

# Environmental fungal spore aerosolization: a review

## Abstract

Bioaerosol containing fungal spores became public health hazards. The aerosols contain the fungal spores of different species of *Aspergillus*, *Cladosporium*, *Chaetomium*, *Penicillium*, *Walleimia*, *Stachybotrys* etc. and caused various life-threatening respiratory diseases such as hypersensitivity, pneumonia, Aspergillosis, Candidiasis, Mucormycosis, Cancer, etc. They are easily transmitted from one individual to another. They also cause extreme damage to crops and create problems in food security by producing mycotoxins. The transmissions of fungal spores depend upon the environmental factor, seasonal variation, growth surface, type of fungal spore, etc. There are various biophysical, biochemical and molecular techniques that are present to detect fungal spores in aerosol. There are numerous physical and chemical agents that can kill fungi. Good public health and food security can be achieved through the detection and management of fungal spores in aerosols.

**Keywords:** fungal spores, aerosols, public health, fungal diseases

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## Introduction

Fungal spores are omnipresent in nature.<sup>1</sup> Fungal spores can be released passively from a variety of natural and anthropogenic sources.<sup>2</sup> Green spaces, farms, forests, green spaces, and decaying plant matter are the primary sources of fungus spores in the air.<sup>3</sup> Fungal spores could be dangerous to immunosuppressed and allergic people. They can pose severe health hazards.<sup>4</sup> Aerosolization of fungal spores increased the risk of fungal spread.<sup>5</sup> Not only outdoor people, fungal spores equally affect indoor people.<sup>6</sup> Indoor environments that are warm and humid are favorable for the growth of fungi.<sup>2</sup> According to atmospheric sampling, most fungal spores have a size between 2 and 10  $\mu\text{m}$ . Although they are small in number, due to their size, they may considerably contribute to particulate matter (PM) mass concentrations. They also contribute to organic carbon and aerosol mass balance.<sup>7</sup> Additionally, they are capable of producing a variety of stress proteins for their survival under adverse conditions.<sup>8</sup> A favorable humid condition can help fungal spores to germinate and form mycelium and then hyphae.<sup>2</sup> Several diseases can be brought on by breathing in ultrafine aerosol particles such as hypersensitivity, pneumonia, Aspergillosis, Candidiasis, Mucormycosis, Cancer etc.<sup>9,10</sup> The liberation and deposition of fungal spores depend on several physical and chemical parameters.<sup>11</sup> However, research in field of aerosol originated fungal spores and associated disorder is miniscule in the world.<sup>12</sup> As a result, much less is known about the diversity of fungus found in airborne particulate matter.<sup>13</sup> Various studies

suggested that most of the aerosol spores are generated by the species of Basidiomycota and Ascomycota.<sup>13</sup> Although, there are several physical, chemical, and biological methods are available to understand the presence of fungal spores in the environment. For instance, chemical molecules such as ergosterol, arabinol and mannitol are considered as the important biomarkers for measuring the fungal spores in aerosols.<sup>14</sup> However, modern molecular biological techniques such as RNA ribotyping of ITS region are gaining much importance now a days. Therefore, the method that relies on fungus cultivation and high-throughput sequencing has been selected to determine fungal spores in the environment.<sup>15</sup>

## Important findings of aerosol originated fungal spores

Studies have shown that the constituents of fungal spores vary from environment to environment. The indoor constituents of fungal spores are different from that of the outdoor environment. For instance, the species of *Deuteromycotina*, *Ascomycotina* along with *Basidiomycotina* are predominant in outdoor aerosols described by Zoppas et al. in the city of Brazil.<sup>16</sup> Fungal spores also exhibit seasonal variations. The report by Lang et al.<sup>15</sup> demonstrated that factors such as PM<sub>10</sub> content NO<sub>2</sub>, SO<sub>2</sub>, and temperature influence the fungal spores population significantly in the environment.<sup>15</sup> Table 1 shows a brief review on important findings related to fungal spores.

**Table 1** A brief review on important findings related to fungal spores

Location of aerosol-based fungal spores location	Method	Important findings	Reference
Fungal spores in indoor environment	Gypsum plate method	Species of <i>Aspergillus</i> , <i>Penicillium</i> , and <i>Walleimia</i> , <i>Stachybotrys</i>	(Madsen et al.) <sup>6</sup>
Fungal spores in air particulate matter	DNA Isolation and extension of ITS region	Species of <i>Basidiomycota</i> (BMC, club fungi, 64%) or <i>Ascomycota</i> (AMC, sac fungi, 34%)	(Fröhlich-Nowoisky et al.) <sup>12</sup>
Samples from urban and semiurban areas	Chemical mass balance modeling	Fungal spores are the main component of environmental PM <sub>10</sub> , total organic carbon	(Bauer et al.) <sup>7</sup>
PM <sub>10</sub> mass of outdoor aerosol	DNA Isolation and extension of ITS region and qPCR	<i>Alternaria</i> , <i>Cladosporium</i> , <i>Epicoccum</i> , <i>Penicillium</i> and <i>Aspergillus</i>	(Dannemiller et al.) <sup>31</sup>

## Variation in fungal spores in aerosols

Various studies suggested that suburban / rural location had greater fungal spores.<sup>14-17</sup> Significant invasion of fungal spores can be indicated by a distinctive musty smell brought about by volatile metabolites of fungus emitted into the atmosphere.<sup>8</sup>

## Adhesion of fungal spores

The adhesion of fungal spores in the substratum plays a pivotal role in their germination and growth. Numerous fungus species' spores have the ability to quickly and randomly adhere to different surfaces.<sup>18</sup> The adhesion is mainly dependent on the surface property of the substratum.<sup>19</sup> Fungal spores prefer a hydrophilic surface instead of hydrophobic one because the hydrophilic surface requires a shorter incubation period.<sup>20</sup> Microscopic studies suggested that the fungal spores secreted glue-like material to adhere the surface of the substratum.<sup>21</sup> An efficient way to stop fungus growth is to create surfaces that are hostile to the adhesion of fungal spores.<sup>17</sup>

## Fungal spores and diseases

Fungal spores are responsible for various diseases in human animals and plants. In humans, they elevate IgE and eosinophils after inhalation and cause Asthma, conjunctivitis, and other hypersensitivity.<sup>8</sup> The infection became more problematic to the

immunocompromised and to those who already suffer from other respiratory issues such as bronchitis Asthma etc.<sup>8</sup> The symptoms of such hypersensitivity involve fever, chills, combined with attacks of dyspnea, headache, muscle pain, stinging in the chest, and a feeling of total breakdown. The autoimmune reaction that is produced by fungal spores is due to homology of the fungal antigen with the human antigen. Few of them produce carcinogenic and teretogenic mycotoxic substances that can increase the chances of malignancies in the human population.<sup>8</sup> For example, species of *Aspergillus* produce aflatoxins by infecting various food products. Aflatoxins are a potent cause of hepatocellular cancers.<sup>22</sup> They inactivate the tumor suppressor gene p53 through mutation and also weakened the mechanism of liver cytochrome p450<sup>22</sup> (Table 2).

## Inactivation of fungal spores

Controlling fungus contamination in water and creating more potent disinfection techniques to destroy fungi are crucial.<sup>23</sup> Various ongoing research efforts focus on finding the safe and effective methods for fungal eradication. PAA, which is paracetic acid, can inactivate the fungal spores by penetrate into their membrane. Zuo et al.<sup>24</sup> described that PAAs are not as effective as other disinfectants such as Cl<sub>2</sub>, ClO<sub>2</sub>.<sup>24</sup> Xia et al.<sup>25</sup> described that solar disinfection not only affects the respiratory chain and DNA of the fungal spores but also induces esterase activity in them<sup>26-31</sup> (Table 3).

**Table 2** Fungal spores, diseases and type of mechanism

Disease	Fungal spore	Mechanism	Reference
Bronchospasm and aphonia	<i>Penicillium</i>		(Żukiewicz-Sobczak) <sup>8</sup>
Bronchopulmonary aspergillosis	<i>A. fumigatus</i>	Induce type III hypersensitivity	(Jack and Bajaj, 2022) <sup>29</sup>
Asthma	<i>Alternaria</i>	Increase Ig E antibodies	(Bush and Prochnau) <sup>30</sup>
Dermatitis	<i>Aspergillus niger</i>		(van Burik et al.)
Hepatocellular Cancer	<i>Aspergillus flavus</i> and <i>Aspergillus parasiticus</i>	Fungal species produce aflatoxin that causes mutation in p53 gene	(Magnussen and Parsi) <sup>21</sup>

**Table 3** Antifungal spores compounds and their mechanism

Antifungal spores compounds	Target fungal spores	Mechanism	Reference
Synergistic effect of UV and PAA	<i>A. niger</i> and <i>A. flavus</i>	UV/PAA could decrease the regrowth of microorganisms	(Xu et al.) <sup>26</sup>
PAA	<i>A. niger</i> and <i>A. flavus</i>	PAA inactivates the fungal spores	(Zuo et al.) <sup>23</sup>
Solar disinfection	<i>P. polonicum</i> , <i>A. niger</i>	Damage the DNA and respiratory chain of fungus spores	(Xia et al.) <sup>25</sup>
Silver bio nanoparticle	<i>Fumigous</i> , <i>A. parasiticus</i> , <i>A. aculeatus</i> spores	Collapse the enzymatic system of fungal spores	(Noman et al.) <sup>28</sup>
Low-dose chlorine augment Solar inactivation	<i>Penicillium polonicum</i> , <i>Aspergillus niger</i>	Increased free radicals damage the cellular mechanism of fungal spores	(Wan et al.) <sup>24</sup>
Nanosilica	<i>A. oryzae</i>	Eliminate the adhesive force between fungal spores and glass plate coated with nano silica	(Nomura et al.) <sup>16</sup>

## Conclusion

Variation in the constituent of fungal spores can change the status of the aerobiological space. Therefore, it would require ongoing aerobiological monitoring to find changes in the surrounding environment. Fungal spores are responsible for indoor and outdoor pollution and must be eradicated to prevent diseases in human animals and plants.

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## Conflicts of interest

The author(s) declares that there is no conflict of interest.

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