



Seasonal variation of airborne allergenic fungal spores in ambient PM₁₀—a study in Guwahati, the largest city of north-east India

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Abstract

Fungal spores in ambient particulate matter (PM) is one of the major constituents which can adversely affect human health. For the first time, an investigation was conducted for 1 year at a residential region in north-east India to study the seasonal variation of PM₁₀-associated fungal spore concentration and their diversity. Using fine particulate sampler, samples were collected at 12 h intervals for 1 week of every month during July 2016–June 2017. Twelve-hour averaged PM₁₀ concentration was 79.74 µg/m³ and 103.47 µg/m³ during day and night time, respectively. Fungal spore concentration was 126 (54–294) CFU/m³ during day time and 107 (55 to 161) CFU/m³ during night time. Seven individual genera of fungal spores, namely *Aspergillus*, *Penicillium*, *Cladosporium*, *Fusarium*, *Curvularia*, *Rhizopus*, and *Non-sporing isolates*, were identified. Strong correlations between the *Cladosporium* and *Penicillium* ($R = 0.83$) and *Cladosporium* and *Aspergillus* ($R = 0.82$) were observed, which are well-known asthma allergens. *Penicillium* (30%), *Fusarium* (41%), and *Aspergillus* (25%) were the dominant fungi species in winter, monsoon, and summer seasons, respectively. Fungal spore concentrations peaked during summer and were least during monsoon. Fungal concentrations were negatively correlated with precipitation ($R = -0.25$). Fungal counts had more significant positive correlation with temperature in non-rainy samples ($R = 0.80$), compared to negligible correlation ($R = -0.16$) in all samples.

Keywords PM₁₀ · Fungal spores · Asthma · North-east India · Bioaerosols

Introduction

In this decade, the prevalence of air-borne allergic diseases has significantly increased. Globally, more than 400 million people were affected with chronic respiratory diseases of which India accounts for 7% of deaths and 3% loss of disability adjusted life years (Reddy et al. 2005). Asthma is one of the common chronic respiratory diseases among the air-borne allergies (Gielen et al. 1997; Larsen et al. 2002; Rohr et al. 2014; Schachter et al. 2016). The reported asthma patients in north-eastern Indian state, Assam (3278 per 100,000), are significantly higher than the national average (2468 per 100,000) (Rajan et al. 2012). Asthma is associated with air-borne fungi and is triggered by amplified concentrations of fungal spores in the environment (Anderson et al. 2013; Denning et al. 2006). Fungal

spores constitute a large portion of aerosol particles in rural and urban environments (Elbert et al. 2007; Womiloju et al. 2003). The ability of fungal spores to survive in extreme environmental settings enables them to survive for longer periods (Kumar and Attri 2016). Fungi in ambient air are released from plants or soil surfaces. While the number and composition of fungal spores released from plants in a location are dependent on the types and abundance of plants in the region (Elbert et al. 2007), dust storms and construction activities are responsible for release of fungi from soil surface (Hawkes et al. 2010). Fungi move to new host in the form of spores (2–20 µm) (Moore-Landecker 2011). The spore released will travel through the air (Elbert et al. 2007; Kakikawa et al. 2008), water, or soil (Fitt 1989). But air is the most common medium for their dispersion (Egan et al. 2014).

Fungal spore diversity and its concentration depend on the meteorological conditions, type of vegetation, and geo physical and anthropogenic activities (Després et al. 2012). For example, sharp decrease in relative humidity (RH) results in significant increase in fungal spore concentrations in ambient air (Adams et al. 1986; Gottwald 1982; Timmer et al. 1998). Similarly, air temperature (Kumar and Attri 2016; Langenberg et al. 1977), precipitation, wind speed, interaction between microorganisms

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etc., influence the spore release (Jones and Harrison 2004). Approximately 1.5 million fungi species exist on earth (Bush and Portnoy 2001; Elbert et al. 2007), of which only 80 individual genera are recognized for their allergenic properties and associated respiratory tract disorders (Portnoy et al. 2005). Most commonly observed fungi in ambient air are *Cladosporium*, *Alternaria*, *Penicillium*, *Aspergillus*, *Epicoccum*, and a variety of yeasts, smuts and rusts, and other basidiomycetes (Madelin and Johnson 1992). *Cladosporium*, for example, are generally dry spores which remain for prolonged durations in the environment and are directly linked to human respiratory diseases (Kallawicha et al. 2015; Pringle 2013).

Fungi presence in PM is poorly characterized in spite of their concern to impact on environment and human health hazards. Most of the research investigations characterizing fungi was carried out in different indoor environmental conditions (Nasir et al. 2012) like bakery, library (Singh et al. 1995), home (Emberlin et al. 1995), dairy cattle shed (Adhikari et al. 2004), fruit market (Kakde et al. 2001), schools (Aydogdu et al. 2005) etc. However, only few studies carried out monitoring of long-term ambient fungi levels in India (Adhikari et al. 2004; Chakrabarti et al. 2012; Kumar and Attri 2016) with scanty research in north-east India.

Exposure to outdoor allergens is of particular concern in north-east India, facing moist wet tropical climate (Gollapalli and Kota 2017), with high temperature and relative humidity, which are two important parameters influencing microbial growth. Therefore, the present study involves the collection of ambient PM₁₀ (particles with aerodynamic diameter less than or equal to 10 µm) and the quantification of fungi

concentrations in different seasons. The specific objectives of the study are: (1) estimation of year-long concentrations of different fungi in ambient PM₁₀ and (2) understanding the role of meteorological factors on PM₁₀-bound fungi. As per the knowledge of the authors, this is first such study carried out in this eco-sensitive region till date.

Material and methods

Description of sampling site

The samples for the present study were collected at the residential location in the largest city in north-east India, Guwahati (Fig. 1), with total population of around 968,549 (<http://censusindia.gov.in>). Study site (26°11'14"N and 91°41'30"E) lies between the north bank of the river Brahmaputra around 20 km from the heart of the city and the foothills of Shillong plateau. With the majestic Brahmaputra River on one side and with hills and vast open spaces on others, the site location was covered with dense trees sprawling 285 ha with vast varieties of flora and fauna. This part of India has various vegetation patterns such as cultivated plains to grasslands, meadows, scrub forests, marshes, sacred groves, and alpine forests. Presence of seven or eight thousand flowering plant species, which account for 50% of Indian flora, makes this region one of the world's few biodiversity hotspots (Chatterjee et al. 2006; Chowdhery 2001; O'Hollaren et al. 1991). Most of these forest floors are richly covered with

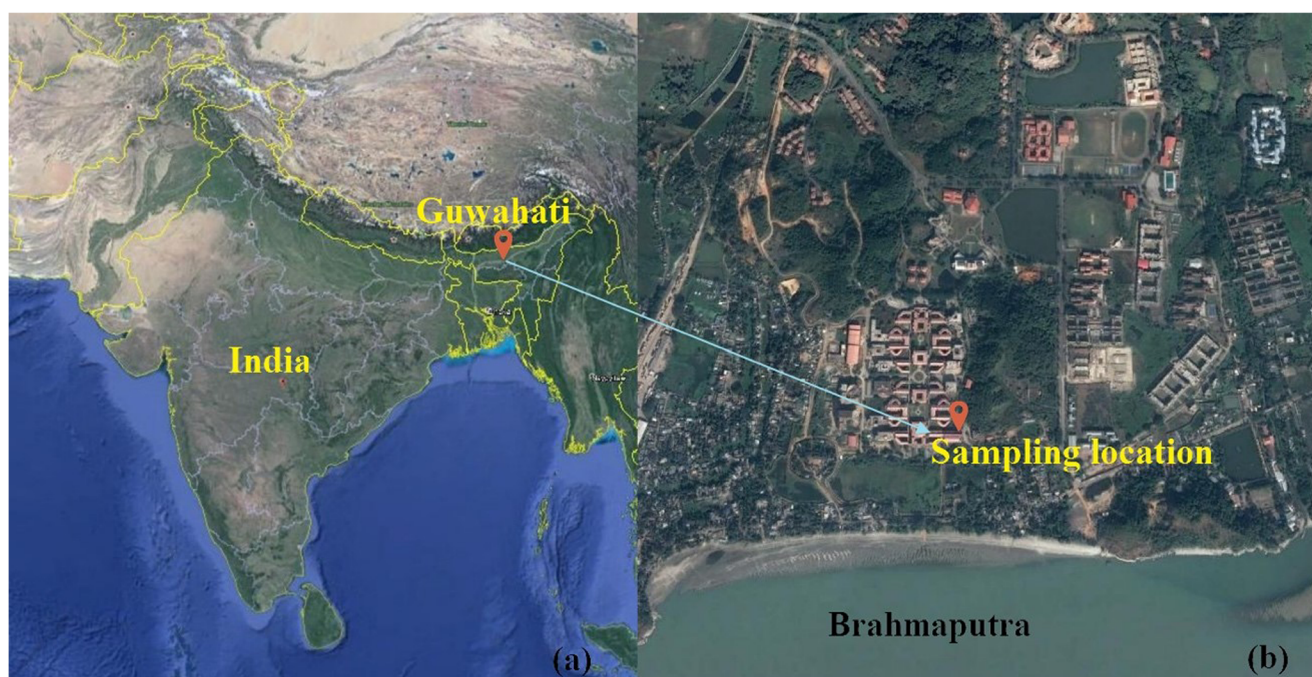


Fig. 1 The location of Guwahati, the largest city in India (a) and the sampling location (b)

fungi, mosses, and variety of yeasts, smuts, and rusts due to the climate in this region.

With these diversities, the present study well suits for the identification of PM-associated fungal spores. This region experiences warm-dry periods from March to April, a heavy-rainfall monsoon from late May to October, and cold-dry winters from late November to February (Gollapalli and Kota 2017). In the last decade, the mean annual precipitation in this region was approximately 150 mm, occurring mainly between May and October. The recorded temperature ranges between 11 °C in December/January and around 40 °C recorded in July/August (<https://www.worldweatheronline.com/lang/en-in/guwahati-weather-averages/assam/in.aspx>).

Data collection

The sampling in the residential site was carried out at a height of approximately 15 m above the ground, to avoid obstruction of air flow to the sampler from any direction. PM₁₀ samples were collected for a period of 1 year, i.e., from July 2016 to June 2017. Samples were collected during the second week of each month for 7 days on quartz fiber filter (Whatmann QMA; 47 mm diameter and pore size of 0.22 µm) using a fine particulate sampler (Model-APM 550, Envirotech Instruments, New Delhi). Two samples, one during day (9 AM to 8.30 PM) and another during night (9 PM to 8.30 AM), were collected at the constant flow rate of 1 m³/h. The filters used for sample collection were sterilized at 120 °C using an autoclave

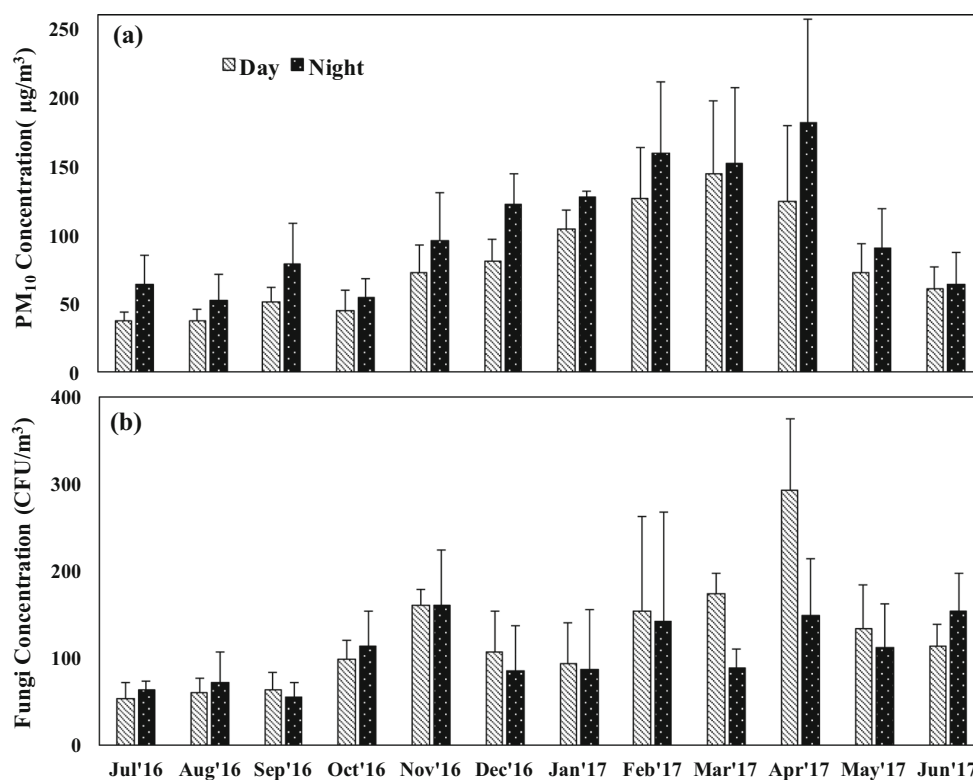
and kept in a dry oven for 2 h to remove existing contaminants and later desiccated for 24 h to minimize the hygroscopic errors. Thereafter, the filter was carefully inserted and retrieved from the sampler using a pair of sterilized tweezers and weighed before and after, using an electronic microbalance (Model-Kerb & Sohn GmbH) with a sensitivity of 0.1 mg. After collection, samples were preserved at −4 °C until further analysis. For further quality assurance, blank samples were analyzed in the similar manner and necessary corrections were included. All glassware was sterilized by immersing in 70% ethanol and thoroughly dried within the sterile laminar flow hood.

Meteorological data, i.e., temperature (T), relative humidity (RH), and precipitation (P), was obtained from the weather station (Model-Vantage pro 2, Davis Instruments) placed near the PM₁₀ sampler.

Sample preparation for fungi identification

Fungal spores from particulate constituents in PM load were separated for their microscopic examination. The known amount of PM sample was suspended in double distilled water and centrifuged at 900g for 4 min to remove water soluble material. Then, the solution was filtered to remove any crustal material present. Filtered sample was poured in the Potato Dextrose Agar (PDA) medium for fungi cultivation. To inhibit the growth of bacteria in the sample, an antibacterial solution (Ampicillin) of 100 µg/mL was mixed with agar media. Sample

Fig. 2 Monthly 12-h variation of **a** PM₁₀ concentration (µg/m³), **b** fungi concentration (CFU/m³) during day (9 AM to 8:30 PM) and night time (9 PM to 8:30 AM)



was serially diluted and the plates were incubated at 25 °C for 4–6 days and the total culturable colony counts were presented as colony forming units in air (CFU/m³). A total of 168 samples were collected and cultivated in a PDA agar medium for their identification and population count. After the incubation, the number of colonies was counted. To identify the type of fungi up to their genus level, colonies were smeared in the microscopic slide and visualized under Nikon EclipseTi Inverted light microscope at an optimal magnification (100×, 200×, and 1000×) on the basis of their morphological characteristics. Further identification was ascertained with the help of previous studies (Campbell and Johnson 2013; Navi et al. 1999) and online database (<http://onlinelibrary.wiley.com/doi/10.1002/9781118520055.ch1/summary>).

Results and discussion

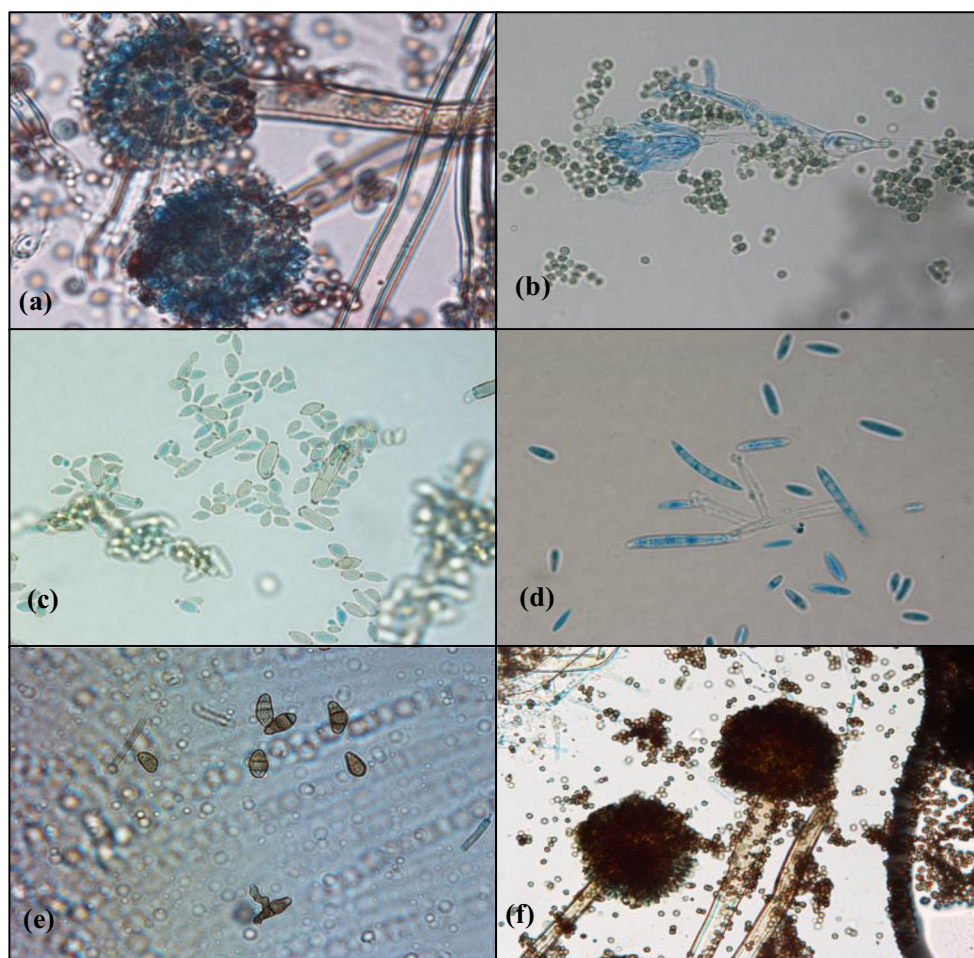
Ambient PM₁₀ and fungi concentrations

The monthly variation of 12 h PM₁₀ in the samples is shown in the Fig. 2a. The average PM₁₀ concentration during the

sampling period was $79.7 \pm 16.6 \mu\text{g}/\text{m}^3$ during day and $103.5 \pm 20 \mu\text{g}/\text{m}^3$ during night. On most of the days, the concentrations were higher in night compared to day, which could be due to lower ambient temperature and stable atmosphere leading to build up of concentrations in a shallow boundary layer (Kota et al. 2018; Li et al. 2013). The maximum 24-h average PM₁₀ concentration was observed during March to April and minimum in July to September months, which represent monsoon. The lower concentrations during monsoon are due to washout of PM (Guo et al. 2017; Sahu and Kota 2017). The 24-h average PM₁₀ concentrations during the analysis period were $89.5 \pm 23.6 \mu\text{g}/\text{m}^3$. The PM₁₀ levels exceeded its 24-h Indian National Ambient Air Quality Standard (NAAQS) limit of $100 \mu\text{g}/\text{m}^3$ (<http://cpcb.nic.in>) on 40% of the sampling days.

The average count of fungal colonies in PM₁₀ was $126 \pm 40 \text{ CFU}/\text{m}^3$ during day ranging from 54 to 294 CFU/m³ and $107 \pm 49 \text{ CFU}/\text{m}^3$ during night ranging from 55 to 161 CFU/m³ as shown in the Fig. 2b. The concentration of fungal spores during day time was more than night time, on most of the sampling days, indicating the importance of sunlight and temperature in the growth of fungal spores. Fungal spore count

Fig. 3 Microscopic image of different fungi observed at optimal magnification of 1000× in the PM₁₀ samples: **a** *Aspergillus*, **b** *Penicillium*, **c** *Cladosporium*, **d** *Fusarium*, **e** *Curvularia*, and **f** *Rhizopus*



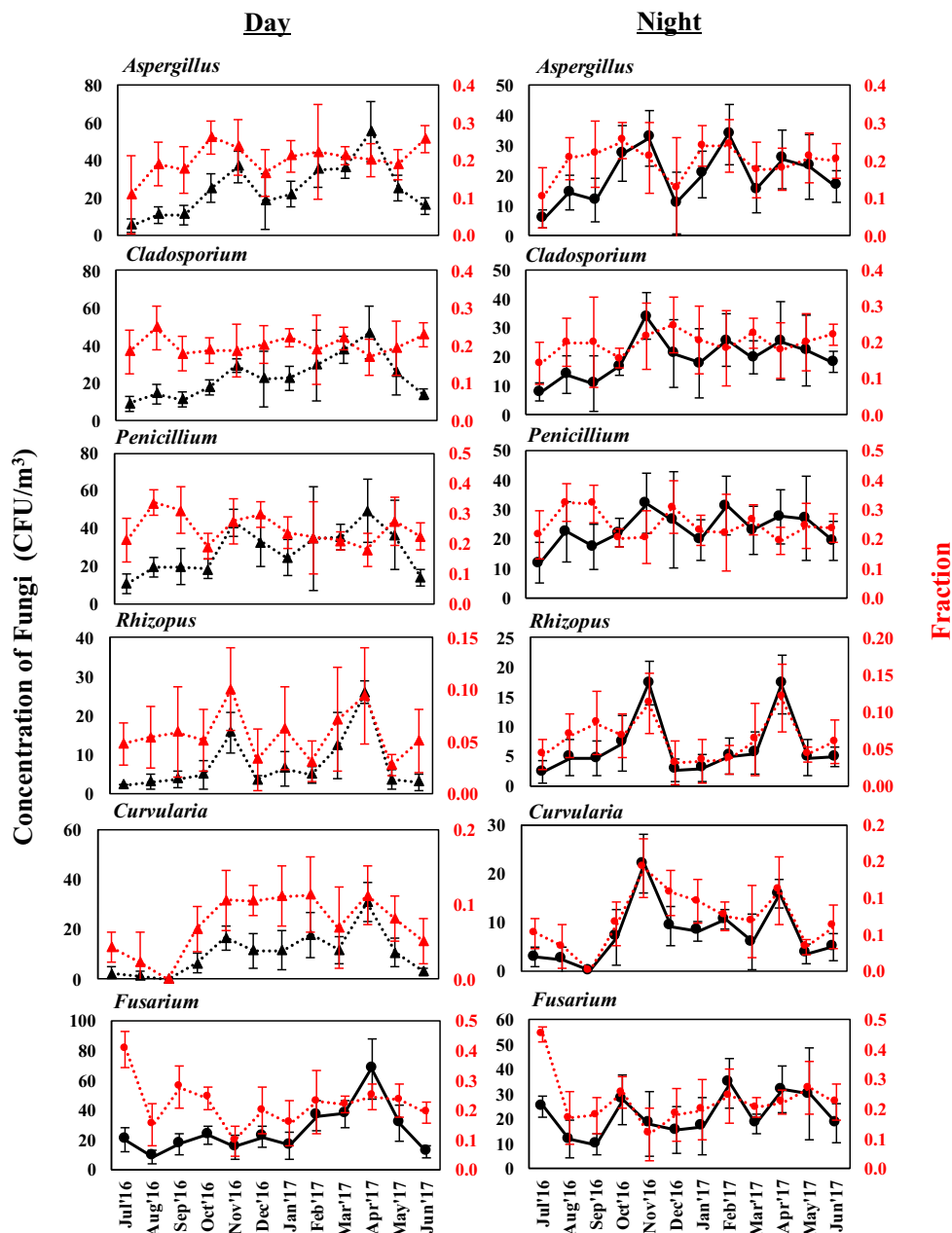
was high during February (late winter) to April (early summer) a transition state during which the allergy patients face complications. The concentration of fungal spores significantly increased during April (early summer) especially during day time which clearly indicates the increase in the microbial activity due to temperature during this period. Low concentrations of fungal counts during monsoon season could be due to wet scavenging of spores.

Fungi diversity

Fungal colonies identified based on their morphological characteristics showed significant variation among PM samples.

Seven individual genera of fungi were identified in PM samples, i.e., *Aspergillus*, *Penicillium*, *Cladosporium*, *Rhizopus*, *Fusarium*, *Curvularia*, and *Non-Sporing Isolates*. The microscopic images of identified fungi are shown in Fig. 3. *Penicillium*, *Cladosporium*, *Curvularia*, *Fusarium*, *Aspergillus* well known for their allergic properties as reported by previous researchers (Chakrabarti et al. 2012; Green et al. 2003; Kumar and Attri 2016) were observed in high concentrations than *Rhizopus* and *Curvularia*. Fungi which did not produce spores even after 7 days of incubation were named as *Non-Sporing Isolates*, and their concentrations were negligible (3 CFU/m^3). In all the samples, *Aspergillus*, *Penicillium*, *Cladosporium*, *Rhizopus*, *Fusarium*, and *Curvularia* had

Fig. 4 Monthly variation of each individually identified fungi genera found predominantly in PM_{10} samples during day and night time along with individual fungi/total fungi fraction shown on secondary Y-axis



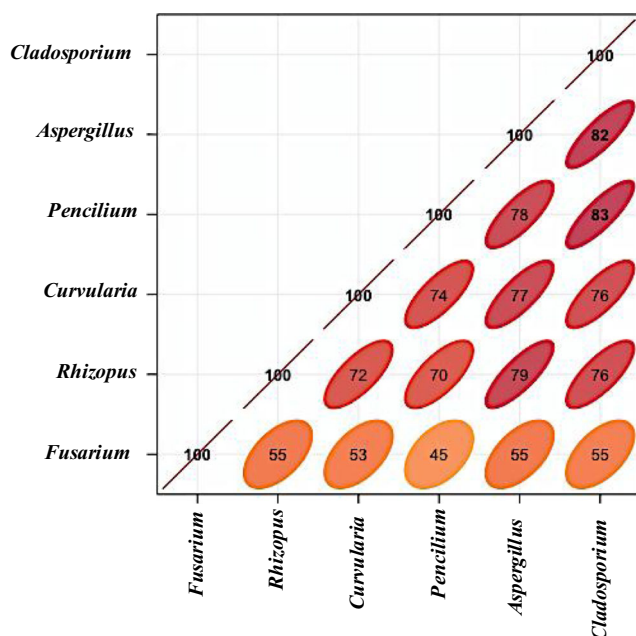


Fig. 5 Correlation coefficient (R) between different types of fungi identified in this study

median concentration of 20 CFU/m³ (6–41 CFU/m³), 26 CFU/m³ (11–38 CFU/m³), 22 CFU/m³ (8–36 CFU/m³), 7 CFU/m³ (2–22 CFU/m³), 23 CFU/m³ (10–50 CFU/m³), and 9 CFU/m³ (0–23 CFU/m³), respectively.

Monthly variation of identified fungi species during day and night along with fraction of individual fungi to total fungi

concentration is shown in Fig. 4. Fungal spores exhibited significant variability in different months. During day time, all the spores peaked in April, with no rainfall and high temperatures, implying aggravated fungal growth due to sunlight (Leach 1975; Li and Kendrick 1994). *Fusarium* (41%), *Penicillium* (30%), and *Aspergillus* (25%) were the dominant fungi species in monsoon, winter, and summer seasons, respectively. Previous studies identified that dominant fungi species changes with season. For example, Singh et al. (1995) reported dominance of *Cladosporium* during winter months and *Penicillium* during autumn.

Figure 5 shows correlation between different fungal spores. Correlation coefficient (R) used in this study was estimated using Eq. 1.

$$R = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sqrt{\sum (x - \bar{x})^2 \sum (y - \bar{y})^2}} \quad (1)$$

where $\bar{x}$ and $\bar{y}$ are the means of variables x and y , respectively. R varies between -1 and $+1$. With R closer to zero indicating little or no relation and $+1$ or -1 showing high correlation. Positive and negative values of R indicate negative and positive correlation, respectively. Strong correlation between the *Cladosporium* and *Penicillium* ($R=0.83$) and *Cladosporium* and *Aspergillus* ($R=0.82$) was observed. The positive correlation indicates that they belong to same fungal body or emitted from the same source and/or instigated by same external force. For example,

Fig. 6 **a** Monthly variation of average fungi concentration (CFU/m³), **b** cumulative rainfall and temperature during the sampling period

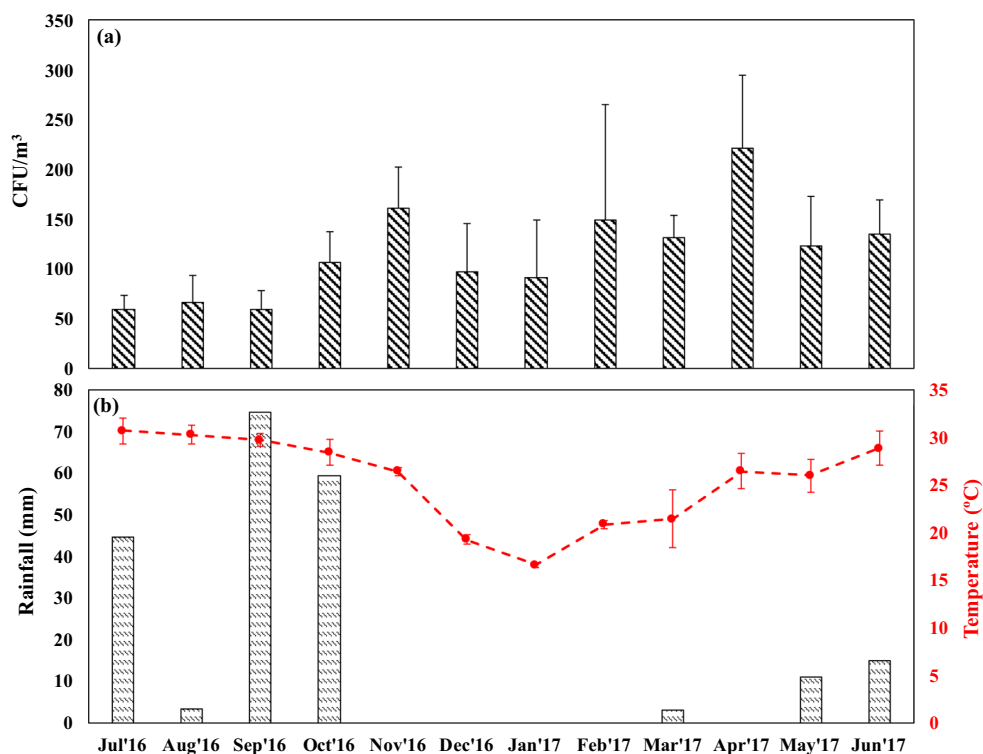
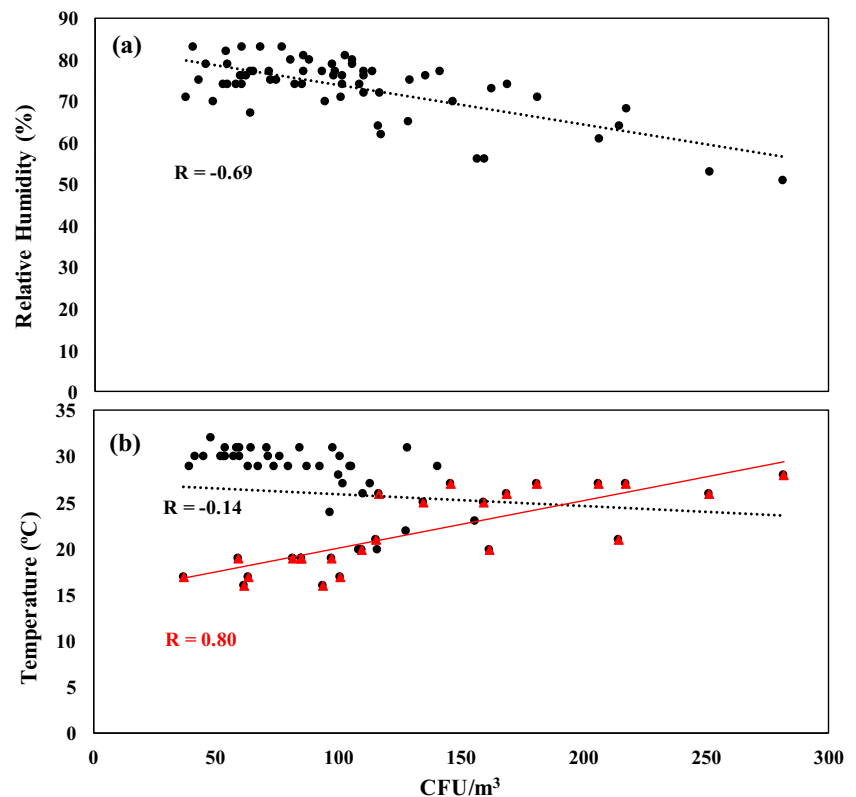


Table 1 Studies on PM-bound fungal spores reported in various parts of the world

Location	Study area	Observations	Predominant fungi	Reference
Guwahati, India	Urban-Outdoor area	High concentration in summer, and low in winter.	<i>Cladosporium</i> , <i>Curvularia</i> , <i>Aspergillus</i> , and <i>Penicillium</i>	This study
Kolkata, India	Suburban-Outdoor area	High concentration in winter and low in summer	<i>Cladosporium</i> , <i>Alternaria</i> , <i>Curvularia</i> , <i>Aspergillus</i> , <i>Penicillium</i> and <i>Drechslera</i>	Chakrabarti et al. (2012)
Delhi, India	Urban-Outdoor area	Higher concentrations during non-monsoon than monsoon months	<i>Alternaria</i> , <i>Cladosporium</i> , small round spores, <i>Curvularia</i> and <i>Helminthosporium</i>	Agarwal et al. (1969)
Jawali, India	Rural-Outdoor area	Higher concentrations in summer and lowest concentrations in winter	<i>Cladosporium</i> , <i>Chaetomium</i> , <i>Nigrospora</i> , <i>Bipolaris</i> and <i>Curvularia</i>	(Kumar and Attri 2016)
Taiwan, China	Urban-Outdoor area	High concentration during summer	<i>Ascospores</i> , <i>Cladosporium</i> , <i>Aspergillus</i> , <i>Penicillium</i> and <i>Ganoderma</i>	Ho et al. (2005)
Beijing, China	Urban-Outdoor area	High concentration in summer and low in winter	<i>Cladosporium</i> , Non-sporing isolates, <i>Alternaria</i> , <i>Aspergillus</i> and <i>Penicillium</i> .	Fang et al. (2005)
Dublin, Ireland	Suburban-Outdoor area	High concentration in summer and low in winter	<i>Cladosporium</i> , <i>Penicillium</i> , <i>Aspergillus</i> and <i>Alternaria</i> .	O’Gorman and Fuller (2008)
Taiwan, China	Urban-Outdoor area	High concentration in summer and low in winter	<i>Cladosporium</i> , <i>Penicillium</i> , <i>Aspergillus</i> , yeasts and <i>Alternaria</i> .	Lin and Li (2000)
Auckland, New Zealand	Urban-Outdoor area	Fungi concentration showed positive correlation with temperature and rainfall except for <i>Aspergillus</i> and <i>Penicillium</i> .	<i>Ganoderma</i> , <i>Coprinus</i> , <i>Hypholoma</i> , <i>Cladosporium</i> , <i>Polythtinium</i>	Hasnain (1993)
Granada, Spain	Urban-Outdoor area	High concentration in summer and low in winter	<i>Cladosporium</i> , <i>Alternaria</i> , <i>Ustilago</i> .	Sabariego et al. (2000)

Fig. 7 Variation of fungi concentration (CFU/m³) with respect to **a** relative humidity (%) and **b** temperature (°C) during the sampling period

house plants contribute to *Cladosporium*, *Penicillium*, and *Aspergillus*, which are highly aggravated and released during watering or strong air currents (Burge et al. 1982; Prussin and Marr 2015). These fungal genera are the highly infectious and cause allergic respiratory diseases mainly asthma (Douwes et al. 2003; Horner et al. 1995). The correlation of other spores was statistically significant but moderate.

Correlations between fungi concentration and meteorological parameters

Local meteorological conditions have strong effects on temporal and spatial variations in concentration of fungal spores (Kumar and Attri 2016; Langenberg et al. 1977). The monthly variation of fungi concentration along with variation of cumulative rainfall and average temperature during the sampling period is shown in the Fig. 6. In the present study, the fungi concentration peaked in April where there is no rainfall and faces high temperature. Also, the minimum fungi concentration was found in monsoon periods (July to October). Table 1 shows the fungi studies reported in various parts of the world. The monthly profiles of fungi spores in different studies showed maximum concentration in the summer and low in monsoon (Chakrabarti et al. 2012; Ho et al. 2005; Kumar and Attri 2016). Similar observations were achieved in other neighboring countries like China. The predominant fungi in China were *Cladosporium*, *Penicillium*, *Aspergillus*, and *Alternaria* (Fang et al. 2005; Ho et al. 2005; Huang et al. 2002; Lin and Li 2000). In other parts of world like Spain, New Zealand, and Ireland, the fungal spore concentrations were higher during summer, with *Cladosporium* being the most common fungi type (Hasnain 1993; O’Gorman and Fuller 2008; Sabariego et al. 2000).

The correlation between temperature and different fungal spores observed was statistically significant and positive for whole study period. Similar good correlation between the temperature and fungal spores was reported by earlier researchers too (Adhikari et al. 2004; Angulo-Romero et al. 1999; Ho et al. 2005; Sabariego et al. 2000). Fungal counts had slight negative correlation with temperature ($R = -0.14$) when the rainy samples were included, while more significant correlation was observed during non-rainy samples ($R = 0.80$) as shown in the Fig. 7. In addition to greater sporulation (Aira et al. 2013), convective upliftment of surface deposits and the wind assisted transported material contributes more fungal spore fraction to ambient PM load in warmer months (Kumar and Attri 2016). Even though rain aids spore release (Aylor and Sutton 1992), the lower concentrations observed on rainy months could be due to wet scavenging of spores, which resulted in the negative correlation ($R = -0.25$). Table 2 shows the correlation between individual fungi types and meteorological parameters. All fungi types had moderate

Table 2 Correlation between different types of fungi and meteorological parameters

Type of fungi	Relative humidity	Temperature
<i>Aspergillus</i>	− 0.59	0.76
<i>Penicillium</i>	− 0.56	0.63
<i>Cladosporium</i>	− 0.63	0.65
<i>Rhizopus</i>	− 0.63	0.80
<i>Fusarium</i>	− 0.65	0.50
<i>Curvularia</i>	− 0.65	0.77

to good correlation with RH and temperature. *Rhizopus* and *Fusarium* showed highest correlation of 0.80 and − 0.65 with temperature and RH, respectively.

Summary and conclusions

This study evaluated the variation of PM_{10} and its associated fungi concentration over a period of 1 year. The total ambient PM_{10} load in the site exceeded the Indian NAAQS limit of $100 \mu g m^{-3}$ in 40% of the samples. PM_{10} concentrations were higher during night compared to day throughout the sampling period. In contrary, fungi concentration was higher during day than night time, indicating that sunlight enhances fungal growth. This resulted in strong correlation between PM_{10} and fungi concentration during day ($R = 0.6$), and poor correlation during night ($R = -0.1$). The present study found out the seasonal variation of fungi and its diversity by their morphological characteristics. Most of the fungi observed in this study were well-known for their allergic properties, i.e., can induce respiratory ailments like Asthma. Similar to previous studies, the fungal counts were higher during warmer months and least during monsoon. Fungal counts were maximum during April ($220 CFU/m^3$) and minimum during July ($61 CFU/m^3$), which experiences severe rainfall. Fungal counts had significant positive correlation with temperature especially during non-rainy days. For example, the correlation between fungal counts and temperature was seven times higher in non-rainy samples compared to analysis with all samples. The RH and fungal count trend was observed to be negative with $R = -0.69$, i.e., the higher the RH, the lower the fungal count and vice versa. Results from this location cannot be generalized for the whole country, as the diversity and magnitude of fungal spores vary with vegetation types, fungal growth patterns, sampler used, media used for culturing, and sampling techniques. However, this study gives useful insight about the distribution of air-borne allergens and their variation with meteorological parameters in this unique bio-diversity hotspot of India.

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References

- Adams GC, Gottwald TR, Leach CM (1986) Environmental factors initiating liberation of conidia of powdery mildews. *Phytopathology* 76:1239–1245
- Adhikari A, Sen MM, Gupta-Bhattacharya S, Chanda S (2004) Airborne viable, non-viable, and allergenic fungi in a rural agricultural area of India: a 2-year study at five outdoor sampling stations. *Sci Total Environ* 326:123–141
- Agarwal MK, Shivpuri DN, Mukerji KG (1969) Studies on the allergenic fungal spores of the Delhi, India, metropolitan area: botanical aspects (aeromycology). *J Allergy* 44:193–203. [https://doi.org/10.1016/0021-8707\(69\)90086-0](https://doi.org/10.1016/0021-8707(69)90086-0)
- Aira M-J, Rodríguez-Rajo FJ, Fernández-González M, Seijo C, Elvira-Rendueles B, Abreu I, Gutiérrez-Bustillo M, Pérez-Sánchez E, Oliveira M, Recio M, Tormo R, Morales J (2013) Spatial and temporal distribution of *Alternaria* spores in the Iberian Peninsula atmosphere, and meteorological relationships: 1993–2009. *Int J Biometeorol* 57:265–274. <https://doi.org/10.1007/s00484-012-0550-x>
- Anderson HR, Favarato G, Atkinson RW (2013) Long-term exposure to air pollution and the incidence of asthma: meta-analysis of cohort studies. *Air Quality, Atmosphere Health* 6:47–56
- Angulo-Romero J, Mediavilla-Molina A, Domínguez-Vilches E (1999) Conidia of *Alternaria* in the atmosphere of the city of Cordoba, Spain in relation to meteorological parameters. *Int J Biometeorol* 43:45–49
- Aydogdu H, Asan A, Otkun MT, Ture M (2005) Monitoring of fungi and bacteria in the indoor air of primary schools in Edirne city, Turkey. *Indoor Built Environ* 14:411–425
- Aylor DE, Sutton TB (1992) Release of *Venturia inaequalis* ascospores during unsteady rain: relationship to spore transport and deposition. *Phytopathology* 82:532–540
- Burge HA, Solomon WR, Muilenberg ML (1982) Evaluation of indoor plantings as allergen exposure sources. *J Allergy Clin Immunol* 70:101–108. [https://doi.org/10.1016/0091-6749\(82\)90236-6](https://doi.org/10.1016/0091-6749(82)90236-6)
- Bush RK, Portnoy JM (2001) The role and abatement of fungal allergens in allergic diseases. *J Allergy Clin Immunol* 107:S430–S440
- Campbell CK, Johnson EM (2013) Identification of pathogenic fungi. John Wiley & Sons,
- Chakrabarti HS, Das S, Gupta-Bhattacharya S (2012) Outdoor airborne fungal spora load in a suburb of Kolkata, India: its variation, meteorological determinants and health impact. *Int J Environ Health Res* 22:37–50
- Chatterjee S, Saikia A, Dutta P, Ghosh D, Pangging G, Goswami AK (2006) Biodiversity significance of north East India WWF-India. New Delhi:1–71
- Chowdhery HJ (2001) Orchid diversity in North-East India vol 15
- Denning D, O'driscoll B, Hogaboam C, Bowyer P, Niven R (2006) The link between fungi and severe asthma: a summary of the evidence. *Eur Respir J* 27:615–626
- Després V, Huffman JA, Burrows SM, Hoose C, Safatov AS, Buryak G, Fröhlich-Nowoisky J, Elbert W, Andreae MO, Pöschl U, Jaenicke R (2012) Primary biological aerosol particles in the atmosphere: a review. *Tellus B: Chemical Physical Meteorology* 64:15598
- Douwes J, Thorne P, Pearce N, Heederik D (2003) Bioaerosol health effects and exposure assessment: progress and prospects. *Annals Occupational Hygiene* 47:187–200
- Egan C, Li D-W, Klironomos J (2014) Detection of arbuscular mycorrhizal fungal spores in the air across different biomes and ecoregions. *Fungal Ecol* 12:26–31
- Elbert W, Taylor P, Andreae M, Pöschl U (2007) Contribution of fungi to primary biogenic aerosols in the atmosphere: wet and dry discharged spores, carbohydrates, and inorganic ions. *Atmos Chem Phys* 7:4569–4588
- Emberlin J, Newman T, Bryant R (1995) The incidence of fungal spores in the ambient air and inside homes: evidence from London. *Aerobiologia* 11:253–258
- Fang Z, Ouyang Z, Hu L, Wang X, Zheng H, Lin X (2005) Culturable airborne fungi in outdoor environments in Beijing, China. *Sci Total Environ* 350:47–58
- Fitt GP (1989) The ecology of *Heliothis* species in relation to agroecosystems. *Annu Rev Entomol* 34:17–53
- Gielen MH, Van Der Zee S, Van Wijnen J, Van Steen C, Brunekreef B (1997) Acute effects of summer air pollution on respiratory health of asthmatic children. *Am J Respir Crit Care Med* 155:2105–2108
- Gollapalli M, Kota SH (2017) Methane emissions from a landfill in north-east India: Performance of various landfill gas emission models. *Environ Pollution* 234:174–180
- Gottwald TR (1982) Spore discharge by the pecan scab pathogen, *Cladosporium caryigenum*. *Phytopathology* 72:1193–1197
- Green BJ, Mitakakis TZ, Tovey ER (2003) Allergen detection from 11 fungal species before and after germination. *J Allergy Clin Immunol* 111:285–289
- Guo H, Kota SH, Sahu SK, Hu J, Ying Q, Gao A, Zhang H (2017) Source apportionment of PM_{2.5} in North India using source-oriented air quality models environmental pollution 231:426–436 doi:<https://doi.org/10.1016/j.envpol.2017.08.016>
- Hasnain SM (1993) Influence of meteorological factors on the air spora. *Grana* 32:184–188
- Hawkes CV, Kivlin SN, Rocca JD, Huguet V, Thomsen MA, Suttle KB (2010) Fungal community responses to precipitation. *Glob Chang Biol* 17:1637–1645. <https://doi.org/10.1111/j.1365-2486.2010.02327.x>
- Ho H-M, Rao CY, Hsu H-H, Chiu Y-H, Liu C-M, Chao HJ (2005) Characteristics and determinants of ambient fungal spores in Hualien, Taiwan. *Atmos Environ* 39:5839–5850
- Horner W, Helbling A, Salvaggio J, Lehrer S (1995) Fungal Allergens *Clinical Microbiology reviews* 8:161–179
- Huang C-Y, Lee C-C, Li F-C, Ma Y-P, Su H-JJ (2002) The seasonal distribution of bioaerosols in municipal landfill sites: a 3-yr study. *Atmos Environ* 36:4385–4395
- Jones AM, Harrison RM (2004) The effects of meteorological factors on atmospheric bioaerosol concentrations—a review. *Sci Total Environ* 326:151–180
- Kakde UB, Kakde HU, Saoji AA (2001) Seasonal variation of fungal propagules in a fruit market environment. Nagpur (India) *Aerobiologia* 17:177–182
- Kakikawa M, Kobayashi F, Maki T, Yamada M, Higashi T, Chen B, Shi G, Hong C, Tobo Y, Iwasaka Y (2008) Dustborne microorganisms in the atmosphere over an Asian dust source region, Dunhuang. *Air Quality, Atmosphere Health* 1:195–202. <https://doi.org/10.1007/s11869-008-0024-9>
- Kallawicha K, Tsai YJ, Chuang YC, Lung SCC, Wu CD, Chen TH, Chen PC, Chompuchan C, Chao HJ (2015) The spatiotemporal distributions and determinants of ambient fungal spores in the greater Taipei area. *Environ Pollut* 204:173–180
- Kota SH, Guo H, Myllyvirta L, Hu J, Sahu SK, Garaga R, Ying Q, Gao A, Dahiya S, Wang Y, Zhang H (2018) Year-long simulation of gaseous and particulate air pollutants in India. *Atmos Environ* 180:244–255. <https://doi.org/10.1016/j.atmosenv.2018.03.003>
- Kumar A, Attri AK (2016) Characterization of fungal spores in ambient particulate matter: a study from the Himalayan region. *Atmos Environ* 142:182–193
- Langenberg W, Sutton J, Gillespie T (1977) Relation of weather variables and periodicities of airborne spores of *Alternaria dauci*. *Phytopathology* 67:879–883

- Larsen GL, Beskid C, Shirmamé-Moré L (2002) Environmental air toxics: role in asthma occurrence? *Environ Health Perspect* 110:501–504
- Leach CM (1975) Influence of relative humidity and red-infrared radiation on violent spore release by *Drechslera turcica* and other fungi. *Phytopathology* 65:1303–1312
- Li D-W, Kendrick B (1994) Functional relationships between airborne fungal spores and environmental factors in Kitchener-Waterloo, Ontario, as detected by canonical correspondence analysis. *Grana* 33:166–176
- Li X, Wang Y, Guo X, Wang Y (2013) Seasonal variation and source apportionment of organic and inorganic compounds in PM_{2.5} and PM₁₀ particulates in Beijing, China. *J Environ Sci* 25:741–750
- Lin W-H, Li C-S (2000) Associations of fungal aerosols, air pollutants, and meteorological factors. *Aerosol Sci Technol* 32:359–368
- Madelin T, Johnson H (1992) Fungal and actinomycete spore aerosols measured at different humidities with an aerodynamic particle sizer. *J Appl Microbiol* 72:400–409
- Moore-Landecker E (2011) Fungal Spores. In: eLS. John Wiley & Sons, Ltd. doi:<https://doi.org/10.1002/9780470015902.a0000378.pub2>
- Nasir ZA, Colbeck I, Sultan S, Ahmed S (2012) Bioaerosols in residential micro-environments in low income countries: a case study from Pakistan. *Environ Pollut* 168:15–22
- Navi S, Bandyopadhyay R, Hall A, Bramel-Cox P (1999) A pictorial guide for the identification of mold fungi on sorghum grain. vol 59. International Crops Research Institute for Semi Arid Tropics,
- O'Hollaren MT, Yunginger JW, Offord KP, Somers MJ, O'Connell EJ, Ballard DJ, Sachs MI (1991) Exposure to an aeroallergen as a possible precipitating factor in respiratory arrest in young patients with asthma. *N Engl J Med* 324:359–363
- O'Gorman CM, Fuller HT (2008) Prevalence of culturable airborne spores of selected allergenic and pathogenic fungi in outdoor air. *Atmos Environ* 42:4355–4368
- Portnoy JM, Kwak K, Dowling P, VanOsdol T, Barnes C (2005) Health effects of indoor fungi. *Ann Allergy Asthma Immunol* 94:313–320
- Pringle A (2013) Asthma and the diversity of fungal spores in air. *PLoS Pathog* 9:e1003371
- Prussin AJ, Marr LC (2015) Sources of airborne microorganisms in the built environment. *Microbiome* 3:78. <https://doi.org/10.1186/s40168-015-0144-z>
- Rajan K, Chakrabarty MAG, Eric M, Wilcox and Hans Moosmülle (2012) India: Guwahati One of the most polluted city in the World, Available: <http://chimalaya.org/2012/06/28/india-guwahati-one-of-the-most-polluted-city-in-the-world/> (Accessed 30 Nov, 2017)
- Reddy KS, Shah B, Varghese C, Ramadoss A (2005) Responding to the threat of chronic diseases in India. *Lancet* 366:1744–1749
- Rohr AC, Habre R, Godbold J, Moshier E, Schachter N, Kattan M, Grunin A, Nath A, Coull B, Koutrakis P (2014) Asthma exacerbation is associated with particulate matter source factors in children in new York City. *Air Quality, Atmosphere Health* 7:239–250
- Sabariago S, De La Guardia CD, Alba F (2000) The effect of meteorological factors on the daily variation of airborne fungal spores in Granada (southern Spain) international. *J Biometeorology* 44:1–5
- Sahu SK, Kota SH (2017) Significance of PM_{2.5} air quality at the Indian capital. *Aerosol Air Qual Res* 17:588–597. <https://doi.org/10.4209/aaqr.2016.06.0262>
- Schachter EN, Moshier E, Habre R, Rohr A, Godbold J, Nath A, Grunin A, Coull B, Koutrakis P, Kattan M (2016) Outdoor air pollution and health effects in urban children with moderate to severe asthma. *Air Quality, Atmosphere Health* 9:251–263. <https://doi.org/10.1007/s11869-015-0335-6>
- Singh A, Ganguli M, Singh A (1995) Fungal spores are an important component of library air. *Aerobiologia* 11:231–237
- Timmer LW, Solel Z, Gottwald TR, Ibañez AM, Zitko SE (1998) Environmental factors affecting production, release, and field populations of conidia of *Alternaria alternata*, the cause of Brown spot of Citrus. *Phytopathology* 88:1218–1223. <https://doi.org/10.1094/PHTO.1998.88.11.1218>
- Womilolu TO, Miller JD, Mayer PM, Brook JR (2003) Methods to determine the biological composition of particulate matter collected from outdoor air. *Atmos Environ* 37:4335–4344