

Intradiurnal periodicity of fungal spore concentrations (*Alternaria*, *Botrytis*, *Cladosporium*, *Didymella*, *Ganoderma*) in Cracow, Poland

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Abstract Aerobiological monitoring enables the definition of seasonal fungal spore concentrations and also intradiurnal time when the highest concentrations of spores could cause or increase allergy symptoms. These data are useful to estimate symptoms of disease, duration of infection and how advanced the illness is in people suffering from fungal allergens. The aim of the study was to compare the concentrations of fungal spores (*Alternaria*, *Botrytis*, *Cladosporium*, *Didymella*, *Ganoderma*) during dry and rainy periods and to analyse their intradiurnal changes. Average daily spore concentrations in dry and rainy periods were compared, using *z* test, separately for each taxon, season and for a combined 3-year period. Intradiurnal periodicity of fungal spore concentrations was analysed on the basis of three complementary diagrams. These spore concentrations were presented using three curves for all, dry and rainy days in 1997–1999 (April–November). The spore percentage in particular hours was normalized in relation to the daily spore sum accepted as 100%. Two further diagrams enabled the more precise analysis of the highest concentrations in dry

days. Daily *Botrytis* and *Cladosporium* spore concentrations did not show significant differences between dry and rainy periods. In the case of *Didymella* and *Ganoderma* spore concentrations, there were no significant differences between both weather types in the single years, although there was a significant difference when a 3-year period was considered. The differences between daily concentrations of *Alternaria* spores in dry and rainy periods occurred in 1997 and in a 3-year period. Intradiurnal periodicity of spore concentrations was different for ‘dry’ and ‘wet’ fungal spores. Dry spores are released from the spore-producing parts of the fungus under conditions of decreasing humidity and increasing airflow. Examples of dry spores are those from *Alternaria*, *Cladosporium* and *Botrytis*. Wet spores, such as those from many Ascomycetes (*Didymella*) and Basidiomycetes (*Ganoderma*), are released into the atmosphere by processes related to humidity conditions or rain. The highest concentrations of ‘dry’ spores were observed early in the afternoon, while highest values of ‘wet’ spore concentrations occurred in the predawn hours. Statistically non-significant differences between daily spore concentrations in dry and rainy periods of single seasons were found except for *Alternaria*. Statistically significant differences could occur when the studied period was longer than one season (*Alternaria*, *Didymella*, *Ganoderma*). The highest concentrations of *Alternaria*, *Botrytis* and *Cladosporium* spores were recorded at noon and early in the afternoon.

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Concentrations of *Didymella* and *Ganoderma* spores were highest in the predawn hours.

Keywords Fungal spores · Intradiurnal periodicity

1 Introduction

Fungi and their spores occurring in the atmosphere have been shown to be important aeroallergens in many regions throughout the world. Fungi grow near places where people inhabit and in all climatic zones. They are present in water, soil and the atmosphere. The most important factors that influence the development of fungi are temperature and relative humidity of the air. Optimum relative humidity ranges from 75 to 95%. However, xerophilic fungi could develop even at humidity below 75%. The majority of fungi are mesophilic with optimum temperatures between 20 and 40°C. For psychophilic fungi i.e. *Cladosporium*, the optimum temperature is below 20°C (Shaheen 1992). Thermophilic fungi require temperatures over 40°C to develop (Gravesen 1979; Herrero et al. 1996).

Fungal spores are distributed by the air, water, animals and people. The main vector passively transporting spores is the air (Govi 1992). Monitoring of fungal spore concentrations allows efficient protection of plants against pathogens by applying appropriate means such as using fungicides. Fungi also cause many allergic diseases in people. The most observed inhalative allergy refers to the upper and lower respiratory tracts, which are penetrated easily by spores because of their small size that ranges from 100 to 2 µm. Studies on the occurrence and distribution of different fungal spores using volumetric methods have been performed for a long time in Europe (Larsen 1981; Munuera Giner and Carrion Garcia 1995; Nikkels et al. 1996; Tariq et al. 1996; Kurkela 1997; Grinn-Gofroń and Mika 2008), Northern America (Levetin 1991; Craig and Levetin 2000), Australia (Mitakakis et al. 1997; Mitakakis and Guest 2001) and in the Middle East (Shaheen 1992; Al-Suwaine et al. 1999).

In Poland the first study on fungal spores in the atmosphere was carried out in Cracow and Rabka Spa in 1960 (Weiss 1962). In the aerobiological literature, many authors indicate the differences in the intradiurnal periodicity of fungal spores of particular fungi

taxa. These differences depend on weather conditions, spore occurrences during day and night, seasons, geographical situation and the distance from sources of spores production (Hjelmroos 1993; Corden and Millington 1994; Kurkela 1997; Mediavilla et al. 1997; Stach 1997; Fernandez et al. 1998; Hollins et al. 2004; Stennett and Beggs 2004). Aerobiological monitoring enables definition of fungal spore concentrations seasonally and also times of the highest concentrations during day and night, when spores could cause or increase allergy symptoms. These data are useful to estimate symptoms of disease, duration of infection and how advanced the illness is in people suffering from fungal allergens. The aim of the study was to compare daily concentrations of fungal spores (*Alternaria*, *Botrytis*, *Cladosporium*, *Didymella*, *Ganoderma*) during dry and rainy periods and to analyse their intradiurnal changes.

2 Materials and methods

Fungal spore concentrations were analysed on the basis of data collected in Cracow in 1997–1999 using a Burkard volumetric spore trap of the Hirst design (Hirst 1952). Daily average concentrations (spores m⁻³) were obtained by counting spores every hour along one horizontal, central line at 400× magnification of a light microscope Nikon Eclipse E400 (with phase contrast optics) and applying an appropriate conversion factor (field width of the traverse is 0.54 mm). A horizontal scan will not miss a sudden burst of spores (Operating instruction, Airborne...1994). Average daily spore concentrations in dry and rainy periods were compared using *z* test separately for each taxon, season, and for a combined 3-year period.

Analysis of intradiurnal periodicity of fungal spore concentrations was performed on the basis of three complementary diagrams. Intradiurnal periodicity of spore concentrations was presented using three curves: for all, dry (0.0 mm rain within 24 h) and rainy (above 0.0 mm rain within 24 h) days (April–November). The spore percentage in particular hours was normalized in relation to a daily spore sum, which was accepted as 100%. Two further diagrams enabled the more precise analysis of the highest concentrations in dry days.

Cracow and Poland are influenced by the air masses of the polar-maritime origin coming from over the Northern Atlantic. Mean January and July temperatures in Cracow are -3.4 and 17.6°C , respectively. Mean annual sunshine duration per day is 3.9 h although from April to September, it is 5.7 h. Mean annual precipitation is approximately 700 mm. The highest rainfall level is recorded in summer (June, July and August). Mean annual relative humidity is 79% and wind from westerly direction prevails (Woś 1999).

3 Results

Meteorological factors in the seasons 1997–1999 varied clearly. In the whole study period, seasonal average maximum and minimum temperatures were the lowest in 1997 (17.5°C , 8.2°C , respectively) and the highest in 1999 (19.1°C , 9.1°C , respectively). Rainfall also varied. The lowest accumulated rainfall 559.5 mm was recorded in 1998. In 1997 and 1999 rainfall levels were higher: 736.3 and 566.6 mm, respectively. In 1997–1999 daily average relative humidity was about 77%. Sunshine in Cracow is a factor of great variation in consecutive days. It fluctuates from sun absence to 15 h of sunshine.

The comparison of average daily spore concentrations in dry and rainy periods, using z test, showed that in the case of *Botrytis* and *Cladosporium* spores, no significant differences between concentrations in both periods were found (Table 1). Daily concentrations of *Didymella* and *Ganoderma* spores did not show differences between dry and rainy periods in single years. However, there were differences revealed over the 3-year period. The differences between daily concentrations of *Alternaria* spores in dry and rainy periods were significant in 1997 and in a combined 3-year period. If we consider only 1 year, there is a small sample of data (about 238) and some statistical regularities are not apparent. This could explain the fact that in the case of *Didymella* and *Ganoderma* spores, significant differences between concentrations in dry and rainy periods occurred when a 3-year period was taken into consideration (larger dataset, approximately 714 days).

The study of intradiurnal periodicity of concentrations was performed for *Alternaria*, *Botrytis*, *Cladosporium*, *Didymella* and *Ganoderma* spores occurring in high numbers in Cracow.

Table 1 A comparison of average intradiurnal spore concentrations during dry and rainy periods

Taxon	Season	z	P	Difference
<i>Cladosporium</i>	1997	0.815	0.4149	NS
	1998	0.993	0.3208	NS
	1999	-0.035	0.9721	NS
	1997–1999	0.468	0.6395	NS
<i>Botrytis</i>	1997	0.393	0.6942	NS
	1998	-0.133	0.8941	NS
	1999	-0.701	0.4835	NS
	1997–1999	-0.176	0.861	NS
<i>Ganoderma</i>	1997	1.941	0.0523	NS
	1998	1.128	0.2595	NS
	1999	0.528	0.5977	NS
	1997–1999	2.125	0.0336	*
<i>Alternaria</i>	1997	4.000	0.0001	*
	1998	1.685	0.0920	NS
	1999	1.408	0.1592	NS
	1997–1999	4.137	0.0000	*
<i>Didymella</i>	1997	-1.901	0.0573	NS
	1998	-1.802	0.0716	NS
	1999	-1.0173	0.3090	NS
	1997–1999	-2.754	0.0059	*

z , test; P , probability of H_0 that no difference between daily spore concentrations in rainy and dry periods occurs

* Significant difference at significance level $\alpha = 0.05$ (two-sided test); NS non-significant difference

The three curves (for all, dry, rainy days) of intradiurnal periodicity of *Cladosporium* spore concentrations were similar in their courses (Fig. 1a). The highest concentrations occurred at noon, and the lowest between 7 and 8 a.m., and then the concentration did not exceed 200 spores per $\text{m}^{-3} \text{h}^{-1}$ (Fig. 1b). From 8 a.m. concentrations increased to reach daily maximum (about 1,150 spores per $\text{m}^{-3} \text{h}^{-1}$) at noon. The highest number of occurrences of maximum concentrations was recorded between 1 and 2 p.m. (Fig. 1c). For *Botrytis* spores, all the curves were similar in their courses from midnight to 4 p.m. (Fig. 2a). The curve for dry days showed the highest spore concentration at about 5 p.m., for rainy and all days between 9 and 10 p.m. The lowest values for all the curves fell between 7 and 8 a.m. In dry days the lowest values did not exceed 10 spores per $\text{m}^{-3} \text{h}^{-1}$ (Fig. 2b). The highest daily concentration (48 spores per

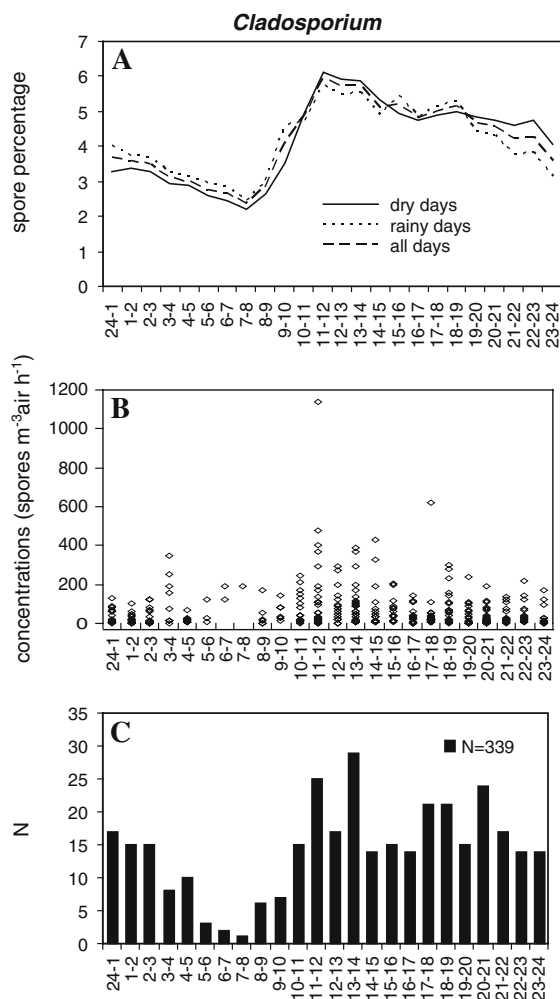


Fig. 1 Intradiurnal periodicity of *Cladosporium* spore concentration (a), maximum concentration per hour of day (b) and the number (*N*) of times the maximum concentration occurred at each hour (c); during 1997–1999 (b and c for dry days only)

$\text{m}^{-3} \text{h}^{-1}$) was noted between 2 and 3 a.m. The highest number of maximum concentration occurrences was observed from 1 to 2 a.m. and from 9 to 10 p.m. (Fig. 2c).

The courses of three curves of *Alternaria* spore concentrations showed similar tendencies although some differences between curves were observed (Fig. 3a). The decrease in concentrations for all the curves started between 8 and 9 p.m. reaching the lowest values for rainy and all days between 5 and 6 a.m. For dry days the lowest value was reached between 7 and 8 a.m., and then it did not exceed 10 spores per $\text{m}^{-3} \text{h}^{-1}$ (Fig. 3b). The highest value for

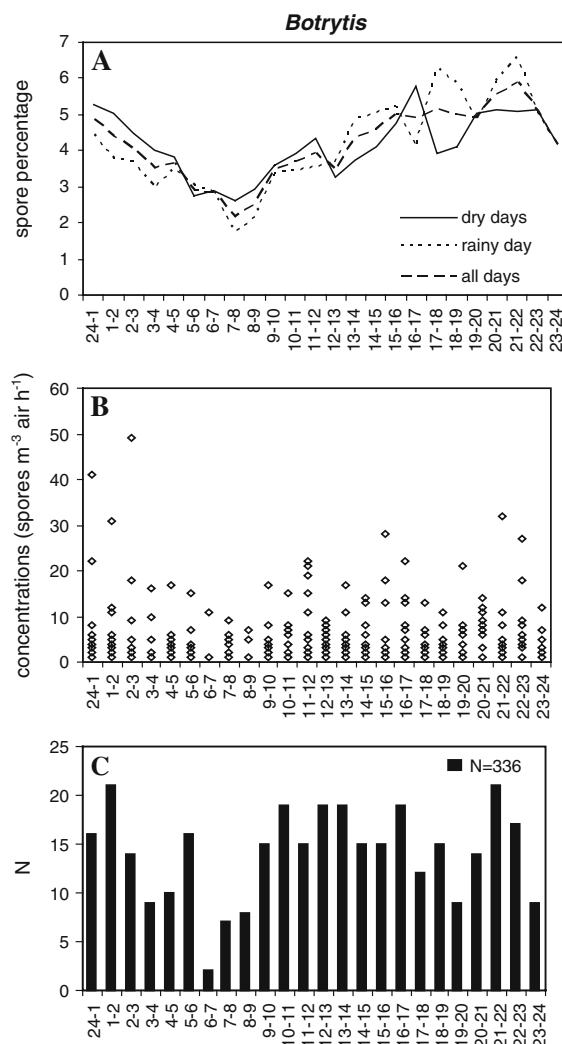


Fig. 2 Intradiurnal periodicity of *Botrytis* spore concentration (a), maximum concentration per hour of day (b) and the number (*N*) of times the maximum concentration occurred at each hour (c); during 1997–1999 (b and c for dry days only)

dry days occurred between 1 and 2 p.m. (45 spores per $\text{m}^{-3} \text{h}^{-1}$). The highest number of maximum concentration occurrences was noted between 8 and 9 p.m. (Fig. 3c). All the curves of *Ganoderma* spore concentrations fluctuated together (Fig. 4a). From 8 p.m. a clear increase in concentrations was noted reaching the highest values (about 28 spores per $\text{m}^{-3} \text{h}^{-1}$) at 3 a.m. (Fig. 4b). Then the decline in concentration, at first slow and then rapid, occurred between 6 and 9 a.m. For rainy and all days the lowest spore concentrations were observed between 2 and 3 p.m. and for dry days between 11 and 12 a.m.,

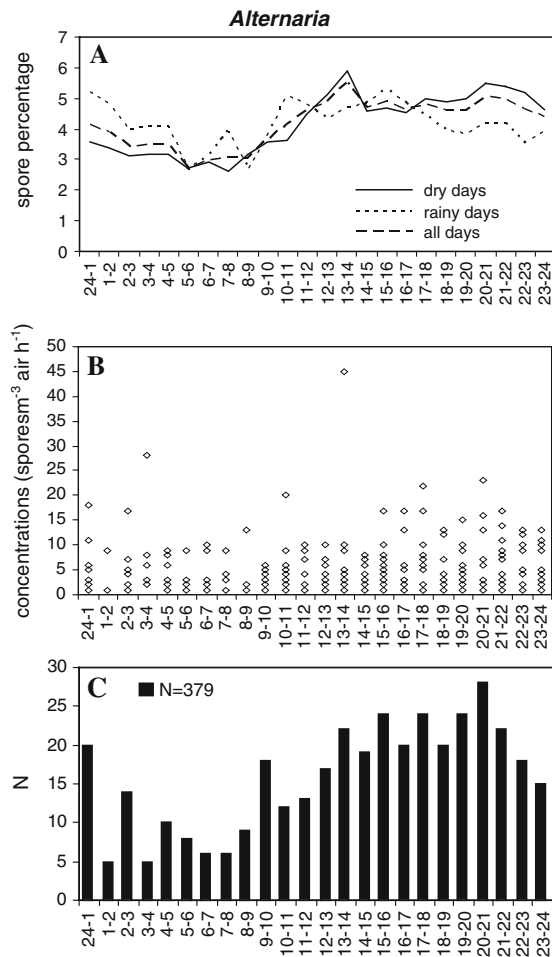


Fig. 3 Intradiurnal periodicity of *Alternaria* spore concentration (a), maximum concentration per hour of day (b) and the number (*N*) of times the maximum concentration occurred at each hour (c); during 1997–1999 (b and c for dry days only)

and then it did not exceed 7 spores per $\text{m}^{-3} \text{h}^{-1}$. The highest number of maximum concentration occurrences was noted from 3 to 4 a.m. (Fig. 4c).

The curves of *Didymella* spore concentrations were similar except for dry days between 5 p.m. and midnight (Fig. 5a). From midnight, a sudden increase in concentration was noted reaching the highest value between 3 and 4 a.m. and then a rapid decline. However, the highest daily value (73 spores per $\text{m}^{-3} \text{h}^{-1}$) occurred between 5 and 6 a.m. (Fig. 5b). The lowest concentrations for rainy and all days showed between 2 and 3 p.m., for dry days between 11 and 12 p.m. Then the concentration did not exceed 5 spores per $\text{m}^{-3} \text{h}^{-1}$. The highest number of

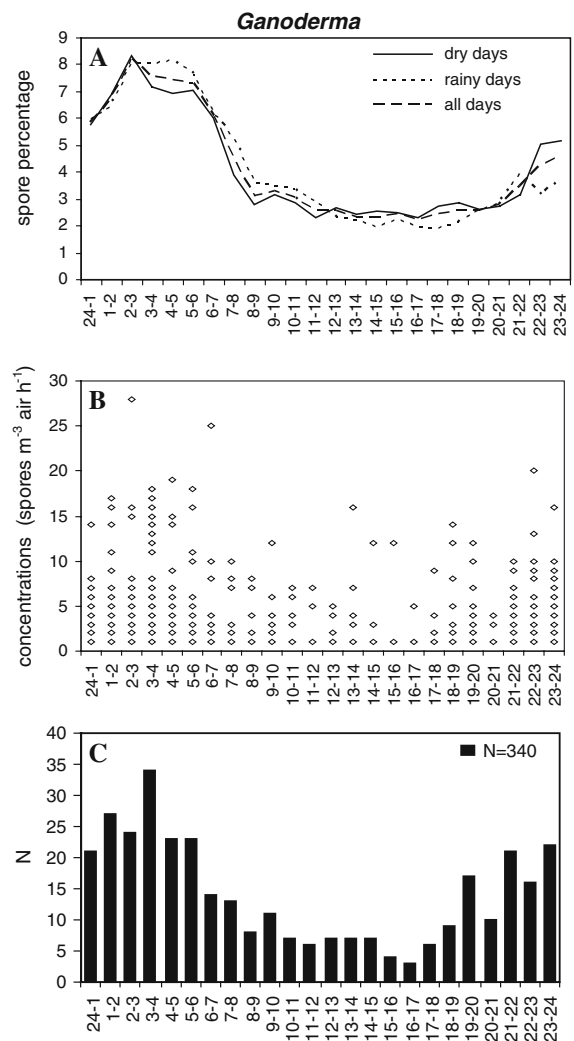


Fig. 4 Intradiurnal periodicity of *Ganoderma* spore concentration (a), maximum concentration per hour of day (b) and the number (*N*) of times the maximum concentration occurred at each hour (c); during 1997–1999 (b and c for dry days only)

maximum concentration occurrences was between 3 and 4 a.m. and between 5 and 6 a.m. (Fig. 5c).

Intradiurnal periodicity of spore concentrations was different for ‘dry’ spores released from the spore-producing parts of the fungus under conditions of decreasing humidity and increasing airflow (*Alternaria*, *Botrytis*, *Cladosporium*) than ‘wet’ spores released into the atmosphere by processes related to high humidity conditions or rain (*Didymella*, *Ganoderma*). The highest concentrations of ‘dry’ spores were observed early in the afternoon, while highest

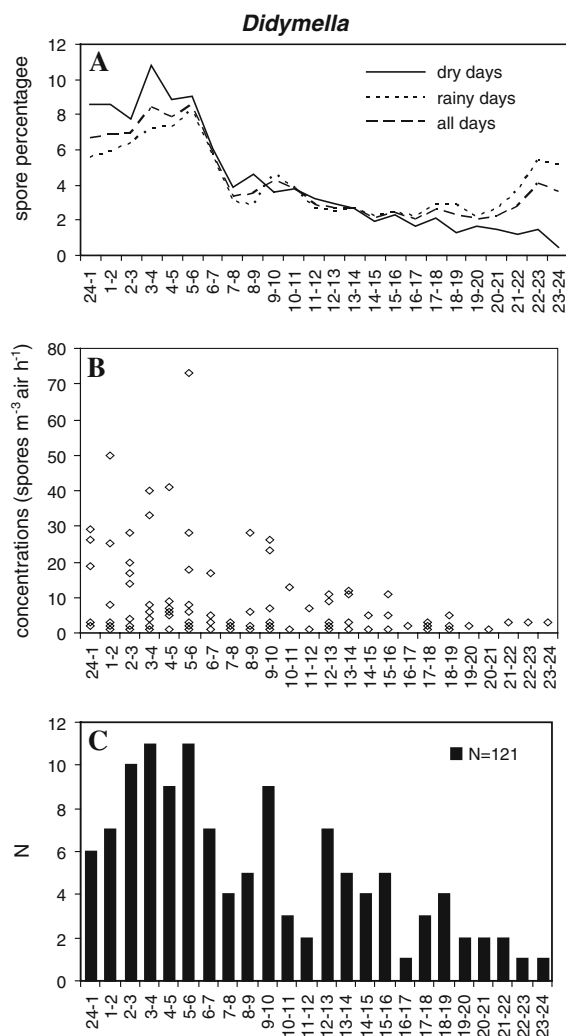


Fig. 5 Intradiurnal periodicity of *Didymella* spore concentration (a), maximum concentration per hour of day (b) and the number (*N*) of times the maximum concentration occurred at each hour (c); during 1997–1999 (b and c for dry days only)

values of ‘wet’ spore concentrations occurred in the small hours.

4 Discussion

The comparison of average daily spore concentrations in dry and rainy periods showed no significant differences between concentrations in the two periods in single seasons except for *Alternaria*. In the case of *Alternaria* significant differences in concentrations occurred in 1997. This could have been caused by the

then specific weather conditions that enhanced the effect of relationship between spore concentration and rainfall and temperature. In that year exceptionally high seasonal rainfall and the lowest seasonal average maximum temperature were noted (736 mm, 17.5°C).

The results obtained in Cracow suggest that daily maximum concentration of *Cladosporium* spores occurred at about noon. Results similar to those obtained in Cracow were found in Poznań, Poland (Stach 1997), Stockholm (Hjelmroos 1993) and Helsinki (Kurkela 1997). Later daily maxima, between noon and 2 p.m., were reported by Rantio-Lehtimäki et al. (1991) and Fernandez et al. (1998). Maxima between 2 and 3 p.m. were observed by Burge (1986), and between 3 and 4 p.m. by Adams (1964). Mediavilla et al. (1997) noted daily maximum concentration between 8 and 10 p.m. We compared our results with peak spore concentrations given by authors in other countries, assuming it was their local time. This could have been the reason for differences in the time of peak concentrations as well as a different distance between a source of spores and the air sampler location. The majority of the studies showed some similarity of the results. Maximum spore concentration occurred at noon and early in the afternoon. It is caused by the increase in temperature and wind velocity during a day, and the decline of relative humidity from morning hours to the afternoon.

The lowest spore concentrations were observed during the night when relative humidity increased and temperature reduced. Daily maximum concentration of *Botrytis* spores occurred in the afternoon. At the same time maximum concentration showed in England (Adams 1964). *Botrytis* spores are ‘dry’ spores and occur abundantly in the afternoon at temperature over 20°C and decreasing relative humidity (Diaz et al. 1997). For *Alternaria* spores, daily maximum concentration occurred between 1 and 2 p.m. In Poznań maximum was observed much later between 8 and 10 p.m. (Stach 1997). This was the result of a 1-year study. However, a 3-year investigation performed in England confirmed the maximum concentration occurrence in the evening hours about 8 p.m. (Corden and Millington 2001). Hjelmroos (1993) observed very early daily maximum at about 8 a.m. in Stockholm. Spores of *Cladosporium*, *Botrytis* and *Alternaria* as ‘dry’ spores are released into the atmosphere in warm and dry conditions during the day when the relative humidity is

low. The negative effect of relative humidity on the distribution of 'dry' spores was observed also by Ballero et al. (1992) and Kurkela (1997).

Energy is required to detach spores from their sources. It may be an active process through which, by some explosive or hygroscopic mechanism, spores are released by energy acting through the parent structure. Or it may be passive, by the energy of an external factor, usually wind. Activity of the various discharge mechanisms is more or less affected by external conditions. Results of the earlier studies performed in Cracow suggest that temperature is the most influential variable correlating significantly and positively with the spore concentrations (Stępańska and Wolek 2005). Discharge mechanisms include both wetting and drying so that the pattern of air spores shows intradiurnal changes.

In anamorphic fungi, such as *Cladosporium*, spores are formed in loose chains. When these chains dry, the hyphae twist and collapse, releasing the conidia but not forcefully discharging them. In *Alternaria*, spores are also produced in chains. In these thick-walled spores, drying facilitates discharge. As the cells dry, the cells shrink slightly and water is under tension. Then a gas bubble forms inside one of the cells, the cell expands abruptly, and conidia fly off. Ascospore discharge occurs by both passive and active means. In many Ascomycetes, ascospore release is active and often violent. The asci require humidity for spore release. Then the ascus becomes very stretched by internal water pressure, and finally it bursts and spores shoot out. In Basidiomycetes when the spores are mature, they are forcibly ejected.

The results obtained for maximum *Ganoderma* spore concentration in Cracow indicated some similarity to other authors' results. Daily maximum spore concentration in Cracow took place between 2 and 3 a.m. although high concentration occurred up to 6 a.m. Very similar results (about 4 a.m.) were obtained by Adams (1964) and Craig and Levetin (2000), and between 2 and 4 a.m. by Calderon et al. (1995). However, Hasnain (1993) found late-evening maxima (a nocturnal pattern) of *Ganoderma* spore concentrations. Maximum spore concentrations in the predawn hours and the daily depression are probably associated to high relative humidity of the air during the night which is accompanied by the decrease in temperature (Burge 1986). Other opinions were suggested by Lyon et al. (1984) that rainfall more

than humidity is connected with the release and distribution of fungal spores of Basidiomycetes.

On the basis of results obtained in Cracow, the daily maximum concentration of *Didymella* spores was observed at 4 a.m. although high concentrations occurred between 1 and 6 a.m. Similar data were reported in England where daily maximum was found at 5 a.m. for dry days and at 4 a.m. for all days (Corden and Millington 1994). Other authors in England observed the relationship between the release of *Didymella* spores, so-called wet spores, into the atmosphere and high humidity or rainfall (Frankland and Gregory 1973; Harries et al. 1985). Packe and Ayres (1985) suggested that high temperature during 4 days before a thunderstorm could cause exceptionally high concentration of *Didymella* spores which was reflected by high number of patients with asthma symptoms. This suggestion was supported by Corden and Millington (1994) who indicated that temperature over 20°C just before rainfall could have been the important factor for the release and distribution of spores.

5 Conclusions

1. Statistically non-significant differences between daily spore concentrations in dry and rainy periods in single seasons were found except at *Alternaria*.
2. Statistically significant differences could occur when the studied period was longer than one season (*Alternaria*, *Didymella*, *Ganoderma*).
3. The highest concentrations of *Alternaria*, *Botrytis* and *Cladosporium* spores were recorded at noon and early in the afternoon.
4. Concentrations of *Didymella* and *Ganoderma* spores were highest in the predawn hours.

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References

- Adams, K. F. (1964). Year to year variation in the fungus spore content of the atmosphere. *Acta Allergologica*, XIX, 1, 1–50.

- Airborne Pollens and Spores. (1994). *A guide to trapping and counting*. The British Aerobiology Federation.
- Al-Suwaine, A. S., Hasnain, S. M., & Bakhali, A. H. (1999). Viable airborne fungi in Riyadh, Saudi Arabia. *Aerobiology*, 15, 121–130.
- Ballerio, M., De Gioannis, N., Goretti, G., Lombardini, S., & Frenguelli, G. (1992). Comparative study about airborne spores in Cagliari and Perugia. *Aerobiologia*, 8, 141–147.
- Burge, H. A. (1986). Some comments on the aerobiology of fungus spores. *Grana*, 25, 143–146.
- Calderon, C., Lacey, J., McCartney, H. A., & Rosas, I. (1995). Seasonal and intradiurnal variation of airborne basidiomycete spore concentrations in Mexico City. *Grana*, 34, 260–268.
- Corden, J. M., & Millington, W. M. (1994). *Didymella* ascospores in Derby. *Grana*, 33, 104–107.
- Corden, J. M., & Millington, W. M. (2001). The long-term trends and seasonal variation of the aeroallergen *Alternaria* in Derby, UK. *Aerobiologia*, 17, 127–136.
- Craig, R. L., & Levetin, E. (2000). Multi-year study of *Ganoderma* aerobiology. *Aerobiologia*, 16, 75–81.
- Diaz, M. R., Iglesias, I., & Jato, M. V. (1997). Airborne concentrations of *Botrytis*, *Uncinula* and *Plasmopara* spores in a vineyard in Leiro-Ourense (N.W. Spain). *Aerobiologia*, 13, 31–35.
- Fernandez, D., Valencia, R. M., Molnar, T., Vega, A., & Sagües, E. (1998). Daily and seasonal variations of *Alternaria* and *Cladosporium* airborne spores in León (North-West, Spain). *Aerobiologia*, 14, 215–220.
- Frankland, A. W., & Gregory, P. H. (1973). Allergenic and agricultural implications of airborne ascospore concentrations from a fungus *Didymella exitialis*. *Nature*, 245, 336–337.
- Govi, G. (1992). Aerial diffusion of phytopathogenic fungi. *Aerobiologia*, 8, 84–93.
- Gravesen, S. (1979). Fungi as a cause of allergic disease. *Allergy*, 34, 135–154.
- Grinn-Gofron, A., & Mika, A. (2008). Selected airborne allergenic fungal spores and meteorological factors in Szczecin, Poland, 2004–2006. *Aerobiologia*, 24, 89–97.
- Harries, M. G., Lacey, J., Tee, R. D., Cayley, G. R., & Newman, T. A. J. (1985). *Didymella exitialis* and late summer asthma. *The Lancet*, 11, 1063–1066.
- Hasnain, S. M. (1993). Influence of meteorological factors on the air spora. *Grana*, 32, 184–188.
- Herrero, B., Fombella-Blanco, M. A., Fernandez-Gonzalez, D., & Valencia-Barrera, R. M. (1996). Aerobiological study of fungal spores from Palencia (Spain). *Aerobiologia*, 12, 27–35.
- Hirst, J. M. (1952). An automatic spore trap. *The Annals of applied biology*, 39, 257–265.
- Hjelmroos, M. (1993). Relationship between airborne fungal spore presence and weather variables. *Grana*, 32, 40–47.
- Hollins, P. D., Kettlewell, P. S., Atkinson, M. D., Stephenson, D. B., Corden, J. M., Millington, W. M., et al. (2004). Relationship between airborne fungal spore concentration of *Cladosporium* and the summer climate at two sites in Britain. *International Journal of Biometeorology*, 48, 137–141.
- Kurkela, T. (1997). The number of *Cladosporium* conidia in the air in different weather conditions. *Grana*, 36, 54–61.
- Larsen, L. S. (1981). A three-year-survey of microfungi in the air of Copenhagen 1977–79. *Allergy*, 36, 15–22.
- Levetin, E. (1991). Identification and concentration of airborne basidiomycetes. *Grana*, 30, 123–128.
- Lyon, F. L., Kramer, C. L., & Eversmeyer, M. G. (1984). Variation of airspora in the atmosphere due to weather conditions. *Grana*, 23, 177–181.
- Mediavilla, M. A., Angulo, R. J., Dominguez Vilches, E., Castro, O. A., & Infante Garcia-Pantaleón, F. (1997). Annual and diurnal incidence of *Cladosporium* conidia in the atmosphere of Cordoba, Spain. *Journal of Investigational Allergology & Clinical Immunology*, 7(3), 179–182.
- Mitakakis, T. Z., & Guest, D. I. (2001). A fungal spore calendar for the atmosphere of Melbourne, Australia, for the year 1993. *Aerobiologia*, 17, 171–176.
- Mitakakis, T. Z., Ong, E. K., Stevens, A., Guest, D., & Knox, R. B. (1997). Incidence of *Cladosporium*, *Alternaria* and total fungal spores in the atmosphere of Melbourne, Australia, over three years. *Aerobiologia*, 13, 83–90.
- Munuera Giner, M., & Carrion Garcia, J. S. (1995). Daily variation of *Alternaria* spores in the city of Murcia (semi-arid southeastern Spain). *International Journal of Biometeorology*, 38, 176–179.
- Nikkels, A. H., Terstegge, P., & Spieksma, F. T. M. (1996). Ten types of microscopically identifiable airborne fungal spores at Leiden, The Netherlands. *Aerobiologia*, 12, 107–112.
- Packe, G. E., & Ayres, J. G. (1985). Asthma outbreak during a thunderstorm. *The Lancet*, 27, 199–203.
- Rantio-Lehtimäki, A., Helander, M. L., & Pessi, A.-M. (1991). Circadian periodicity of airborne pollen and spores; significance of sampling height. *Aerobiologia*, 7, 129–135.
- Shaheen, I. (1992). Aeromycology of Amman area, Jordan. *Grana*, 31, 223–228.
- Stach, A. (1997). Dobowe wahania stężenia pyłku wybranych taksonów alergogennych w powietrzu nad Poznaniem w 1996 roku. In: I Ogólnopolska Konferencja Naukowa: Biologia kwitnienia, nektarowania i zapylania roślin, Lublin 13–14 listopada 1997, *Lubelskie Towarzystwo Naukowe*, pp. 197–203.
- Stennett, P. J., & Beggs, P. J. (2004). *Alternaria* spores in the atmosphere of Sydney, Australia, and relationships with meteorological factors. *International Journal of Biometeorology*, 49, 98–105.
- Stępańska, D., & Wołek, J. (2005). Variation in fungal spore concentrations of selected taxa associated to weather conditions in Cracow, Poland, in 1997. *Aerobiologia*, 21, 43–52.
- Tariq, S. M., Matthews, S. M., Stevens, M., & Hakim, E. A. (1996). Sensitization to *Alternaria* and *Cladosporium* by the age of 4 years. *Clinical and Experimental Allergy*, 26, 794–798.
- Weiss, A. (1962). Über das Pilzsporenvorkommen in der Luft in Kraków und bei Rabka. *Allergia Asthma*, 8, 298–303.
- Woś, A. (1999). *Klimat Polski*. Warszawa: PWN.