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ORIGINAL PAPER

Exposure to indoor fungi in different working environments: A comparative study

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Abstract In this study an attempt was made to evaluate the qualitative and quantitative fungal burden (load) in five different working environments of South Assam (India) and the possible risks of indoor fungi to employees and stored products. Fungal concentrations in different working environments were studied using a Burkard personal petriplate sampler. The survey was done in five different working environments for one year. A total of 76 fungal types were recorded in the indoor air of South Assam during the survey period. The maximum fungal concentration (5,437.6 ± 145.3 CFU - m^{-3} air) was recorded in the indoor air of medical wards, followed by the paper-processing industry (3,871.7 ± 93.4 CFU m^{-3} air). However the lowest concentration was observed in the indoor air of a bakery (1,796.8 ± 54.4 CFU m^{-3} air). The most dominant fungal genera were *Aspergillus* (34.2%) followed by *Penicillium* (17.8%), *Geotrichum* (7.0%) and the most dominant fungal species were *Aspergillus fumigatus* (2,650.4 CFU m^{-3} air) followed by *Aspergillus flavus* (1,388.2 CFU m^{-3} air), *Geotrichum candidum* (1,280.3 CFU m^{-3} air), *Aspergillus niger* (783.3 CFU m^{-3} air), and *Penicillium aurantiovirens* (774.0 CFU m^{-3} air). The fungal species viz., *Aspergillus fumigatus*, *Penicillium aurantiovirens, Aspergillus flavus*, *Aspergillus niger*, *Geotrichum candidum*, and *Penicillium thomii*, which were recorded well above threshold levels, may lead to adverse health hazards to indoor workers. Setting occupational exposure limits for indoor fungal spores as reference values is obligatory for prevention and control of adverse effects of indoor fungal exposure.

Keywords Indoor air · Colony-forming unit · SMC · HPC · FCI

Abbreviations

SMC	Silchar Medical College and Hospital
HPC	Hindustan Paper Corporation
FCI	Food Corporation of India
CFU	Colony-forming unit
MMW	Male medicine ward
FMW	Female medicine ward
OT	Operating theatre

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1 Introduction

Fungal growth in indoor air has long been regarded as detrimental, basically because of its tendency to reduce perceived indoor air quality. A wide spectrum of fungi has been reported as a result of indoor aerobiological research performed throughout the world in places such as dwelling houses, poultry sheds, and dairies (Agashe et al. 1992; Cormier et al. 1991; Nandi and Chanda 1989). Fungi usually enter a building from outdoors but their concentration may well be higher in indoor air when there are indoor sources. Increasingly, fungi in indoor air are being proposed as a cause of adverse health effects (Bush and Portnoy 2001; Ren et al. 2001). The health risks connected with exposure to fungi involve not only immunosuppressed patients but also perfectly healthy persons among whom hyper-reactivity to the fungal allergen may develop; such hyper-reactivity may cause respiratory disorders and may exacerbate asthma (Cross 1997; Institute of Medicine 2004). There are reports of the possible onset of respiratory disorders after hyper-sensitization to various genera of fungi. In particular, various strains of *Aspergillus* and *Penicillium* seem to be chiefly involved in the genesis of asthma and allergic alveolitis (pulmonitis because of hypersensitivity) (Kanny et al. 1996). Many epidemiological studies in several countries have consistently detected an association between respiratory symptoms and reported home dampness and mould growth, but causality in these studies has not been established (Pei-Chih et al. 2000; Ren et al. 1999). Besides allergic and respiratory problems, some indoor moulds, when ingested or inhaled, could produce mycotoxins, including aflatoxins and microbial volatile organic compounds which may lead to several health complaints, for example headache, dizziness, and inability to concentrate, consistent with mycotoxicosis (Burge and Amman 1999; Prasad et al. 1994). Indoor fungal growth may therefore lead to multiple health effects if neglected. In this study an attempt was made to evaluate the qualitative and quantitative fungal burden of indoor air of five important working environments in South Assam (India), which may help in predicting possible risks of indoor fungi to employees and stored products.

2 Materials and methods

The indoor atmospheric fungal survey was carried out in five different working environments in South Assam, India, which lies between 24°5′N latitude and 92°48′E longitude and approximately 27 m above mean sea level (Fig. 1). The survey sites were Silchar Medical College and Hospital (SMC, Silchar), Hindustan Paper Corporation (HPC, Panchgram), The Food Corporation of India (FCI, Itkhola), poultry farms (a private poultry farm, Irongmara, and a government poultry farm, Silkoori), and private bakeries (Das Bakery, Rangirkhari, and Ujjala Bakery, Vivakananda Road, Silchar). In SMC, samples were collected from three different sections comprising five different wards (viz., gynaecology (general ward and operating theatre), medicine (male ward and female ward), and Pediatric (general ward)). In HPC, samples were collected from five different places (viz., bamboo stock yard, chipper house, pulp house, paper house, and finishing house). For FCI, poultry farms, and bakeries, however, samples were collected from two places each (i.e., grain and sugar warehouses of FCI; hatchery and broiler house of poultry farms, and preparation and packaging rooms in bakeries). The sites were chosen keeping in mind the probable effect of indoor fungi on employees and/or manufactured products. SMC and HPC are big establishments with more than 500 employees. Although there are fewer number of employees at the FCI, poultry farms, and bakeries, as compared to SMC and HPC, the indoor environment of these industries should however be evaluated as it is related to the health of workers and the bio-safety of their products. The entire indoor working environments surveyed had concrete buildings. The SMC and HPC buildings were more than 100 years old whereas the buildings of the other sites were approximately 20–30 years old. They were situated close to the national highway and were surrounded by local inhabitants. Most of the indoor survey sites were naturally ventilated by outdoor air (through windows and doors); the exception was the operating theatre of SMC, which was air-conditioned and was receiving filtered air.

Burkard personal petriplate sampler (Burkard, UK) containing Rose Bengal agar medium was used to collect culturable fungi (Martin 1950). It is a volumetric, compact, battery-operated sampler of

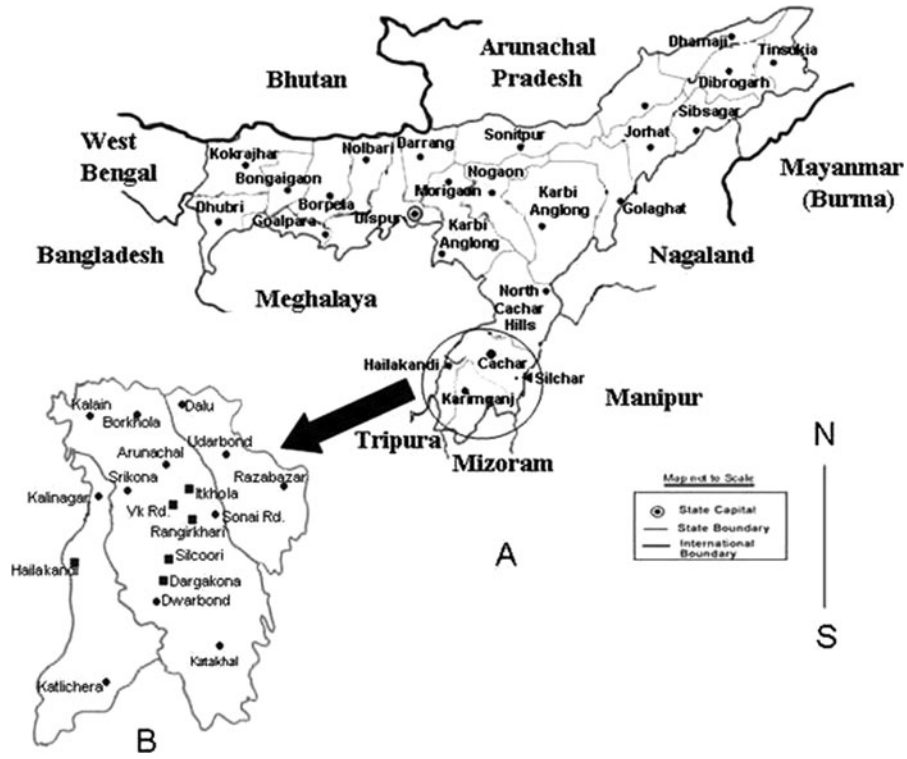

Fig. 1 Maps of South Assam highlighting the study area (*open circle*)

10 cm high and 8 cm in diameter. It has a circular orifice at the top and a removable cap to insert the petriplate. The impaction orifice is mounted in the vertical plane and the instrument operates at a nominal air throughput of 10 l per min. The sampler was run for 10 min in each site between 10 to 12 h (IST) at a height of approximately 1 m above ground. Sampling was also conducted in the outdoor environment, approximately 100 m from the respective indoor sites, to act as a control. The exposed plates were incubated for 5–7 days at 25 ± 2°C before identification. Identification was based on colony characteristics and microscopic features with the help of standard literature (Dumsch et al. 1980; Gillman 1975). Fungal count was expressed as daily colony-forming unit per cubic meter air after multiplication by a correction factor. Sampling was conducted once a week for one year from January 1999 to December 1999. A total of 50 samples were obtained in both SMC and HPC. In the poultry farms and bakeries 40 samples were obtained during the survey period. Similarly, in FCI, 20 samples were obtained and studied. The numbers of samples were different due to the variations in number of sampling areas among the different sites; however the total number of samples obtained in each section of the different sites were equal (ten each). Total sampling duration in SMC and HPC was 4,800 min (960 min/section). However, in the poultry farms and bakeries the total sampling time was 3,840 min (960 min/section) and in the FCI the total sampling duration was 1,920 min (960 min/section). Statistical analysis was performed using MS-Excel, Minitab 12.2, and Biodiversity Professional 2. The average number of colony-forming units per m^3 of air of fungi was calculated separately for all the sites and the standard deviation of the mean value was calculated. Separate analyses were conducted for each location (site-specific indoor samples and outdoor samples, and site-wide average indoor concentrations) as proposed by (Tsai and Macher 2005). Similarities in the distribution of fungal species in all 16 sections of the study sites were studied by cluster analysis using Biodiversity Professional 2 statistical software.

3 Results

The atmospheric survey carried out in different working environments (viz., SMC, HPC, FCI, poultry

farms and bakeries), revealed significant variation in indoor fungal concentrations ($F = 2.37$; $P < 0.05$). The indoor fungal survey at SMC revealed 42 fungal types belonging to 21 genera (Table 1). The genus *Aspergillus* contributed 34.8% of the total number of CFU m^{-3} air followed by *Penicillium* (17%), *Geotrichum* (11%), *Cladosporium* (5%), *Mucor* (5%), *Humicola* (5%), and *Curvularia* (4%). The highest fungal count (7,701 CFU m^{-3} air) was measured in the female medical ward, followed by the male medical ward (6,543 CFU m^{-3} air), the pediatric ward (5,776 CFU m^{-3} air), and the general gynaecology ward (5,328 CFU m^{-3} air) and the count was lowest (3,419 CFU m^{-3} air) in the operating theatre (gynecology) (Table 2). Fungal diversity was maximum in the male medical ward (29 types) followed by the general gynaecology ward (23 types) and the female medical ward (22 types) and lowest in the operating theatre (gynaecology) with 14 fungal types. *Aspergillus fumigatus* made the largest contribution in the indoor air of the medical wards (2,057 CFU m^{-3} air in the FMW and 1,096 CFU - m^{-3} air in the MMW) whereas *A. flavus* made the largest contribution in the general gynaecology ward (705 CFU m^{-3} air). *Penicillium* represent the dominant species in the MMW (1,274 CFU m^{-3} air) followed by the FMW (1,010 CFU m^{-3} air). The monthly distribution pattern showed maximum fungal concentrations in June (712 CFU m^{-3} air) however there was no definite seasonal pattern of distribution of indoor fungi in SMC (Fig. 2).

At the HPC, a total of 48 fungal types belonging to 17 genera were identified (Table 1). Among the different sites surveyed at the HPC, the fungal concentration was maximum in the chipper house (6,828 CFU m^{-3} air) followed by the bamboo stock yard (5,107 CFU m^{-3} air) whereas the concentration of fungi was lowest in the pulp house (1,796 CFU - m^{-3} air) (Table 2). *Aspergillus* was the dominant genus (30%) followed by *Penicillium* (24%) and *Rhizopus* (9%). *Aspergillus* was dominant in all sites except the chipper house where *Geotrichum* and *Penicillium* were dominant. Among the fungal species identified at the HPC, *Aspergillus flavus*, *A. fumigatus*, *A. terreus*, *Geotrichum candidum*, *Penicillium aurantiovarens*, *P. thomii*, and *P. citrinum* were dominant. *Acremonium*, *Rhizopus*, and *Geotrichum* were also encountered frequently. The monthly distribution pattern showed the fungal concentration was maximum during May to July (480–591 CFU - m^{-3} air) and lowest during December and January (149 and 170 CFU m^{-3} air) (Fig. 2).

In the indoor survey in the FCI warehouse, 31 fungal types belonging to 16 genera were identified (Table 1). *Aspergillus* was found to be the dominant genus, contributing approximately 39% of the total colony-forming units, followed by *Penicillium* (17%) and *Curvularia* (7%). *Aspergillus fumigatus*, followed by *A. terreus, A. flavus, A. niger, Penicillium brevicampactum*, and *P. aurantioverens* were the dominant fungal species from the FCI warehouse. The fungal population was higher in the grain storage room (4,356 ± 117.2 CFU m^{-3} air) than in the sugar storage room (3,251 ± 93.6 CFU m^{-3} air). In the FCI, the indoor fungal concentration increased with the onset of rain from April to September and continued until the end of summer.

The indoor fungal survey at the poultry farms revealed 33 fungal types belonging to 16 genera (Table 1). The genus *Aspergillus* contributed the maximum colony-forming units (38%) followed by *Penicillium* (13%). *A. fumigatus* (14%), *A. flavus* (6%), *A. clavatus* (5%), and *A. niger* (4%) were the dominant *Aspergillus* species. Among *Penicillium* only *P. brevicompactum* and *P.frequentans* were recorded and identified. *Alternaria alternata*, *A. peponicola*, *Cladosporium herbarum*, *Curvularia lunata*, *C. subulata*, *Fusarium poae*, *Mucor hiemalis*, and *M. racemosus* were also identified in the poultry farms at different concentrations. Fungal diversity was almost the same in the hatcheries and broiler houses of the poultry farms (31 and 32 varieties, respectively) but the total number of colony-forming units was higher in the broiler houses (3,965 ± 104.0 CFU m^{-3} air) than in the hatcheries (2,882 ± 81.5 CFU m^{-3} air). The fungal concentration was lower in the government poultry farm (2,459 ± 76.8 CFU m^{-3} air) than in the private poultry farm (4,386 ± 116 CFU m^{-3} air). Seasonal changes were also observed in the indoor fungal concentrations in poultry farms, with higher concentration during summer (i.e., from May to August) and peak concentration in June (507 CFU m^{-3} air).

Finally, in the bakeries 23 fungal types belonging to 13 genera were identified. *Aspergillus* was found to be the dominant genus and contributed 37% of the total colony-forming units followed by *Penicillium* (15%) and *Cladosporium* (8%). *A. fumigatus* (21%),

Table 1 Comparison of the distribution of airborne fungi (average CFU m^{-3} air) in the indoor air of different working environments, measured by use of the Burkard personal petriplate sampler

Fungal types[a]	Survey sites				
	SMC	HPC	FCI	Poultry	Bakery
Acremonium kiliense	37.5 (22.5)[b]	118.4 (47.3)			
A. mumorum		49.6 (24.8)			
A. species	12.2 (6.1)	59.9 (29.9)			
Alternaria alternata			93.0 (18.6)	35.4 (0)	
A. cassiae	39.2 (0)		42.6 (12.8)		
A. eichhorinae	31.8 (12.7)				
A. peponicola	31.2 (0)			20.6 (0)	
A. species	59.7 (47.7)			21.4 (6.4)	
Aspergillus candidus	50.8 (25.4)		74.1 (7.4)	81.7 (24.5)	
A. clavatus	9.2 (0)		92.5 (0)	165.9 (49.7)	
A. flavus	424.0 (169.6)	296.3 (59.2)	275.2 (137.6)	214.4 (107.2)	178.3 (17.8)
A. fumigatus	917.1 (458.5)	449.3 (134.8)	431.7 (172.7)	470.6 (141.2)	381.7 (152.7)
A. nidulans		51.5 (5.1)			
A. niger	103.2 (51.6)	127.8 (76.7)	367.7 (220.6)	126.5 (101.2)	58.1 (29.5)
A. ochraceous	40.3 (8.1)			28.6 (0)	
A. restrictus		39.4 (7.8)			
A. terreus	38.8 (15.5)	149.2 (74.6)	247.2 (123.6)	71.1 (21.3)	
A. ustus		5.0 (0)			
A. versicolor		43.7 (13.0)			30.7 (3.1)
A. species	87.5 (61.2)			125.5 (62.7)	16.1 (20.9)
Botrytis sp.	30.0 (6)				
Calcarisporium sp.	8.9 (0)		39.6 (7.9)	56.8 (11.4)	54.3 (0)
Candida sp.	2.0 (0)		28.9 (17.3)		
Cladosporium cladosporioides	80.7 (32.3)	8.7 (11.3)	56.8 (17.0)		95.1 (104.6)
C. herbarum	107.2 (64.3)	21.7 (17.3)	43.5 (13.0)	64.7 (97.0)	58.8 (47.0)
C. species	107.2 (108.0)	17.7 (15.9)	23.2 (11.7)	24.4 (14.6)	
Cunninghamella sp.	0.8 (0)				
Curvularia lunata	127.0 (50.8)	35.7 (14.3)	131.8 (79.1)	83.7 (50.2)	17.7 (7.1)
C. subulata	75.2 (15.4)	6.6 (3.9)		64.9 (45.4)	
C. tetramera		13.8 (0)			
C. species	46.4 (32.5)		127.6 (38.3)	51.5 (30.9)	71.5 (35.7)
Fusarium moniliforme		25.0 (5.0)			
F. oxysporium	5.5 (0)	37.1 (14.8)			
F. poae	3.7 (1.5)	21.7 (6.5)	25.6 (12.8)	37.5 (15)	
F. species	10.1 (5.0)	65.5 (19.6)	19.7 (5.9)	77.1 (38.5)	
Fusarila sp.				64.6 (0)	
Geotrichum candidum	579.5 (347.7)	233.4 (93.3)	156.9 (78.4)	221.9 (110.9)	88.6 (35.4)
Helminthosporium sp.	9.5 (3.8)		96.4 (19.3)		18.2 (7.3)
Humicola brevi		42.5 (12.7)			
H. fuscoatra	41.3 (20.6)	31.4 (12.5)	78.6 (31.4)		54.1 (43.3)
H. grisea		1.1 (0)			
H. nigrescens omvik	80.2 (56.1)	35.3 (10.6)	95.3 (47.6)		

Table 1 continued

Fungal types[a]	Survey sites				
	SMC	HPC	FCI	Poultry	Bakery
H. species	153.4 (61.3)	6.7 (10.2)	20.8 (4.1)		35.3 (17.6)
Meria species		10.3 (0)		119.1 (23.8)	
Mucor hiemalis	196.1 (98.0)	56.1 (22.4)	146.1 (0)	26.4 (23.2)	76.7 (107.4)
M. racemosus	21.7 (8.7)	20.5 (14.3)		18.1 (9.0)	
M. species	71.6 (57.3)	16.1 (9.7)	19.6 (9.8)	69.8 (41.9)	
Nigrospora sp.	102.1 (30.6)	170.3 (51.1)	82.8 (16.6)	112.4 (44.9)	35.0 (24.5)
Oidiodendron sp.					28.3 (0)
Oidium sp.					9.3 (0)
Penicillium aurantiovirens	131.5 (78.9)	462.7 (231.3)	179.8 (89.9)		
P. brevicompactum	60.2 (30.1)	109.3 (53.1)	123.1 (73.8)	65.0 (26)	8.9 (8.0)
P. camemberti	50.7 (10.1)				
P. citrinum	118.6 (71.1)	98.3 (49.1)			
P. cyclopium	70.4 (28.1)				25.3 (7.6)
P. expansum			153.2 (91.9)		142.9 (99.9)
P. frequentans		32.8 (19.7)		76.1 (30.4)	
P. glabrum	23.9 (9.5)				
P. roquefortii		52.1 (20.8)			
P. thomii		100.1 (30.0)			
P. viridicatum		42.2 (12.6)			
P. species	499.4 (249.6)	26.2 (10.5)	211.5 (126.9)	307.3 (122.9)	92.0 (64.4)
Phialocephala sp.		144.4 (0)			
Popularia sp.		23.5 (7.0)			
Pseudotorula sp.			14.6 (8.7)	116.7 (35.0)	23.1 (18.5)
Rhizopus sp.	25.6 (10.1)	352.6 (211.5)	168.5 (101.1)	119.6 (83.7)	59.4 (83.1)
Spedonium sp.		32.5 (0)			
Stachybotrys sp.		29.1 (0)			
Staphylotrichum sp.	6.9 (0)				
Stigmia sp.	5.3 (0)				
Torula sp.	79.9 (47.9)	35.1 (17.5)	65.3 (39.2)	87.6 (52.5)	
Trichoderma koningii	23.4 (9.4)	12.9 (0)		17.4 (8.7)	
T. viride	62.1 (12.4)	22.9 (11.4)	59.3 (17.8)		
T. species	23.7 (9.5)	18.2 (12.7)	10.2 (8.1)	23.2 (9.2)	46.7 (18.7)
Trichothecium roseum	151.7 (75.8)				
Ulocladium sp.	1.2 (0)				
Unidentified[a]	360.5 (216.3)	9.5 (15.2)		135.2 (94.6)	90.7 (54.4)
Total CFUm^{-3} air[c]	5,437.6 ± 145.3	3,871.7 ± 93.4	3,802.7 ± 86.4	3,402.7 ± 78.2	1,796.8 ± 54.4

[a] Fungi which could not be identified because of indistinct morphology were placed in "unidentified" group, and fungi which could not be categorized up to species level were placed under "species" of the respective genera

[b] The value in parentheses is the outdoor fungal concentration (average CFU m^{-3} air) of the respective survey site

[c] ±Standard deviation

A. flavus (10%), and *P. expansum* (8%) were the dominant species in the bakeries. The indoor fungal concentration in the Das bakery was higher than that in the Ujjala Bakery (1,986 ± 63.7 and 1,881 ± 47.9 CFU m^{-3} air, respectively). In the two different sections of the bakeries surveyed, the

Table 2 Total CFU of fungi recorded m^{-3} of air from various indoor survey sites, measured by use of the Burkard personal petriplate sampler

Sampling sites	No. of samples collected	Total CFU m^{-3} air[a]
Gynaecology		
General ward	10	5,327.9 ± 171.3
Operating theatre (O.T)	10	3,418.9 ± 133.3
Medicine		
Male ward (MMW)	10	6,543.5 ± 219.3
Female ward (FMW)	10	7,700.6 ± 336.2
Pediatric		
General ward	10	5,776.5 ± 312.3
HPC		
Bamboo stock yard	10	5,107.4 ± 188.4
Chipper house	10	6,828.2 ± 306.9
Pulp house	10	1,796 ± 58.4
Paper house	10	2,585.2 ± 88.6
Finishing house	10	3,045.2 ± 154.8
FCI warehouse		
Grain storage	10	4,355.8 ± 117.2
Sugar storage	10	3,250.9 ± 93.6
Poultry farm[b]		
Hatchery	20	2,881.9 ± 81.5
Broiler house	20	3,964.7 ± 104.0
Bakery[b]		
Preparation room	20	2,495.7 ± 89.3
Packaging room	20	1,071.8 ± 41.1

[a] ±Standard deviation

[b] In the hatchery and broiler house of the poultry farms the number of samples is the sum of the total number of samples in two different poultry houses. The same applies to the preparation and packaging rooms of the bakeries

fungal concentration was higher in the preparation room (2,496 ± 89.3 CFU m^{-3} air) than in the packaging room (1,072 ± 41.1 CFU m^{-3} air). Statistical analysis showed significant variation ($F = 4.28$, $P < 0.05$), in the mean colony count of the two different sections of the bakeries. Seasonal study showed fungal concentrations were highest in April and May, during which average fungal concentrations were 238 CFU m^{-3} air and 271.9 CFU m^{-3} air, respectively.

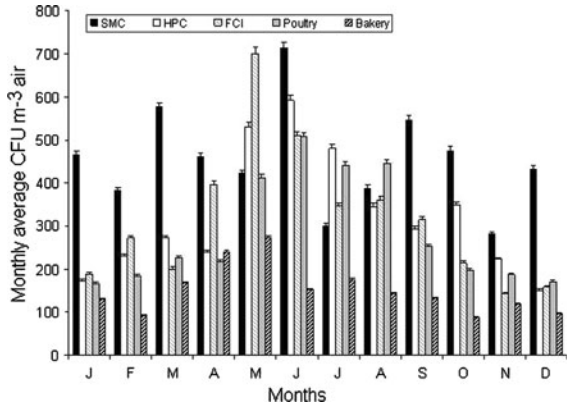

Fig. 2 Monthly average colony-forming units of fungal spores per m^3 of air in different survey sites of South Assam. *SMC*, Silchar Medical College and Hospital; *HPC*, Hindustan Paper Corporation; *FCI*, Food Corporation of India; *Poultry*, Both Government and private poultry farms; *Bakery*, Ujjala and Das bakeries

Overall, the maximum atmospheric fungal concentration was in SMC (5,437 ± 145.3 CFU m^{-3} air) followed by the HPC (3,872 ± 93.4 CFU m^{-3} air); the lowest atmospheric fungal concentration was recorded in the bakeries (1,797 ± 54.4 CFU m^{-3} air). *Aspergillus* was found to be the dominant genus in all the working environments, accounting for 34% of the total fungal colonies identified, followed by *Penicillium* (18%), *Geotrichum* (7.0%), *Curvularia* (5%), and *Humicola* (4%). Among the different species of fungus identified, *A. fumigatus* (2,650 CFU m^{-3} air) was the dominant species followed by *A. flavus* (1,388 CFU m^{-3} air), *G. candidum* (1,280 CFU m^{-3} air), *A. niger* (783 CFU^{-3} air), and *P. aurantiovirens* (774 CFU m^{-3} air). Amongst the known allergenic fungi, *Aspergillus* and *Penicillium* were largest in the indoor atmosphere of SMC. Indoor fungal concentrations were usually higher than the respective outdoor concentrations, except in some cases where outdoor fungal concentration was found slightly higher (Table 1). The genera *Alternaria, Aspergillus, Cladosporium, Curvularia, Geotrichum*, and *Mucor* were dominant in SMC whereas the genera *Acremonium, Fusarium, Penicillium*, and *Rhizopus* were found dominant in HPC. The genera *Humicola* and *Trichoderma* were dominant in both SMC and HPC (Fig. 3). Maximum similarities in the fungal varieties were recorded among the MMW and FMW of SMC, the preparation and packaging rooms of the bakeries, and the hatcheries and broiler houses of the poultry

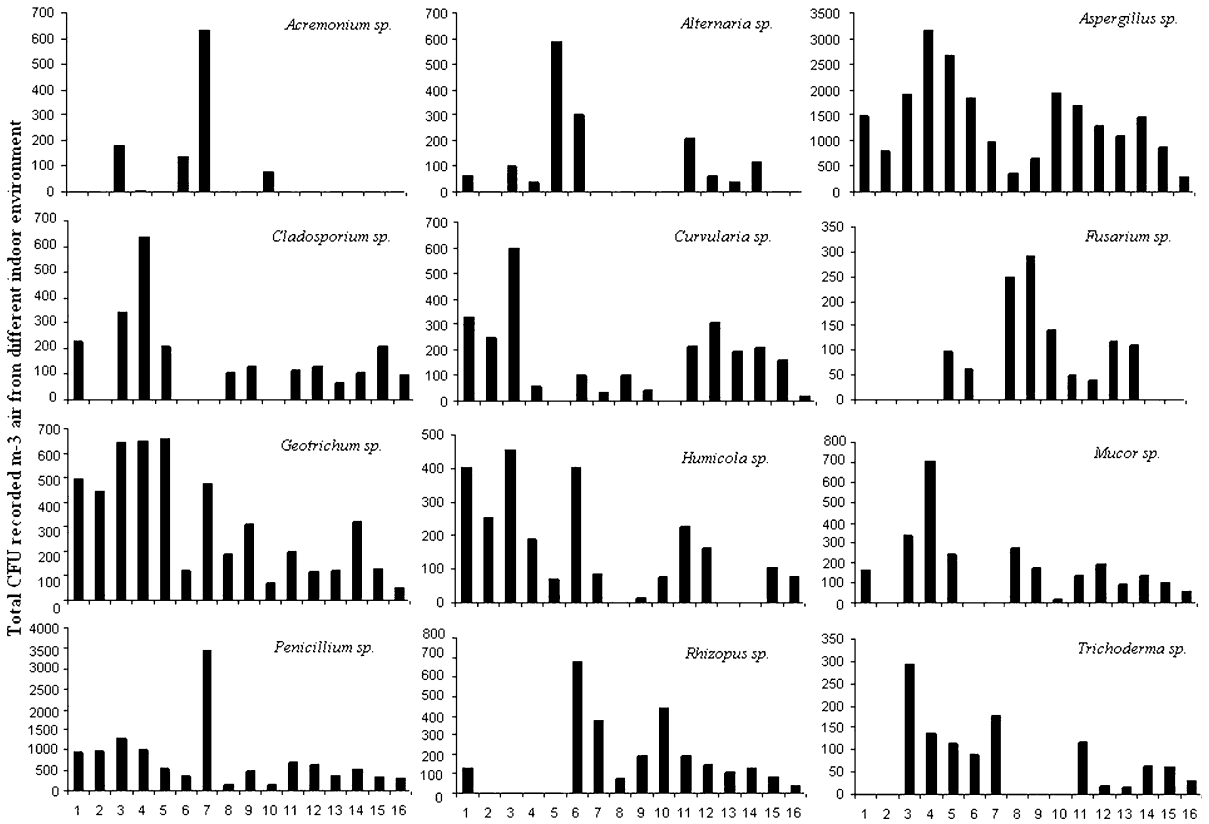

Fig. 3 Distribution of the dominant fungal genera in 16 different sections of the study sites of South Assam: *1*, gynaecology general ward; *2*, gynaecology OT; *3*, MMW; *4*, FMW; *5*, pediatric general ward; *6*, bamboo stock yard; *7*, chipper house; *8*, pulp house; *9*, paper house; *10*, finishing house; *11*, grain storage; *12*, sugar storage; *13*, hatchery; *14*, broiler house; *15*, preparation room of bakery; *16*, packaging room of bakery

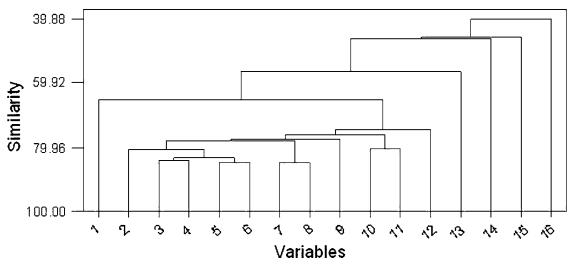

Fig. 4 Cluster analysis of similarities in the distribution of fungal species in 16 different sections of the study sites *1*, gynaecology general ward; *2*, gynaecology OT; *3*, MMW; *4*, FMW; *5*, preparation room of bakery; *6*, packaging room of bakery; *7*, hatchery; *8*, broiler house; *9*, finishing house; *10*, grain storage; *11*, sugar storage; *12*, bamboo stock yard; *13*, paper house; *14*, pulp house; *15*, chipper house; *16*, pediatric general ward

farms, for which similarity was greater than 80% (Fig. 4). Seasonal and monthly study showed fungal concentrations in the indoor working environment of the sites were higher from March to September during which the average total indoor fungal concentration was between 1,441 and 2,337 CFU m^{-3} air.

4 Discussion

This study described large samples of culturable fungi obtained from indoor and outdoor air of five industrially important establishments. The study also described the monthly and seasonal distribution of fungi in indoor working environment of South Assam. Several medically important fungi, for example *Aspergillus*, *Botrytis*, *Candida*, *Calcarisporium*, *Cunninghmela*, *Geotrichum*, *Meria*, *Penicillium*, and *Stachybotrys*, were identified in the indoor air. The most common indoor fungal genera identified in this study were *Aspergillus*, *Penicillium*, *Geotrichum*, *Cladosporium*, and *Humicola*. Overall, indoor fungal

concentrations were twice as high as outdoor concentrations, in contrast with the findings of Jensen and Schafer (1998) and http://cpcbenvis.nic.in/newsletter Studies on Indoor and Outdoor Air micro flora (2008). This could because of improper management of the indoor environment and poor ventilation. In the naturally ventilated hospital ward, with continuous mixing of indoor and outdoor air, the concentration of fungi can be two to five (and occasionally 100) times higher than the outdoor level (US EPA report 2004). However, the indoor spore concentration has been observed to be much lower in hospital areas receiving filtered air (through mechanical ventilation) compared with the controlled environment. Predominance of *Aspergillus, Penicillium*, and *Cladosporium* in indoor air is well supported by several studies (Ebner et al. 1992; Shelton et al. 2002). *Alternaria, Rhizopus, Mucor, Trichoderma, Chaetomium, Yeasts*, and *Fusarium* species, also, are often reported indoors (Shelton et al. 2002; Curtis et al. 2000; Beaumont et al. 1984). It has been reported that microorganisms may enter buildings from outside but the most important sources are usually within the building. Factors such as building dampness, indoor temperature, relative humidity, and hygiene conditions indoors and in the surrounding environment favour the growth and proliferation of fungi including the pathogenic species (Bornehag et al. 2001). There is clinical evidence that exposure to mould and other dampness-related microbial agents increases the risk of the rare conditions hypersensitivity pneumonitis, allergic alveolitis, chronic rhinosinusitis, and allergic fungal sinusitis (WHO 2009).

Because many people spend as much as 90% of their time indoors, the health risk of indoor air pollutants is a critical public health concern. Studies have shown association between reported indoor dampness and health outcomes, including respiratory symptoms, headache, and upper respiratory airway infections (Peat et al. 1998; Verhoeff and Burge 1997). Nonetheless, the presence of fungal spores, even in large quantity, is unimportant unless fungal extracts are capable of producing immunological reaction (Grevesen 1979). An individual may prove to be highly susceptible to even a mild dose of allergens, irrespective of the concentration of the spores. Curtis et al. (2000) reported that 6–10% of the general population and 15–50% of atopics had immediate skin sensitivity to fungi.

There are numerous reports of contamination of indoor air with fungal spore levels well in excess of 1,000 CFU m^{-3} (Shelton et al. 2002; Ebner et al. 1992; Beaumont et al. 1984; Curtis et al. 2000). In India, indoor fungal concentrations as high as 431–690 CFU m^{-3} in different occupational indoor environments were reported by Jain (2000) and Sawane and Saoji (2004). However, Srikanth et al. (2008) have reported fungal concentrations as high as 10^5 CFU m^{-2} on different indoor surfaces of India. No significant work has yet been reported from the North Eastern part of India including Assam. In this study some of the fungal species, for example *Aspergillus fumigatus* and *Penicillium aurantiovirens*, were well above the threshold level of 1,000 CFU m^{-3} and several other fungal species, for example *Aspergillus flavus*, *Aspergillus niger*, *Geotrichum candidum*, and *Penicillium thomii*, were above 500 CFU/m^{-3} in some of the sites surveyed and all these indoor fungal species are known to have human health effects of one kind or another (Fischer and Dott 2003; Kullberg and Oude 2002; Singh 1998). Nevertheless, the World Health Organization working group has concluded that the individual species of microbes and other biological agents responsible for health effects cannot be identified, because people are often exposed to multiple agents simultaneously (WHO 2009). They were unable to recommended quantitative health-based guideline values or thresholds for acceptable levels of contamination with microorganisms. Instead, it is recommended that dampness and mould-related problems should be prevented as they increase the risk of hazardous exposure to microbes and chemicals. The Japan Society for Occupational Health (2007) has recommended occupational exposure limits for chemical and physical factors as reference values but exposure limits for bio-pollutants have not been set. The ENVIS centre of the Central Pollution Control Board (2001) has reported major organic and inorganic air pollutants of India, but no data on bio-pollutants. Hence, there is a need to prepare occupational exposure limits for individual and multiple indoor biopollutants which can be set as a reference value for indoor atmospheres.

The high fungal concentrations in the HPC could be because of the availability of much cellulose

material in the form of raw bamboo and paper. The pulp house, on the other hand, deals with the chemical process (bleaching and chlorination) of crushed bamboo and, because of the chemical smog produced in the pulp house, fungal growth in this section is restricted. In SMC, high fungal concentration could be because of several combined factors, because of the favourable microclimate of South Assam, laxity in hospital maintenance, lack of proper ventilation, and ongoing construction activity. In the bakeries, besides the availability of raw food materials, vaporization to maintain humidity may also be responsible for suitable fungal growth (Jain 2000). Moreover, because of the smaller number of workers compared with the capacity of the industry/institute, indoor maintenance was poor in all the sites selected. The major sources of fungal growth in outdoor air could be the improper sanitation and poor drainage in the vicinity of the sites.

The higher concentrations of *Aspergillus* in the FCI, the bakeries, and the poultry farms could lead to mycotoxins, including aflatoxins, in the stored food items (Burge and Amman 1999). A correlation between the extent of fungal aerial bio-contamination and cases of invasive aspergillosis has been reported (Alberti et al. 2001; Nolard 1994). Indoor mould species are also identified to be the major source for the production of MVOCs, even if the indoor mould concentration is low (Fischer et al. 1999). These volatile organic compounds are associated with building-related symptoms such as headache, dizziness, and inability to concentrate, besides various mycotoxic effects (Burge and Amman 1999).

Because fungal growth in indoor air depends on moisture and a carbon source, the most important strategy for reducing or eliminating its growth is controlling the amount of moisture present and reducing indoor organic contaminants. Mechanized ventilation, forced air-heating systems, dehumidifiers, air filters, and air conditioners reduce indoor fungal count (Portnoy et al. 2005). Well-designed, well-constructed, and well-maintained building envelopes are critical to the prevention and control of excess moisture and microbial growth, because they prevent thermal bridges and the entry of liquid or vapour-phase water (WHO 2009). Due attention should be given to the surrounding outdoor environment which could be the source of indoor fungal growth. Systematic awareness among industrial workers and others is obligatory to minimize the health hazards due to indoor fungal growth.

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