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Industrial sources and dispersion in the air of fungal spores

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1. Introduction

Micro-organisms, chiefly spores of fungi, are almost always present in the air but their numbers and types change with the time of day, weather, season, geographical location and the presence of local spore sources. *Cladosporium* and *Alternaria* species predominate during the day in dry weather throughout much of the world, especially in summer. In contrast, ascospores and basidiospores with active spore release mechanisms predominate at night and after rain. Numbers may exceed 10^6 spores/m^3 air when the weather is favourable for sporulation and spore liberation but total concentration of airborne spores are usually in the order of $10–10^3/m^3$ air.

Growing crops are immense sources of fungal spores out of doors and large numbers may be liberated during agricultural operation such as harvesting. Indoors, numbers of micro-organisms are usually smaller than outdoors unless there is a source of contamination within the building. Such sources include stored products of food, timber, compost, air conditioning systems and, increasingly biotechnological processes. Sometimes these can give rise to concentrations of airborne micro-organisms in excess of $10^6/m^3$ air. Many of these micro-organisms are 1–5 µm in diameter and well suited for deep penetration into the lung.

Most of the time and for most people, the numbers of micro-organisms encountered in the air and inhaled are of little consequence, but for some they can be the cause of respiratory responses and diseases. Its nature and type depend on the immunological constitution of the person, the nature of exposure and the micro-organisms present. This represents a bio-hazard, either for the people working on the industrial sources and for people living or working in the close proximity of it.

2. Circumstances of presence and exposure of fungal spores in selected environments

The exposure of workers to fungal spores in occupational environments is seldom constant but changes both quantitatively and qualitatively. The nature and the extent of the air spores in the air of such environments is determined by the degree of the colonization of the substrate, how often it is disturbed and by the effectiveness of ventilation. The principal environments are the following where high amounts of fungal spores can be detected.

2.1 The farm environment

Growing and stored crops form vast sources of fungal spores. The fungi which colonize growing crops are those that predominate in the air, both by day and by night, and are those that are dispersed during haymaking, harvesting, and other agricultural operations. Harvesting can lead to concentrations exceeding 10^8 spores/m^3 air near the cutter bar and straw discharge, and about 10^8 spores/m^3 air near the driver. Up to 75% of these may be *Cladosporium*, 25% *Alternaria* and 10% *Verticillum* type spores. Rust or smut disease within the crop will increase the contribution from *Puccinia* and *Ustilago* to 3–4% or more.

With storage, the nature of the microflora in hay and grain usually changes, the field microflora becoming replaced by species typical for storage. The predominant species (*Aspergillus fumigatus, Absidia corymbifera, Rhizomucor pusillus*) are determined by storage conditions, especially temperature and water content. Airborne fungi levels are highest where fresh air exchange is limited or non-existent. In unsealed silos, a mouldy layer usually develops at the surface where gaseous exchange can still occur. Removal of this can generate vast quantities of fungal spores creating conditions in which organic dust syndrome can occur. All species of storage fungi produce abundant spores which easily become airborne when the substrate is disturbed, to give up to 10^{10} spores/m^3 air.

2.2 Mushroom production

During the various phases of the mushroom industry, all material, from chicken manure to whole mushrooms, was found to be contaminated with micro-organisms (bacteria and fungi) and organic toxins. When mushroom spawn is mixed with the compost and when it is moved along conveyors, especially when it drops from one level to another, or during the cleaning operations after harvest, very dense fungal aerosols are produced. (10^4–10^7

spores/m^3 air). Predominant fungi include *Agaricus bisporus, Torula thermophilum, Penicillium* spp., *Humicola grisea, Cephalotrichum stemonitis, Aspergillus fumigatus, A. niger, Pleurotus ostreatus.*

2.3 Wood processing

The most significant levels of exposure in these environments are associated with the dust from handling moldy bark and dapwood. Measurements of fungi in the air at wood processing facilities provide data on total fungal concentrations of 10^4–10^5 cfu/m^3 air. When wood is cut into chips for use as fuel and then stored in bulk moulding of the chips can occur. The predominant fungal species include *Aspergillus fumigatus, A. niger, Penicillium* spp., *Mucor* spp., *Trichoderma* spp., *Talaromyces* spp., *Aureobasidium pullulans, Paecilomyces variotii, Phanerochaete chrysosporium, Monilia sitophila, Rhizopus microsporus.*

Composting of wood chips support also a considerable load of fungal spores (>10^6 cfu/m^3). Predominant fungi include *Aspergillus fumigatus, A. niger, Penicillium* spp., *Rhizopus stolonifer, Cladosporium* sp. *and Trichoderma* sp.

2.4 Food processing

Usually exposure to fungal spores during food processing is related to stored products. For instance, coffee beans, prior to roasting, usually carry fungal spores which can be dispersed into the air. Highest numbers (up to 10^4 cfu/m^3 air) were found in containers being unloaded at a ware house. They included *Eurotium* spp., *Aspergillus fumigatus, A. flavus, A. niger, Wallemia sebi.*

Fungi are frequent in the air of bakeries, especially *Aspergillus, Penicillium and Mucor* spp. Flour and dried fruits are important sources, up to 10^3 cfu/m^3 air, mostly *Penicillium* spp. where flour was weighed and mostly *Wallemia sebi* and yeasts where dry fruit was handled.

Penicillium spp. are also important in the maturation of some cheeses and sausages and may grow abundantly on the surfaces. When these are cleaned prior to sale the spores are easily dispersed.

2.5 Other industrial and biotechnological environments

Biotechnological processes are being increasingly used to produce nutritional proteins, enzymes and other useful metabolites and to degrade wastes and recalcitrant molecules. Aerosols may be produced during the handling of culture mats, through the breaking of liquid films and the leaking of fermenters. Predominant fungi released into the air include *Aspergillus* spp., *Penicillium* spp., *Verticillium lecanii,* and yeasts.

Sugar cane bagasse waste after the extraction of sugar, when stored in bales, rapidly heats to temperatures above 40°C and permits the development of abundant thermotolerant fungi, particularly the mould *A. fumigatus.*

Feed mills are contamined with the same type of fungi as are found in grain stores on farms, with *Aspergillus* spp. often predominant. When grain is germinated for malting, the conditions of the malt floor favour *Aspergillus clavatus.* Turning the sprouting grain releases abundant spores into the air.

Fungal dispersion and exposure also occurs in sawmill industry (*Crytostroma corticale, Aureobasidium pullulans, Graphium* spp.)

The processing of cork may involve the proliferation of moulds in bales stored in humid warehouses. The predominant species are *Penicillium glybrum, P. granulatum, Aphanocladium album, Monilia sitophila and Mucor plumbeus.*

2.6 Composting of organic wastes

Composting is a biological process by which organic kitchen and garden wastes are, by microbial activity, transformed into humus. Besides the microflora necessary for these transformations, the composting process, if not properly managed, can also harbour the proliferation of potentially pathogenic and/or allergenic bacteria and fungi. Predominant fungal genera include *Alternaria, Aspergillus, Cladosporium, Fusarium, Mucor, Trichoderma, Penicillium* and yeasts. Among the fungi, the mould *Aspergillus fumigatus* is predominant. Because of its cellulolytic and thermotolerant (best growth between 30°C and 45°C) properties it finds ideal growth conditions in compost, particularly in the outer layers of compost heaps.

Numbers of *A. fumigatus* were high in fresh compost (up to 10^7 cfu/g dry weight compost) and diminished towards the end of the composting process. In general, more *A. fumigatus* could be found in the outer layers of the heaps than in the centre, where high temperatures (> 60°C) prevented mould growth.

A. fumigatus spores present in composts can be dispersed in the air during shredding of the green waste, turning of the heaps, aeration of the windrows, and to a minor degree during sifting of the mature compost. During mechanical agitation of the compost heaps, very high amounts of *A. fumigatus* (> 10^6 cfu/m^3 air) were measured in the vicinity of turning machines. At 20 m downwind, the number was reduced 100 fold and reached at a distance of 500 m background level (0–6 cfu/m^3 air). Correlation was found between the amount of moulds in the compost and their concentration in the air, although weather conditions and type of turning system influenced the dispersion of *A. fumigatus.*

The concentrations of fungi in composts vary considerably, depending on the type of green waste composted, but also on the type of composting technology and management used. Actually in our laboratory studies are performed on the optimization of the composting process by intensive management in collaboration with several compost industries. An intensive compost management is defined by a judicious mixture of the initial substrate, by a frequent mixing of the compost, and sufficient aeration and hydratation. These conditions are met by composting in a closed bioreactor with automatic aeration and mixing, by classical open air windrow composting with frequent or daily turnings of the heaps, or by automatic aerated and mixed windrows.

The optimization of the thermogenic phase at 60–75 °C and the extending of this hot phase permits thorough thermohygienization of the whole composting material, and the acceleration of the organic matter degradation and mineralization, leading to a final compost of high quality in a short span of time. The lower potential pathogenic fungi concentration in the intensively managed compost are reflected in the much lower dispersion of fungi in the air during the turning of the windrow. Health risks for people can be strongly diminished.

3. Health effects of bioaerosols

Exposure of high bioaerosols containing micro-organisms, toxins and organic/inorganic compounds can cause a range of human health effects. Inhalation is the major exposure route. However, systemic effects may also occur either as a result of ingestion of material cleared from the lungs or through release of bioactive substances from the cells of the lung into the blood. The responses of individuals depend on their genetic predisposition, on the frequency of exposure, on the type and the number of inhaled spores. Some individuals may respond to concentration that do not affect others.

Immunocompromised, asthmatic and allergic individuals are at increase risk to responses from bioaerosols and opportunistic pathogens. When such invasive or systemic, opportunistic infections occur they usually occur in individuals whose immune defense systems are very severely compromised (functionally abnormal) because of genetic or acquired conditions.

Considering the wide range of potential respiratory responses and diseases to bioaerosols, it was also the consensus that additional research be conducted to more clearly define the nature and health impacts of bioaerosols that accur naturally in the environment and from industrial sources.

4. References

Information about sources and the potential health risk of fungal spores or particles dispersion in the air in industrial environments other than composting can be found in Lacey and Crook (1988) and Millner et al (1994). Informations about the composting process and the microbiology implied can be found in the other references, including Millner et al. (1994).

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