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THE OCCURRENCE OF *Cladosporium* SPORES IN THE AIR AND THEIR RELATIONSHIPS WITH METEOROLOGICAL PARAMETERS

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Abstract

Together with *Alternaria, Cladosporium* spores are known to be potent aeroallergens and its concentrations in the air are strongly dependent on meteorological factors. There are many articles from different parts of the world about relationships between *Cladosporium* spore count and weather parameters. The aim of the study was to review all available publications about *Cladosporium* spores in the air and compare the results in a short, useful form.

Key words: *Cladosporium*, airborne spores, meteorological factors, statistical correlation

INTRODUCTION

Cladosporium is one the most abundant worldwide airborne fungi. The abundance of conidia in the atmosphere is due in a large part to their ability to exist and thrive on a wide array of subsubstrates. A number of studies have confirmed that *Cladosporium* spores are an important aeroallergen and exposure to high concentrations affects human health by increasing the incidence of asthma and bronchial ailments (B a r n e s et al. 2001; T a r i q et al. 1996). *Cladosporium* has relatively small spores and so airborne concentrations must reach high levels in order to induce allergenic symptoms (B r o w n and J a c k s o n , 1978). G r a v e s e n (1979) has estimated an allergenic airborne concentration threshold of 3000 spores m^{-3} for *Cladosporium*. More recently, a figure of 4000 spores m^{-3} has been cited (A n o n , 2002). In Poland R a p i e j k o et al. (2004) reported that subjects with hypersensitivity to *Cladosporium* allergens experienced the symptoms during exposure to a concentration of approximately 2800 spores m^{-3} of air.

The genus *Cladosporium* includes over 30 species. *Cladosoprium herbarium*, *Cladosporium cladosporoides* and *Cladosporium macrocarpum* are all common species. The spores usually have distinctive “scars” at both ends where they were joined both to the spore at one end and to the conidiophores at the other. Although often single-celled spores, spores with a single transverse septum or several transverse septa are frequently seen. Their size ranges from 4 to 20 micrometers in length. Temperature optimum ranges from 18-28°C, but growth down to -6°C is possible (G r a v e s e n , 1979). *Cladosporium* species live on many kinds of plants. *Cladosporium* is soil borne and airborne, a saprophytic on dead wood, leaf debris and grasses. It is ubiquitous in the environment and a natural part of fungal flora almost everywhere. Its spores are responsible for infecting and causing plant diseases such as scab of cucumber (R o b a k and W i e c h , 1998).

The highest concentrations

Cladosporium spores are reported to form the majority of airborne spores in the temperate zones as a secondary invader of dead plants and trees (D a v i e s , 1969). *Cladosporium* species live as saprophytes or as parasites on many kinds of plants. Dry spores produced in excessive quantities can be transported over wide areas, even oceans. There is a great seasonal variation in the concentration of *Cladosporium* conidia in the air; the highest concentrations occur during the summer from June to September (B a l l e r o et al. 1992 – Cagliari, Perugia, Italy; E b n e r et al. 1989; H a l w a g y , 1989 – Kuwait; Ş a k i y a n and İ n c e o ğ l u , 2003 – Ankara, Turkey). The highest concentration of *Cladosporium* during summer was observed by H j e l m r o o s (1993) in Sweden and by S t ę p a l s k a et al. (1999) in Poland. The opposite occurrence was noted in Spain (I n f a n t e and D o m i n q u e z , 1988) and on Sardinia (C o s e n t i n o et al. 1990; P a l m a s and C o s e n t i n o , 1990) where a decrease in spore concentration was observed during summer. This situation has been related to the lack of rain and very high air temperature (Cosentino et al. 1990). In Jordan spores of *Cladosporium* are the most common in the air due to the wet and warm season, and maximum spore counts are noted in October (Shaneen, 1992). Oliveira et al. (2005) reported *Cladosporium* spores present in the air of Porto throughout the year in quite high concentrations. The first investigations of airborne fungal spores in Poland were carried out in the cities of Kraków and Rabka in 1960 (Gaweł et al. 1996; Weiss, 1962). Fifteen types of fungal spores were identified then, including *Cladosporium* which had the highest concentration in the total spore count. Many surveys of the occurrence of *Cladosporium* spores in different regions of the world clearly show their dominance in comparison with other spores (Calderon et al. 1997; Mitakakis et al. 1997; Shaheen, 1992). *Cladosporium* spores had the highest concentration in the seasonal spore count. The dominance of this genus in comparison with other spores has been observed in many locations, including Denmark (Larsen and Gravesen, 1991), Spain (Fernández-Gonzáles et al. 1993; Infante and Dominquez, 1988; Infante et al. 1992), Italy (Cosentino et al. 1990; Fillipello Marchisio et al. 1997), Austria (Ebner et al. 1992), Jordan (Shaneen, 1992) Sweden (Hjelmroos, 1993), India (Chakrabatory et al. 2003; Singh et al. 1994), Canada (Li and Hsu, 1995), Finland (Kurkela, 1997), Australia (Mitakakis et al. 1997; Mitakakis and Guest, 2001) and in some stations in the United States (Sneller and Roby, 1979).

Correlations with meteorological variables

Maximum temperature

In Szczecin daily *Cladosporium* spore concentration has a positive, significant correlation with maximum temperature. The same correlation was noted in southern Poland (Stępalska and Wołek, 2005), Finland (Kurkela, 1997), Sweden (Hjelmroos, 1993), Spain (Fernandez et al. 1998) and New Zealand (Hasnain, 1993). Hasnain (1993) also reported the strongest correlation between *Cladosporium* spore count and maximum day temperature in comparison with the concentrations of other airborne fungal spores.

Minimum temperature

A positive, significant correlation between spore count and minimum temperature for *Cladosporium* was noted in Cracow by Stępalska and Wołek (2005) and in Szczecin by Grinn-Gofroń (2008). Herrero et al. (1996) found a positive correlation between minimum temperature and *Cladosporium* concentrations. Also Fernandez et al. (1998) observed an increase in *Cladosporium* spore level at a minimum temperature above 13°C in summer.

Mean temperature

A slight correlation between *Cladosporium* spore count and mean temperature, but not significant, was noted by Stępalska and Wołek (2005) in Southern Poland (Kraków) and Mitakakis et al. (1997), Sen and Asan (2001) reported a significant, positive correlation with average temperature in Australia and Turkey. A similar correlation, based on Spearman rank correlation test, was noted by Oliveira et al. (2009) in two rural areas of Portugal.

Relative humidity

Kurkela (1997), Sen and Asan (2001), Stępalska and Wołek (2005), Oliveira et. al. (2009) found a negative correlation between *Cladosporium* spore and relative humidity. During a rainy period, the level of spore concentration was low. Fernandez et al. (1998) reported that relative humidity, in connection with minimum temperature, was a factor affecting spore release. Hasnain (1993) did not observe an influence of relative humidity on *Cladosporium* spore concentration, contrary to other ascospores. Katial et al. (1997) noted a positive correlation between *Cladosporium* spore count and relative humidity.

Rainfall

A slight correlation between precipitation and the number of *Cladosporium* spores was observed in Finland by Kurkela (1997). Only in one season did rain have a significant correlation with the number of spores counted 14 hours later. Hjelmroos (1993) noted that the increase in atmospheric concentrations after rainfall is generally long lasting, with the peak observed some hours after the rain. Katial et al. (1997), Mitakakis et al. (1997), Sen and Asan (2001), Oliveira et al. (2009) reported a negative correlation with rain for *Cladosporium*.

Wind speed

During the seasons in question, the correlation between *Cladosporium* spore concentration and wind speed did not show a statistically significant correlation. The same results were noted by Levetin and Dorsey (2006), Hasnain (1993), Lopez and Salvaggio (1983). Wind speed was clearly associated with spore dispersal in Finland (Kurkela, 1997), in Turkey (Sen and Asan, 2001) and in Portugal (Oliveira et. al. 2007). The long-distance dispersal of spores depends on wind conditions, but the detachment of spores dispersed in dry conditions is also strongly influenced by wind (Mallaiah and Rao, 1982).

Pressure

In contrast to the positive relationship with temperature, the concentration of *Cladosporium* spores was significantly and negatively correlated with air pressure. That correlation was noted only in one analysed season (Grinn-Gofroń, 2008). Hjelmroos (1993) noted the same results for *Cladosporium* in Sweden. A positive, significant correlation during one season in spring was reported by Troutt and Levetin (2001) from the United States.

Dew point temperature

Hasnain (1993) reported that dew point might play a secondary role in *Cladosporium* release but, as the atmosphere warmed, more *Cladosporium* seemed to be found in the air. A significant, negative correlation between *Cladosporium* spore count and dew point was noted in multiple regression analysis employed by Troutt and Levetin (2001). They noted that the temperature and dew point seemed to be the most important meteorological factors associated with *Cladosporium.*

Statistical models

Meteorological conditions clearly have a profound influence on the production, dispersal and deposition of fungal spores. The influence of meteorological factors on the concentrations of airborne fungal spores appears to be additive, not independent. The relationship might also be multiplicative and non-linear. Hence, the best statistical method which gives the most reliable results is the predictive model.

There are some forecasting models for *Cladosporium* spore concentration and meteorological parameters.

Li and Kendrick (1995) created a statistical model using CANOCO analysis which contains the data for eight types of spores in one-year study. The concentrations of *Cladosporium* spore were significantly correlated only with mean temperature. This factor was considered as the most important by the authors.

Katial et al. (1997) found a direct correlation with relative humidity and average temperature and inverse correlation with precipitation. They used time series analysis for three spore types in a eight-year study cycle. Their model incorporated the annual cycle and serial correlations of the errors with regard to spore variability. However, this method did not show the exact value of the key parameters correlated.

A more simple analysis to create a statistical model was used by Troutt and Levetin (2001) in Tulsa (United States). Multiple regression showed a positive, significant correlation between *Cladosporium* spore concentrations and temperature. This correlation was calculated for the two spring months during the two years of research.

Hollins et al. (2004) created multiple linear regression models using the number of days above threshold as the response variable against the climatic variables. The number of days in summer when *Cladosporium* spores were above the allergenic concentration was positively correlated with regional temperature and negatively correlated with precipitation over the study period.

The autoregressive predictive models created by Damialis and Gioulekas (2006) proved to be of high forecasting ability for the circulation of fungal spores in Thessaloniki, Greece, explaining the greatest variance of the time series and with relatively low forecast error. The obtained results showed that *Cladosporium* spores were strongly related to solar radiation.

The sporulation and dispersion of *Cladosporium* spores are closely related to variations in atmospheric conditions. Therefore, there is an increasing interest in the development of statistical models of high predictive power for atmospheric levels of airborne fungal spores that will allow allergic individuals to take preventative action.

For the abovementioned reasons, it was the first time that *Cladosporium* spore level was forecasted in Poland by Grinn-Gofroń and Strzelczak (2008).

Spearman's rank correlations for the whole data set showed a direct correlation with dew point temperature, three temperature parameters (maximum, minimum and average) and inverse correlation with relative humidity, average and maximum wind speed. Similar results were observed for spore seasons, although correlation level decreased with lags and was lower. The presence of many 0 values in *Cladosporium* variable probably overstated Spearman's correlation coefficients for the whole data set. ANN models confirmed the importance of the above listed parameters. The classification model indicated dew point temperatures (3 days prior, the same day and 2 days prior) as the most important variables, while the regression model for spore seasons - dew point temperature recorded the previous day, then humidity, maximum temperature on the same day and with lag 1.

It is confirmed that the ANN method gives the possibility to forecast satisfactorily *Cladosporium* spore concentration. It has turned out that time series with many 0 values are quite difficult to predict, since they actually contain 2 subsets (equal to 0 and higher than 0). Two ways of forecasting *Cladosporium* spore concentration are proposed in this study. The first model includes classification of spore presence or absence with good accuracy, and the focus on the prediction of log (x+1) transformed spore concentration during spore seasons. The second modelling possibility is to use time series prediction, based on meteorological parameters and other unknown factors, "hidden" in spore concentration values recorded in one sample year. Both of those forecasting methods revealed satisfactory performance and we believe that they can be successfully applied in other regions.

CONCLUSIONS

- Maximum, mean and minimum temperature was positively and statistically significantly correlated with *Cladosporium* spore concentration.
- A negative correlation was found for three weather parameters: rainfall, pressure and dew point temperature. The last factor was identified as the most important.
- No authors found significant, statistical relationships with wind speed.
- There was an unclear situation in the case of relative humidity. Some authors noted a positive correlation and others a negative one. In several cases, a statistically significant correlation did not occur.
- In the statistical models, the most important factors influencing the concentration of *Cladosporium* spores were mean temperature and dew point temperature. A positive correlation occurred between spores and relative humidity and negative with rainfall.
- Because despite of many various studies, the weather factors affecting the concentration of spores in the air are not defined precisely and unambiguously, the research methodology should be continually improved.

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Występowanie zarodników *Cladosporium* w powietrzu i ich korelacje z czynnikami pogody

Streszczenie

Zarodniki rodzaju *Cladosporium* są najczęściej i najliczniej notowanym taksonem grzybowym w większości stacji badawczych na świecie. Są też, razem z rodzajem *Alternaria,* uznane za czynnik wywołujący objawy alergii i astmy w okresie letnim czyli podczas wysokich temperatur i przy braku opadów. Było to powodem podjęcia prób określenia który z czynników pogody ma najsilniejszy wpływ na wysokość ich koncentracji w powietrzu.

Statystycznie istotne, pozytywne korelacje były notowane dla dobowych temperatur maksymalnych, średnich i minimalnych a negatywne dla wysokości opadów deszczu i ciśnienia atmosferycznego.

Żaden z autorów nie zanotował istotnej statystycznie korelacji pomiędzy stężeniem zarodników rodzaju *Cladosporium* a prędkością wiatru.

W prognostycznych modelach statystycznych najważniejszymi czynnikami meteorologicznymi wpływającymi na obecność zarodników *Cladosporium* w powietrzu była średnia temperatura powietrza i temperatura punktu rosy.

Przy obecnym stanie badań nad relacjami statystycznymi pomiędzy obecnością (stężeniem) zarodników w powietrzu a czynnikami meteorologicznymi warto popracować nad ulepszeniem istniejących metod badawczych lub zastosowaniem nowych, które precyzyjniej i bardziej jednoznacznie określiłyby rangę poszczególnych czynników meteorologicznych.