



The incidence of fungal spores in the ambient air and inside homes: evidence from London

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Abstract

Little research has been carried out in London concerning fungal spore prevalence yet this information may help to elucidate geographical patterns of asthma and hay fever. Although many types of spore reach peak concentrations outdoors in late-summer, the incidences in the indoor environment may be more important through the winter because of heating and poor ventilation. Daily average concentrations of fungal spores in the ambient atmosphere were monitored with a Burkard volumetric spore trap on an exposed roof in North London from autumn 1991 until the summer of 1992. Indoor spore measurements were taken in 19 homes in the vicinity through the winter months, both by direct air sampling using a portable Burkard sampler and by dust culture. Trends in the occurrence and concentrations of fungal spores indoors and outdoors were examined. Relationships between the abundance of selected allergenic fungi and features of the houses were analysed including age of dwelling, dampness, cleanliness and presence of pets. *Aspergillus* and *Penicillium* were the most frequently occurring spore types in the homes. Overall, high spore incidence was associated with dampness and dust accumulation. The outdoor spore samples revealed generally low concentrations through the winter until March when concentrations of many types including *Cladosporium*, *Epicoccum* and *Alternaria* increased in abundance in response to the warmer weather. Even during the late-spring and early-summer, concentrations of most fungal spores were notably below those reported for rural sites.

Keywords: Allergenic; Fungi; London; Spores

1. Introduction

It has long been established that respiratory allergic symptoms can be caused by the inhalation of airborne spores (Strachon, 1988; Platt et al., 1989; Lacey 1991) but quantitative information on the temporal and spatial distribution of such spores is still largely lacking. Certainly little research has been carried out in or around London concerning fungal spore prevalence. Various medical studies have revealed higher incidence of respiratory conditions including asthma in urban areas as opposed to rural areas (Åberg, 1989; Weeke, 1989). Many factors may be exerting influences to produce this pattern including air pollution, life style and possibly the abundance of some allergens. Concentrations of allergenic pollen are generally lower in urban

areas than in the surrounding countryside (Solomon, 1976; Santra and Chanda, 1989). Similarly, Palmas and Consentino (1989) observed that the largest fungal spore concentrations of most genera were found in rural areas, although no significant qualitative differences were found between rural and urban sites, being more or less similar in both regions. Before this, Gravesen (1972) noted a higher number of colonies and observations of fungi in rural homes as opposed to urban.

Urban residents spend over 90% of their time indoors and as such the importance of aeroallergens within buildings is important. Within homes, growth sites for fungi may be prolific, including rubbish bags, food storage areas, upholstery and wallpaper, together with areas of increased moisture such as shower curtains, window mouldings and basements (Salvaggio and Aukrust, 1981). Although a variety of environmental factors have been implicated by various investigations as

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determinants of fungal growth, increased dampness and the presence of house dust appear to be particularly significant (Lustgraaf and Bronswijk, 1987; Waegmaker et al., 1989), whilst Gravesen (1986) also emphasised the fact that carpets act as reservoirs for large amounts of dust and can function as 'cultivation media' for fungi.

Air pollution may also play an important role in aggravating respiratory disease indoors. Various sources enrich the indoor atmosphere, such as wall paints, carpet cleaning detergents, household solvents, formaldehyde, tobacco smoke and fumes from cooking. Recently, evidence from the work by Szantho et al. (1992) which studied the propagating aerogenic fungi (spores and conidia) in homes of asthmatic children in Hungary found 10.6% of those examined in 1977 were sensitive to fungi and that this figure rose to 30.4% in 1985 and 38.5% in 1987/88. Skin tests indicated that this trend was due to increasing sensitivity to *Alternaria alternata* and *Phoma betae*. During the period of the study, housing conditions improved and air pollutants increased. The study found that the sensitising masses of spores and conidia were most likely to form on moulds living on plants weakened by disease due to air pollution.

Against this background a research project was initiated by the Pollen Research Unit at the University of North London in 1991 to quantify fungal spore concentrations both in outdoor and indoor air, and to examine their qualitative occurrence in dust samples from homes. The prime aims of the project were

1. To compare the trends and magnitude of ambient fungal spore concentrations with concentrations found inside people's dwellings in North London.
2. To observe whether the spore concentrations of selected genera vary with regard to the age or condition of the dwelling.

2. Materials and methods

Data collection commenced on 1 November 1991 and continued until 31 March 1992, measuring both outdoor spore concentrations and those inside selected houses. The outside data is part of a longer term measurement which continued until June 1992 and these are also reported. The main study was conducted through the winter months because this was the time of minimal ventilation when the atmosphere of the houses would be most isolated from that outdoors. It is not the peak time for most spores outdoors but the prevalence of spores indoors is likely to follow a different pattern because of heating and of increased humidity resulting from energy conservation.

Outdoor spore measurements were obtained using a Burkard 7-day volumetric spore trap sited 18 m above ground on the exposed roof of a building at Holloway Rd., North London. Vaseline with paraffin wax (10:1 by weight) was used for the adhesive surface. Sampling

took place continuously through the period, with daily changes at 10:00 h GMT. Exposed tapes were mounted as daily lengths and stained with Poly lactophenol Blue. Spores were counted in adjacent fields of view (diameter 0.67 mm) along one horizontal traverse positioned in the central line of the slide. This yielded a 5% sample of the total slide. Actual counts for individual taxa were then converted to produce estimated average daily concentrations per cubic metre of air sampled.

Indoor spore measurement was conducted in the homes of a volunteer group of 19 asthmatics, self-selected through their response to an advertisement placed in a north London newspaper. Using a portable Burkard volumetric air sampler, weekly indoor air samples were taken within the home of each volunteer. The sample was taken at the same time each week, at floor level. The indoor sampler was run for 20 min to give an estimate of current spore levels for that period. The entire exposed area of the slide was counted in the case of indoor samples. Although constant indoor monitoring would have been preferable here it was not possible for 24-h samplers to be placed in all of the dwellings.

The volunteers' houses were spread over a circular area of approximately 7 km diameter but the whole of this district is intensely built up with few open spaces or large gardens. The topography is mostly flat or gently undulating. The area is about 11 km from the northern edge of the conurbation. The prevailing winds are from the south west. In this direction the open countryside lies approximately 30 km distant. The area can be regarded as one unit environmentally although there may be slight differences in microclimate due to aspect and so on. The homes ranged in age from 170 years to only 3.5 years. Nine residences were built before 1930, seven were built between 1930 and 1980 and three were built during the last 10 years. When describing the age of a residence, the homes were arbitrarily assigned to one of two categories, 'old' and 'new' based on whether they were pre- or post-1930. This division does coincide with a change in style from terraces several storeys high to more double storey semi-detached houses. The three very new homes were also examined as a subgroup.

Dust was collected from each volunteer's house on a weekly basis, giving 204 samples in all. In each case a fine brush was used to collect samples from the same environment as the air samples. The samples were cultured on a standard 0.001 g of dust in Potato Dextrose Agar. An assessment was made of the spectra of spore types in the dust and in the indoor air samples. Details of the house age, structure, general condition/state of repair, type of heating and cooking fuel and cleanliness were obtained by a combination of observation and questionnaire information supplied by the volunteers. The analysis of the dust and the air samples focused on particular types of fungi known to be allergenic, notably *Aspergillus*, *Penicillium*, *Cladosporium* and *Alternaria*

(Andersen, 1985). The presence of other main types including *Tilletiopsis*, Basidiomycetes and Ascomycetes was also noted.

3. Results

Total fungal spore counts rarely exceeded 1000 spores per cubic metre on average per day until March (Fig. 1). The extremely abundant microspora, *Cladosporium*, remained at relatively low concentrations until mid- to late-April. Before this period only occasional mini-peaks, on warmer spring days, were seen to occur, such concentrations exceeding an average of 200 spores per cubic metre per day. However it was not until a warm period in mid-May that *Cladosporium* was observed to become the predominant aerospora, with concentrations exceeding 1000 spores per cubic metre daily average on several occasions. To a lesser degree the same trends were also seen in the results for *Epicoccum* and *Alternaria*. Counts of these spores were negligible in the colder winter months, yet increased markedly in the very warm mid-May period. The trends in *Aspergillus*/*Penicillium* were less clear. These spores seem to peak briefly several times in early/mid-spring and again more frequently in the latter part of May. Levels of Ascospores were, like *Cladosporium*, relatively low until mid-April. However concentrations were seen to increase notably around this period, especially when warmer weather combined with spring showers. This combination of weather conditions saw levels of Ascospores often exceed an average of 1000 spores per cubic metre per day, between the April and June sampling periods. High concentrations of *Tilletiopsis* were observed in early-March, a period of warm wet weather which was associated with an increase in several other

types of spore. After this period, concentrations of *Tilletiopsis* were frequently seen to exceed levels of 400 spores per cubic metre per day. Concentrations reached a second peak in the warm wet conditions of late-May/early-June. The spores of *Didymella*, *Sporobolomyces* and *Leptosphaeria* were also seen to increase in this period.

As a general overview, total spore levels showed an increase with the improving warmer weather, with the highest counts noted when a combination of warm and wet weather occurred. Only low amounts of *Didymella*, suspected of being a highly allergenic spore, were noted at the site. Increased numbers of airborne spores are closely related to open country, particularly cereal crops (Palmas and Cosentino, 1989) and this may be a factor depressing the range and abundance of spore types at the North London sample site.

3.1. Spore levels from indoor samples

Air samples were taken over a 3-month period from January to April within the main survey. In this study, levels of *Aspergillus*/*Penicillium* within residences were nearly always higher than other spore types, being normally 4–5 times as abundant as other fungal spores. Of the other fungal spores observed, *Cladosporium* together with Basidiospores and Ascospores may in some instances be seen to exceed *Aspergillus*/*Penicillium* in the indoor air. Occurrences of *Alternaria*, *Sporobolomyces*, *Leptosphaeria* and *Tilletiopsis* in indoor air were infrequent. Statistical analysis using student's *t*-test showed that significant differences existed in the mean concentrations of fungal spores in different residences. Further analysis in relation to building characteristics revealed no significant differences in spore concentrations between old and new residences ($P = 0.01$), nor between residences in basements or at ground level and those at first floor or above ($P = 0.01$). The presence or absence of pets in the residence also revealed no significant differences in fungal spore concentrations ($P = 0.01$).

Non-parametric correlation, (Spearman's rho) of mean concentrations of individual taxa against age of dwelling was not significant. The same test indicated that indoor concentrations of *Aspergillus*/*Penicillium* were not dependent on external levels of spores ($P = 0.18$, $r = 0.232$). The indoor concentrations were seen to be nearly twice as great as the comparable short-term concentrations occurring outside. Similarly indoor levels of *Cladosporium* were not correlated with existing outdoor concentrations ($P = 0.14$, $r = 0.239$). Further analysis revealed that indoor levels of *Aspergillus*/*Penicillium* and *Cladosporium* were not influenced by the previous day's outdoor concentrations and in effect were not merely lag effects from the ambient air outside (*Aspergillus*/*Penicillium* $P = 0.12$, $r = 0.2467$; *Cladosporium* $P = 0.13$, $r = 0.2451$). Although these spores were observed to be independent of the concentrations

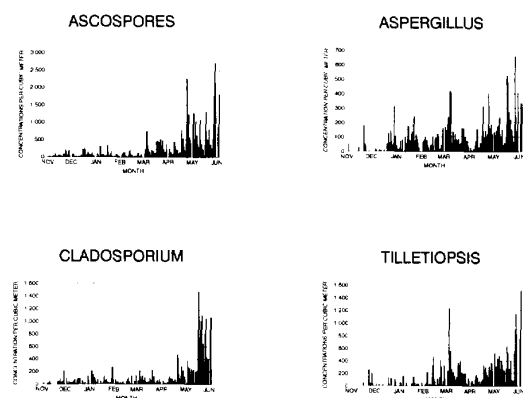


Fig. 1. The daily results of outdoor air samples; *Ascospores*, *Cladosporium*, *Aspergillus*, and *Tilletiopsis*.

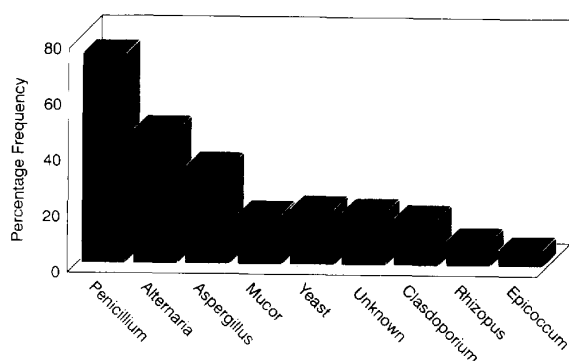


Fig. 2. The percentage frequency of fungi from dust cultures; the total result from 19 homes.

outside they were seen to vary considerably within the same residence over the period of the study. Also, the results from the single outside monitoring site are considered to give a general indication of the trends prevailing but some local deviations could have occurred. Contrary to the findings for the spora mentioned already, *Tilletiopsis* ($P = 0.001$, $r = 0.8527$), *Basidiospora* ($P = 0.001$, $r = 0.9081$) and *Ascospora* ($P = 0.001$, $r = 0.8869$) were found to be significantly influenced by outdoor concentrations and also to a lesser degree by the concentrations of the day before (*Tilletiopsis* $P = 0.01$, $r = 0.405$; *Basidiospora* $P = 0.001$, $r = 0.5810$; *Ascospora* $P = 0.001$, $r = 0.5225$). Other spore types such as *Didymella*, *Fusarium*, *Epicoccum* and *Sporobolomyces* were rarely observed in the outdoor samples and have not been subjected to further examination.

3.2. Dust samples

Analysis of the cultured dust samples revealed that *Penicillium*, with few exceptions, was the most frequent-

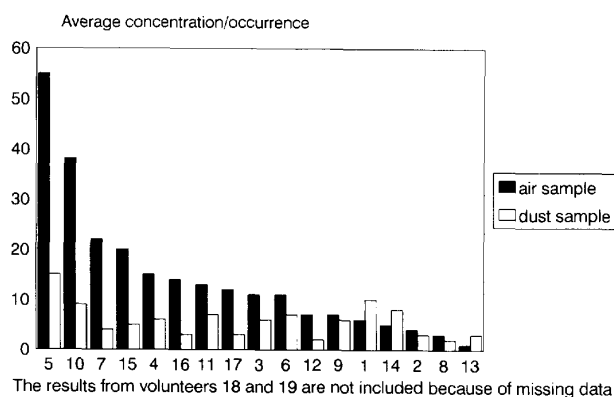


Fig. 3. Indoor air and dust samples. Results for *Aspergillus/Penicillium* from 17 homes.

ly observed fungi (Fig. 2) and that *Aspergillus* also had a high frequency occurrence on the growth medium. The frequency of *Alternaria* in culture agar was disproportionately high in relation to concentrations observed in the air. The same observation held true for *Mucor* which was not recorded in the air samples, yet had relatively frequent occurrences in the cultures. *Aspergillus/Penicillium*, on the other hand, had relatively high concentrations in the air samples yet had low occurrences in the dust samples (Fig. 3). *Epicoccum* and *Rhizopus* had low concentrations/frequencies in both air and dust samples.

It should also be noted that a significant proportion of the cultures had yeast and/or bacteria present on the medium, emphasising the fact that fungi are not the only organisms existing in dust. Chi square analysis revealed that the frequency distribution of *Penicillium*, *Aspergillus* and *Alternaria*, in both old and new homes was not significantly different from what was expected by chance ($\chi^2 = 3.078$, $P = 0.01$). From these results the age or indeed the type of residence were not seen to influence the fungal types in the dust.

4. Discussion and conclusions

The samples were taken over the short period, 1 November 1991 to 31 March 1992. This limits the scope of analysis to 5 months of the year. Furthermore only 19 homes were considered. The results from these may differ from those based on a larger sample. The indoor sampler was run only once a week and the captured spores may represent only transient contamination. However, despite these constraints some patterns and features are apparent.

In the case of the indoor samples *Tilletiopsis*, *Basidiospores* and *Ascospores* appeared in variable concentrations and on some occasions were the principal spore types. Analysis of concurrent spore levels from the outside air revealed a positive statistical relationship. It could be surmised that the major source of these spores within homes was from the outside air. However other sources may contribute to an increase of these spora in the indoor air. From the weekly samples taken, *Aspergillus* and *Penicillium* were without doubt the most frequently encountered spora types noted in the different residences, both showing a greater overall frequency inside than outside the residence. The ability of these fungi to survive in dust was considered to be the main reason why these spore levels were so high. In addition, *Aspergillus* grows on an extremely wide range of substrata within the house including food, leather, paper and fabric.

It is clear that the principal taxa present in the dust samples were not significant in the air samples. This applies particularly to *Alternaria*, which was the second most frequently encountered fungi cultured from the

house dust. The disproportional differences of *Alternaria* concerning occurrence in dust and air can probably be explained by the size of the spore which is 15–20 μ in size, larger than most other micro fungi. This large size effectively reduces the period of time the spores are airborne giving a quicker settling velocity reflected in the low counts from air samples. The frequency of *Mucor* in dust samples again showed significant contrasts to the prevalence in air. The differential may be explained by the stickiness of *Mucor*, which makes these spore types more likely to attach themselves to substrata where dust may collect.

Lumpkins et al. (1973) found that the highest concentrations of *Aspergillus* and *Penicillium* were to be found in basements, with magnitudes increasing by 1.6 and 4 times, respectively. Unfortunately Lumpkins' observations could not be tested fully in the current study as only volunteer 10 lived in a basement dwelling. This made statistical analysis impossible. However the basement dwelling did show the second highest mean count of *Aspergillus* and *Penicillium* from the samples taken. Water leakages made the residence particularly damp on occasions promoting the growth of the fungi.

The residence of volunteer seven had high spore counts including the highest mean concentrations of *Aspergillus* and *Penicillium*, probably enhanced by a combination of damp and poor ventilation. Visible mould growth was evident round the windows. Recent redecoration may have caused disturbance, which would have aided the dispersal of the spora, together with increasing the time when the spores were airborne. All the residences described so far were at least pre-war in age yet no significant difference was determined between the fungal levels in old and new homes. This may be because of the results from volunteer three. This residence was new but had high concentrations of *Cladosporium* possibly due to high temperatures indoors. Statistical analysis revealed no correlation between the concentration of these spores in the outdoor air and the indoor air. The ability of *Cladosporium* to grow in the soil of indoor plants, food stuffs, textiles and areas where condensed water collects could also lead to increased abundance of this taxon. In contrast, low counts of all spore types were noted in the residences of volunteers eight, 13 and 14. All of these three volunteers had little or no dust present in the residence. This plus lack of damp, seemed to be the main reason why spore counts were so low in these cases. Volunteer 14 also lacked carpet. Gravesen (1986) has reported high levels of fungal growth in carpets because these can harbour dust and act like a culture medium.

Penicillium and *Aspergillus*, described by Tunon de Lara et al. (1990) as 'the dust moulds', were the first and third most frequently cultured micro fungi, respectively. Overall these were the dominant micro fungi in both the indoor air and the dust, with the dust being the principal

source for spore release. The significance of *Aspergillus* and *Penicillium* in dust samples may be underestimated. Lustgraaf and Bronswijk (1977) noted that some of the species of *Aspergillus* and *Penicillium*, although present in the dust samples, did not grow on the agar media because it was too wet for xerophytic dust moulds. Further criticism of the use of growth media when determining what spore types are present in dust samples may be applied to the case of *Cladosporium*. Although this genus had the third highest concentration of spora in the air, the frequency of this genus in culture samples was notably lower. Gravesen (1978) believed that 'competitive ability' between fungi is a major factor which makes estimation of fungi in dust dubious. In this study other more frequently encountered fungi may have out competed *Cladosporium* on the agar growth medium.

In summary, it is clearly apparent from the results collected in this study that high spore concentrations in the indoor air were positively associated with dust and with dampness in the residences. These factors were more important than others considered including age of dwelling, and presence of pets. The study has indicated the conditions in which fungi counts increase, emphasising the need for environmental control of these parameters in the indoor atmosphere and reinforcing the findings of several other studies conducted elsewhere. The study illustrates the differences which can occur between the fungal spore spectrum in the outdoor and indoor atmospheres giving support for the contention that fungal spores can reach high concentrations inside homes even when ambient concentrations are negligible. Despite the constraints of sampling through only one season and taking indoor samples only once a week, the work has illustrated the frequency of occurrence of the main allergenic spore types in the homes and has contributed to the evidence of patterns of concentrations in the outside air.

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