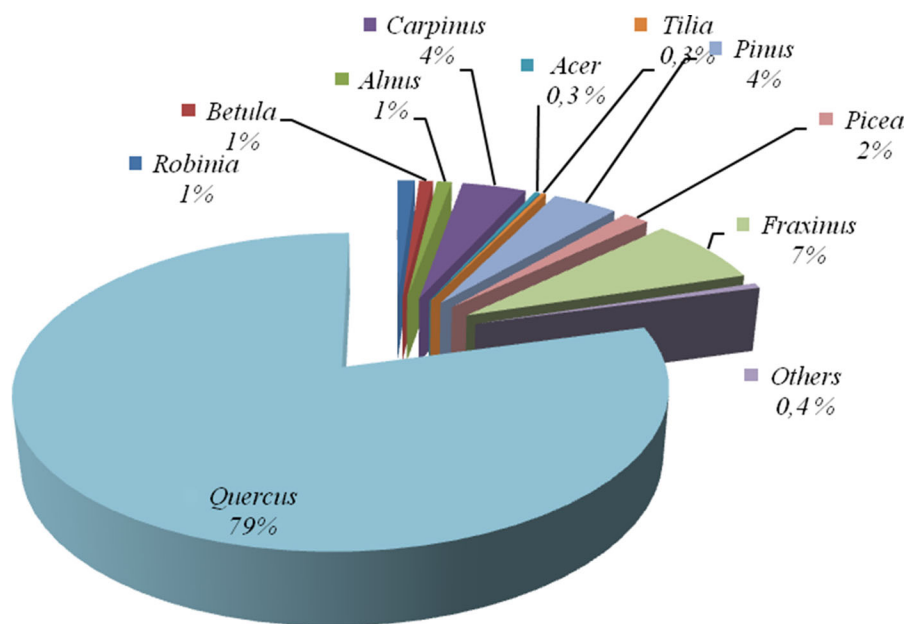


Fig. 4 The spectrum of woody plants on the territory of the Vinnytsia Regional Department of Forestry (217.1 ha) surrounding the city of Vinnytsia

around the sampling site, being common in the Gorky Park and local forests (Table 1, Fig. 4). The high *Betula* and *Fraxinus* pollen count in air samples may be caused by transport pollen fractions of these types and by the inter-annual variations of pollen index (Kubik-Komar et al. 2018; Rodinkova et al. 2018). This is very well described for *Betula*, which is characterized by the bi-annual mode of pollen production in Vinnytsia with higher pollen levels in even years (Rodinkova et al. 2018). Possible inter-annual patterns are possible for *Fraxinus* (Kubik-Komar et al. 2018). In addition, the wind directions and different intensity of pollen production might affect year-by-year variation of its pollen count.

Quercus pollen transport was also observed. While trees of the genus *Quercus* comprise the largest planted genus category in the territory managed by the Vinnytsia Regional Department of Forestry—making up 79% of the total number of tree taxa in the woodland of the green belt around Vinnytsia—their pollen accounted for only 1–4% of the total amount detected in the air samples. Notably, only a few individuals of the genus *Quercus* were identified in close proximity to the Burkard trap; a few more trees were seen in the Gorky Central City Park. Most likely, low *Quercus* pollen levels are seen in the air samples due to the fact that most of the oaks have recently been

planted by the Forestry Department after old trees had been harvested for lumber. In 20–25 years' time—when these trees have matured and reached the age at which oaks usually start blooming, *Quercus* pollen count in Vinnytsia may increase dramatically (Burger et al. 2018). The low percentage of *Quercus* pollen in the registered pollen spectrum in Vinnytsia may also be explained by relative remoteness of scattered oak pollen sources in uninvestigated city parks from the site where the air sampler was situated. Trees of the genus *Tilia*, which are entomophilous and which have been identified as the most numerous among the tree taxa growing in the Vinnytsia urban area (33%), produce sticky pollen. It made up 1% of the annual tree pollen index of each year of observation. Due to its entomophily, *Tilia* pollen is not readily dispersed by wind and the number of trees does not fit with the amount of pollen trapped. However, linden pollen is a moderate allergen (Sulmont 2008), that can be considered by sensitive individuals.

Thus, the pollen rain over Vinnytsia was composed of pollen grains of *Betula*, *Fraxinus*, *Abies*, *Pinaceae*, *Acer*, *Quercus*, *Juglans*, *Tilia* and other genera characteristic of tree populations of the Vinnytsia Region (Bondar 2005). Both the trees that grow within the city boundaries and beyond them may have a significant impact on the pollen rain over the populated

territories. That is why, while selecting the plants for planting in public areas (such as parks, alleys and squares), it is necessary to consider not only their esthetic appeal but also potential threats that their pollen may pose in causing allergy symptoms among urban dwellers.

Since woody plants are perennial, the pollen types they generate are relatively stable, the recorded spatial distribution of the identified emission sources of allergenic pollen together with continuous control of pollen spectrum can be the basis for creating a map of city zones potentially dangerous for people suffering from hay fever symptoms for better prevention of allergy outbreaks.

4 Conclusions

1. The pollen rain over Vinnytsia was comprised of pollen grains of *Betula*, *Fraxinus*, *Abies*, *Pinaceae*, *Acer*, *Quercus*, *Juglans*, *Tilia* and other genera characteristic for tree formations of the Vinnytsia Region. The pollen spectrum qualitatively corresponds with the tree spectrum of the area. However, the composition of the tree species and the percentage of their pollen identified in the atmospheric bioaerosol differ.
2. The percentage of *Betula* pollen in the ambient air was the highest throughout all the years of observation.
3. While trees of the genus *Quercus* comprise the largest species category on the territory of Forestry Department their pollen accounted for only 1–3% of the total amount detected in the air samples due to relative recent planting of these trees.
4. Trees of the genus *Tilia*, which have been identified as the most numerous among the tree taxa growing in the Vinnytsia urban area, produced about 1% of the total pollen count registered in each year of observation.
5. The recorded spatial distribution of the identified emission sources of allergenic pollen and continuous control of pollen spectrum can be the basis for creating a map of city zones potentially dangerous for people suffering from hay fever symptoms for better prevention of allergy outbreaks.

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Compliance with ethical standards

Conflict of interest No conflict of interest has been declared.

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