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ORIGINAL PAPER

Fertile fungal spores collected on different faced surfaces in the atmosphere of Giza, Egypt

A. A. Abdel Hameed · M. I. Khoder · A. A. Emad

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Abstract A quantitative and qualitative survey was carried out for airborne fungus spores coming into contact with horizontally and vertically gravitation sampling oriented surfaces in the atmosphere of Giza city. Czapek Dox agar, malt extract agar, potato dextrose agar and Sabouraud dextrose agar Petri dishes were exposed monthly to the five oriented surfaces of a polystyrene cube, throughout a one-year period. Significant differences ($P < 0.01$) were observed between the total counts of caught airborne fungi contacting with the horizontal compared to other vertically oriented surfaces. Conversely, there were no significant differences observed between the total catch of airborne fungi using the various sampling media. The results revealed that vertical sampling provides valuable information that may be lost from horizontal sampling alone. A total of 5,053 colonies belonging to 40 fungal organisms were identified. *Alternaria* (24.26%), *Aspergillus* (19.2%), *Cladosporium* (14.5%) and *Penicillium* (11.43%) were the most predominant fungal genera. Collected fungi were grouped into high, medium, low and rare components depending upon their frequency in the studied atmosphere. *Aspergillus niger*, *Aspergillus parasiticus*, *Alternaria*, *Cladosporium* and *Penicillium* were regularly found on all oriented surfaces. However, *Arthrobotrys*, *Biospora*, *Chaetomium*, *Pleospora*, *Trichothecium* and *Verticillium* were rarely found in the air. Positive and/or negative correlations were observed between the total fungal counts and the predominant fungal types with meteorological parameters during sampling days.

Keywords Ambient fungi · Orientation · Medium · Occurrence · Pathogen

A. A. Abdel Hameed (✉) · M. I. Khoder
Air Pollution Department, National Research Center, Dokki, Giza, Egypt
e-mail: hameed_33@yahoo.com

A. A. Emad
Botany and Microbiology Department, Faculty of Science, Helwan University, Cairo, Egypt

1 Introduction

Airborne fungal spores concentrations and types are naturally highly variable according to time, season, geographical factors (Lacey, 1981; Su, Wu, Chen, Lee, & Lin, 2001), climatic and physical factors (Hjelmroos, 1993). Additionally, collection method, media, procedures, sampling frequency and duration are all known to impact airborne fungal spores recoverability (Takahashi, 1997). Fungal spores are important agents for spreading plant, animal and human diseases and are known to cause human allergic reactions (Madelin, 1994; Burge and Rogers, 2000). *Alternaria*, *Aspergillus*, *Cladosporium* and *Penicillium*

species are the most prevalent aeroallergens (Tee, Gordon, & Taylor, 1987; Simeray, Mandin, & Chaumont, 1997). In addition to their health impacts, May et al. (1993) listed fungi among agents of microbial deterioration of building stones. Most of these species are ubiquitous, rapidly growing saprophytes, and Leznicka, Strzelczyk, and Wandrychowska (1988) pointed to the significance of dematiaceous fungi in the staining and deterioration of art works.

Airborne fungi have been investigated over the entire world, in Nigeria (Dransfield, 1966), India (Chitaley & Bajaj, 1974), Kuwait (Moustafa & Kamel, 1976), Saudi Arabia (Abdel Hafez, 1984), Turkey (Asan, Sen, & Sarica, 2002), Japan (Takahash, 1997), England (Hudson, 1969), Italy (Marchisio, Airaudi & Barchi, 1997), Spain (Herrero, 1997; Cariñanos, Galan, Alcazar, & Dominguez, 1999), USA (Levetin & Horowitz, 1978) and several others. In Egypt, less attention has been paid to aerobiological studies; however, airborne fungal spores have been studied in Assuit (Moubasher & Moustafa, 1974), Cairo (Abdel Azeez, 1974), Qena (Moubasher, Abdel Fattah, & Swellim, 1981), Ismailia (Abdel Wahid, Moustafa & Moustafa, 1996) and Fayioum and Giza's villages (Abdel Hameed, 2005).

As far as the authors are aware, very little has been reported on the natural picture of airborne fungi at different orientations. The present study aims to quantify and qualify the airborne fungal spores contacting horizontally and vertically oriented plate surfaces and to compare the response of airborne fungi to different sampling media. This will be useful in providing a low-cost alternative to obtain more information regarding the fungal constituents of bioaerosols as an augmentation to the traditional horizontally sampling of the gravitational methodology.

2 Materials and methods

2.1 Site description

Sampling was conducted from the roof of a 20-m high building at the main campus of the National Research Centre, Dokki, Giza. This is an urban area characterized by heavy traffic, parking, playgrounds, small workshops, hospitals and hostels. A variety of vegetation is present in the area, but there is no the predominant ground cover.

2.2 Sampling method

The gravitation method (open plate technique) was used to collect culturable airborne fungal spores (Pelczar, Chan, & Krieg, 1993). This sampling included the traditional plate orientation, horizontal, for gravitation sampling and four vertically oriented samples (facing north, south, east and west). Four Petri plates (10 cm, diameter), containing malt extract agar (MEA), Czapek Dox agar (CZ), Sabouraud dextrose agar (SDA) and potato dextrose agar (PDA) culture media were used for sample collection. The plates were arranged around a polystyrene cube (40 cm per side), (Fig. 1), with each media represented on each surface. The exposure procedure was carried-out in 30-min intervals between 11 AM and 1 PM, once a month (between 25th and 30th), from August 2004 to July 2005. This resulted in 12 samples for each media on each surface of the cube.

The exposed plates were incubated for 5–7 days at 28°C, the resultant colonies were counted and expressed as colony forming unit per plate per hour (CFU/p/h). Colonies were isolated, purified and identified to the genus level; with the exception of *Aspergillus*, which was identified to the species level. Identification was done using macroscopic and microscopic features

Fig. 1 A polystyrene cube with Petri dishes containing the different fungal media

(Raper & Fennell, 1965; Ellis, 1971; Barnett, 1972). The frequency of occurrence (number of cases of isolation out of 12) of airborne fungal taxa was categorized according to Abdel Hafez (1984).

2.3 Meteorological parameters

Temperature, relative humidity and wind speed during the sampling days ranged between 18–35°C, 32–55% and 1.1–5.3 m/s, respectively. Rainfall is rare in Egypt, and averaged 4, 6 and 5.5 mm in November, December (2004) and January (2005), respectively. Wind direction records during sampling days were obtained from the Egyptian Meteorological Authority, with wind blowing mainly from the north and in the lesser extent from south.

2.4 Statistical analysis

Linear correlation coefficient (r) and correlation significant t-test ($P < 0.05$) were determined between total culturable count of airborne fungi with temperature, relative humidity and wind speed. Student's t-test ($P < 0.1$) was used to determine the degree of significance of differences between the mean counts of the predominant airborne fungal genera collected on the different sampling media at all different orientations (Gregory, 1963).

3 Results

A total of 5053 CFU/h in 240 Perti plates were collected and analyzed. The spores belonging to 40 different fungal organisms were identified. *Alternaria* (24.26%), *Aspergillus* (19.2%), *Cladosporium* (14.5%), *Penicillium* (11.43%), sterile hyphae (10.6%), and yeasts (4.5%) were the most common fungal organisms (Table 1). Dematiaceous fungi comprised 46.4% of the total CFUs, where *Alternaria* and *Cladosporium* were the most predominant dematiaceous genera. Thermophilic fungi comprised 3% of the total CFUs where, *Aspergillus fumigatus*, *A. terreus*, *A. niger*, *A. candidus*, *Chaetomium*, *Absidia*, *Mucor*, *Paecilomyces*, *Rhizopus* and *Humicola* were identified, and *Aspergillus fumigatus* (1.07%) were the most common types. *Aspergillus* was found in 100% of the air samples and was represented by 11 species of which *A. niger* and *A. parasiticus* were the most ubiquitous species (Table 1).

Frequency of occurrence (number of isolation out of 12 exposures) was categorized into four groups (Table 1): (1) high-occurrence fungi (recorded 6–12 times out of 12 cases), collectively amounting to 93.48% of total recovery, (2) medium-occurrence fungi (recorded 3–5 times out of 12 cases), constituting 5.3% of total recovery, (3) low-occurrence fungi (recorded 2 times out of 12 cases), occasionally detected and accounting for 0.83% of the total recovery, and (4) rare-occurrence fungi (recorded 1 time out of 12 cases), included seven genera, and accounting for 0.37% of the total recovery (Table 1).

Evaluation of the different sampling culture media indicated that total fungal counts (on sampling days) were relatively higher on malt extract agar and Czapek Dox agar compared to Sabouraud dextrose agar and potato dextrose agar, and no significant differences were found between the different sampling media (Table 2). On the other hand, the greatest airborne fungal count was found on the horizontal surface, and significant differences ($P < 0.01$) were observed between the total fungal recovery on the horizontal surface compared to the vertical surfaces. In addition, there was no significant difference regarding fungal recovery between the variously oriented vertical surfaces. The horizontal surface had a greater recovery compared to all four of the vertical surfaces. In Table 1 subtracting the ''All samples'' column from the ''Horizontal'' column results in the number of sampling events where the fungal organism in questions have been detected through horizontal and vertical sampling. There were sampling events where an organism was recovered on one of the vertical surfaces during a sampling event, but was not recovered on the horizontal surface.

Tables 3 and 4 demonstrate the significance of differences between the total recoveries of the predominant fungal types regarding sampling media and orientation, respectively. Significant differences ($P < 0.01$) were observed between *Penicillium* and *Aspergillus* settled on PDA and

Table 1 Type, percent, and recovery frequency of airborne fungal organisms

	Total count	%	Isolation out of 12 trials					
			All samples	Vertical north	Vertical south	Vertical east	Vertical west	Horizontal
Aspergillus spp.	970	19.2	12 (H)	10	11	12	12	12
A. flavus	**124**	**2.46**	**8 (H)**	**5**	**4**	**4**	**3**	**7**
A. niger	450	8.9	12 (H)	11	8	12	11	12
A. parasiticus	**270**	**5.35**	**12 (H)**	**8**	**6**	**7**	**11**	**10**
A. fumigatus	**54**	**1.07**	**10 (H)**	**3**	**3**	**4**	**4**	**5**
A. sydowi	**12**	**0.23**	**3 (M)**	**0**	**2**	**0**	**1**	**1**
A. versicolor	**30**	**0.6**	**5 (M)**	**0**	**3**	**1**	**2**	**2**
A. terreus	**14**	**0.27**	**4 (M)**	**3**	**1**	**1**	**1**	**2**
****Other A.*** spp.	**16**	**0.32**	**7 (H)**	**1**	**0**	**1**	**2**	**4**
Alternaria	1226	24.26	12 (H)	12	11	12	11	12
Acremonium	**4**	**0.08**	**3 (M)**	**0**	**1**	**1**	**1**	**0**
Aureobasidium	**54**	**1.07**	**8 (H)**	**2**	**2**	**1**	**3**	**5**
Absidia	**4**	**0.08**	**2 (L)**	**0**	**0**	**1**	**1**	**1**
Ascomycetes	18	0.35	2 (L)	1	1	1	1	2
Arthrobotrys	4	0.08	1 (R)	0	0	0	0	1
Basidiomycetes	**10**	**0.2**	**3 (M)**	**0**	**0**	**1**	**1**	**2**
Biospora	2	0.04	1 (R)	0	0	0	0	1
Chaetomium	**2**	**0.04**	**1 (R)**	**0**	**0**	**1**	**1**	**0**
Cladosporium	**732**	**14.5**	**9 (H)**	**7**	**8**	**6**	**7**	**8**
Chlamydomycetes	**52**	**1.03**	**8 (H)**	**2**	**1**	**2**	**2**	**4**
Curvularia	**48**	**1**	**8 (H)**	**6**	**7**	**4**	**7**	**5**
Emericella	**22**	**0.43**	**6 (H)**	**0**	**0**	**1**	**2**	**4**
Eurotium	**30**	**0.6**	**6 (H)**	**3**	**2**	**4**	**0**	**4**
Epicoccum	**50**	**1**	**10 (H)**	**3**	**4**	**2**	**1**	**5**
Dreschlera	**18**	**0.36**	**5 (M)**	**1**	**2**	**0**	**0**	**2**
Fusarium	**88**	**1.74**	**11 (H)**	**6**	**4**	**3**	**3**	**8**
Geotrichum	**10**	**0.2**	**4 (M)**	**1**	**1**	**1**	**1**	**0**
Helminthosporium	**10**	**0.2**	**4 (M)**	**1**	**2**	**0**	**1**	**1**
Humicola	6	0.12	1 (R)	1	0	1	1	1
Mucor	**12**	**0.24**	**3 (M)**	**1**	**0**	**0**	**1**	**2**
Nigrospora	**40**	**0.8**	**3 (M)**	**1**	**1**	**1**	**2**	**1**
Penicillium	578	11.43	12 (H)	10	12	7	10	12
Paecilomyces	**10**	**0.2**	**5 (M)**	**2**	**1**	**0**	**0**	**2**
Pleospora	1	0.02	1 (R)	0	0	0	0	1
Phoma	**6**	**0.08**	**2 (L)**	**0**	**1**	**1**	**0**	**1**
Rhizopus	14	0.28	5 (M)	1	0	1	1	5
Sepedonium	**10**	**0.2**	**2 (L)**	**1**	**1**	**1**	**0**	**0**
Stemphylium	**50**	**1**	**6 (H)**	**2**	**4**	**2**	**3**	**4**
Stachybotrys atra	**8**	**0.15**	**3 (M)**	**0**	**1**	**0**	**2**	**1**
Sterile hyphae	534	10.56	12 (H)	10	9	7	9	12
Scopulariopsis	**26**	**0.52**	**4 (M)**	**0**	**2**	**3**	**2**	**2**
Oidiodendron	**26**	**0.5**	**6 (H)**	**1**	**3**	**0**	**1**	**4**
Trichoderma	**16**	**0.32**	**5 (M)**	**0**	**2**	**1**	**3**	**2**
Trichophyton	**4**	**0.08**	**2 (L)**	**0**	**0**	**1**	**0**	**1**
Trichothecium	2	0.04	1 (R)	0	0	0	0	1
Yeast	**228**	**4.5**	**11 (H)**	**6**	**4**	**4**	**8**	**5**
Ulocladium	**92**	**1.8**	**8 (H)**	**6**	**4**	**4**	**2**	**6**
Verticillium	**2**	**0.04**	**1 (R)**	**0**	**0**	**0**	**1**	**0**
Unidentified	**34**	**0.67**	**5 (M)**	**1**	**2**	**2**	**2**	**4**
Total counts	5053							

H: high occurrence, M: moderate occurrence, L: low occurrence, R: rare occurrence, ** *A. candidus, A. tamarri*, *A. clavatus, A. ochraceus*. Bold rows show organisms that would have been missed during at least one sampling event if the vertical samplers were not employed

Table 2 The data of Student's *t*-test and the degree of significance of difference between the total recovery of airborne fungi regarding orientation and medium

Variable	Orientation					Medium			
	T (184)	N (77)	S (66.3)	E (68.7)	W (66)	MEA (129)	CZ (122.5)	PDA (95.8)	SDA (114.6)
Direction									
T (184)	0	3.81, $P < 0.01$	4.5, $P < 0.01$	4.34, $P < 0.01$	4.47, $P < 0.01$				
N (77)		0	0.57	0.45	0.62				
S (66.3)			0	0.15	0.02				
E (68.7)				0	0.16				
W (66)					0				
Medium									
MEA (129)						0	0.23	1.34	0.53
CZ (122.5)							0	1.1	0.3
PDA (114.6)								0	0.9
SDA (114.6)									0

T: top; N: north; S: south; E: east; W: west; MEA: malt extract agar; CZ: Czapek Dox agar;

PDA: potato dextrose agar and SDA: sabouraud dextrose agar, (mean count/ CFU/p/h)

between *Alternaria* and *Penicillium* settled on SDA. *Aspergillus* and *Alternaria* recovery showed significant difference on CZ (Table 3). No significant differences were found within the same organisms using the different sampling media, except that *Alternaria* species recovery was significantly different on MEA and CZ compared to PDA (Table 3). Regarding direction, significant differences ($P < 0.01$) were observed between *Penicillium* and *Aspergillus* at the horizontal, north and west orientations, and between *Alternaria*, *Cladosporium* and *Penicillium* in the south, north and east orientations (Table 4). Significant differences in directional recovery were also detected within the same organisms; for example *Aspergillus* species recovery was significantly different on the top surface compared to all the vertical directions.

Table 5 shows the correlation coefficients (r) between temperature, relative humidity and wind speed and the total counts of airborne fungi and the dominant fungal genera (during the days when data were taken). There was positive and/or negative influence of meteorological parameters on the airborne fungal spore counts. *Alternaria* and *Penicillium* showed insignificant negative correlations with temperature and relative humidity. *Aspergillus* and *Cladosporium* showed insignificant negative correlations with wind speed and temperature, respectively. A significant correlation ($r = –0.79$, $P < 0.05$) was observed between *Cladosporium* count and temperature (Table 5).

4 Discussion

In the present study, the order of dominance of air spora was *Alternaria* > *Aspergillus* > *Cladosporium* > *Penicillium* > sterile hyphae > yeast > *Ulocladium* > *Fusarium*. The frequent detection of these fungi indicated that such fungal organisms are easily disseminated into the air from many sources, including vegetation and urbanization activities. The same group of dominant genera had been reported by Youssef and El-Din (1988), Abdel Hafez (1984) and Al Suwaine, Hasnain and Mahkali (1999), who found that *Alternaria*, *Aspergillus*, *Penicillium*, *Cladosporium* and *Ulocladium* were the most common fungal types, in Cairo (Egypt), Taief and Riyadh, (Saudi Arabia), respectively. *Alternaria*, *Penicillium*, *Cladosporium* and *Scopulariopsis* were the most frequent fungal types in the atmosphere of Eskishir city, Turkey (Asan et al., 2004). Such differences between the order of dominance was well established by Lacey (1962), who stated that airspora of open sites of any country was more or less the same in the country and differences, if present, were only quantitative and not qualitative.

Table 3 The data from Student *t*-test and the degree of significance between the dominant airborne fungi settled on the different sampling media

Organism	*Cladosporium*				*Penicillium*				*Aspergillus*				*Alternaria*			
	MEA (13.7)	CZ (21)	PDA (10.8)	SDA (16)	MEA (13)	CZ (11.5)	PDA (9.7)	SDA (10.2)	MEA (23.8)	CZ (17.7)	PDA (20)	SDA (21)	MEA (27)	CZ (36.8)	PDA (13.8)	SDA (26.5)
Cladosporium																
MEA (13.7)	0	0.92	0.4	0.27	0.1				1.4				1.66			
CZ (21)		0	1.47	0.63		1.53				0.55				1.67		
PDA (10.8)			0	0.7			0.2				1.66				0.55	
SDA (16)				0				0.9				0.72				1.1
Penicillium																
MEA (13)					0	0.28	0.61	0.55	1.79				1.99			
CZ (11.5)						0	0.4	0.31		1.4				1.94		
PDA (9.7)							0	0.12			2.2 $P < 0.1$				0.9	
SDA (10.2)								0				2.41 $P < 0.1$				2.04 $P < 0.1$
Aspergillus																
MEA (23.8)									0	1.17	0.7	0.5	0.48			
CZ (17.7)										0	05	0.7		2.3 $P < 0.1$		
PDA (20)											0	0.2			1.29	
SDA (21)												0				0.66
Alternaria																
MEA (27.3)													0	1	2.02 $P < 0.1$	0.08
CZ (36.8)														0	2.72 $P < 0.05$	0.95
PDA (13.8)															0	1.54
SDA (26.5)																0

Table 4 Student's *t*–test and the degree of significance of the difference between the dominant airborne fungi at different directions

	Alternaria					*Aspergillus*					*Cladosporium*					*Penicillium*				
	T (33.5)	N (16.3)	S (15.5)	E (20.3)	W (19)	T (33)	N (15.3)	S (9.6)	E (11)	W (13.5)	T (26.16)	N (12)	S (7)	E (8.5)	W (7.8)	T (17)	N (6.7)	S (9)	E (6.3)	W (5.5)
Alternaria																				
T						0.03					0.61					1.91				
N	2.03, $P < 0.1$						0.2					0.8					2.2, $P < 0.1$			
S	2.14, $P < 0.1$	0.14						1.42					2.1, $P < 0.1$					1.3		
E	1.47	0.64	0.73						1.71					2.1, $P < 0.1$					2.5, $P < 0.05$	
W	1.09	0.33	0.44	0.64						0.75					1.51					1.95
Aspergillus																				
T	0.03										0.63					2.3, $P < 0.1$				
N		0.2				2.89, $P < 0.05$						0.7					2.5, $P < 0.05$			
S			1.42			4.02, $P < 0.05$	1.74						1.07					1.15		
E				1.71		3.6, $P < 0.05$	0.6	0.43						0.64					1.15	
W					0.75	3.20, $P < 0.05$	0.48	1.2	0.68						1.38					2.5, $P < 0.05$
Cladosporium																				
T	0.61					0.63										0.88				
N		0.8					0.7				1.38						1.18			
S			2.1, $P < 0.1$					1.07			2, $P < 0.1$	1.16						0.5		
E				2.1, $P < 0.1$					0.64		1.78	0.71	0.44						0.51	
W					1.51					1.38	1.9	0.84	0.22	0.16						0.61
Penicillium																				
T	1.91					2.3, $P < 0.1$					0.88									
N		2.2, $P < 0.1$					2.5, $P < 0.05$					1.18				2.18, $P < 0.1$				
S			1.3					1.15					0.5			1.5	0.6			
E				2.5, $P < 0.05$					1.15					0.51		2, $P < 0.1$	0.09	0.59		
W					1.95					2.5, $P < 0.05$					0.61	2.18, $P < 0.1$	0.09	0.96	0.21	

Table 5 Correlation coefficients (r) between total count of airborne fungi and the predominant fungal genera with temperature, relative humidity and wind speed during the sampling days

Agent	Temperature (°C)	Relative humidity (%)	Wind speed (m/s)
Total fungal counts	–0.35	0.02	0.27
Alternaria	–0.11	–0.09	0.12
Aspergillus	0.46	–0.19	–0.07
Cladosporium	–0.79*	0.54	0.43
Penicillium	–0.53	–0.28	0.14

* Significant correlation ($P < 0.05$)

In the present study *Stachybotrys* was recorded in a medium frequency (recorded three times out of 12); it is a toxic and allergenic fungus (Johanning et al., 1996) and its presence in air is being debated (Etzel et al., 1998). In the present study many damp air fungi: *Acremonium*, ascomycetes, basidiomycetes, *Biospora*, *Chaetomium*, *Eurotium*, *Humicola*, *Penicillium*, *Phoma*, *Stachybotrys* and *Ulocladium* were increased in counts or recorded in wet months (in days after rain showers), and this is comparable with (Kowalski, 2000) who reported that such fungal genera grow well in moist and damp conditions. Moreover, rainfall stimulates release of ascomycetes and basidiomycetes (Allitt, 2000).

The gravitation method (open plate technique) is widely used to collect airborne fungi, due to its practical usage and low cost (Pelczar et al., 1993), however its reliability is highly affected by the particle size, shape and density and the motion of the surrounding wind (Reponen, Willeke, Grinshpun, Nevalanen, 2001). In the present study the sampling time frame was chosen because it was suitable for giving adequate colony counts in Kuwait (Moustafa & Kamel, 1976) and many asexual fungal spores have been shown to have their peaks in the air in early to mid afternoon (Levetin & Horner, 2002). Moreover, the rational behind using different sampling cultural media was to extend the possibility of isolating large amounts of fungal types and allow colonies of slow-growing fungi to sporulate on the appropriate medium.

Airborne fungal spore deposition mainly occurs as gravitational settling and impaction. In the present study, the gravitational method demonstrated that airborne fungal spores have the possibility of coming into contact with horizontally and vertically oriented surfaces. Settling under gravity (in still air or at low wind speed) and impact (under turbulent condition) are the main ways for fungal collection at the top side (horizontal). On the other hand, the impaction mechanism is considered the main way for fungal collection on the vertical orientations. Gregory (1973) reported that impaction is most efficient for larger spores blown fast toward the media; however a zero catch of large particle in still air and of small spores may theoretically be found at ordinary wind speeds. The author added that *Helminthosporium* is suited for impaction on the vertical surface, whereas the small fungal spores *Penicillium* and *Aspergillus* are unsuitable for impaction. This is incomparable with our finding that *Aspergillus* and *Penicillium* were detected in both vertical and horizontal sampling. In the present study *Acremonium*, *Chaetomium*, *Geotrichum*, *Sepedonium* and *Verticillium* were suited for collection by vertical impaction, however *Alternaria*, *Aspergillus*, *Cladosporium*, *Penicillium*, *Curvuralia*, *Fusarium* and *Ulocladium* were detected in all directions, with a higher frequency of occurrence horizontally (Table 1).

Aerodynamic diameter determines fungal transport in air and the difference in fungal particle size distribution would be expected to cause difference in the behavior of airborne particles (Baron & Willeke, 1993). Moreover, it is suggested that geographical characters, source of the fungal particle and wind speed in each direction are important factors for determining the types and counts of the organisms coming into contact with the vertical surfaces. In the present study the vertical samples did yield valuable information. Table 1 demonstrates the importance of vertical sampling; bold rows show organisms that would have been missed during at least one sampling event if the vertical samplers had not been employed.

It should be mentioned that the number of exposures was low (12), one sample per month was not representative and the spore concentrations vary from day to day; therefore the differences observed in Tables 3 and 4 could be due to

chance. In addition it was hard to obtain significant differences. However, it is interesting to study the occurrence frequency of the fungal organisms; in particular melanin-producing fungi (such as *Alternaria* and *Cladosporium*) were recovered in all orientations using different cultural media. These organisms are more resistant to solar radiation (Ali, Salma, & Ali, 1976) and physicochemical agents due to the presence of melanin pigments and clamidospore-like structures (Urzi, De-Leo, Paola, & Criseo, 2001); they may be better adapted to colonize the artifacts, causing black patinas, bio-pitting and marble sugaring. The evaluation of airborne fungi in all directions could be useful for spatial orientation of artifacts as well as taken into consideration for the construction of buildings, particularly those where fungi may have a long-term historical impact, such as monuments and museums, in order to control airborne fungi in any directions.

In the present study there was positive and/or negative influence of meteorological parameters on the airborne fungal spore counts. This influence was shown to be independent of sampling day and fungal type. Meteorological factors affect both growth and sporulation of fungi and in turn affect their numbers and types in the air. Researchers, such as, Bandyopadhyay, Mughogho, and Satyanarayana (1991) and Di Giorgio et al. (1996) have reported that various meteorological factors affect the types and counts of airborne fungi. Among these wind velocity, relative humidity and temperature are very important. Pasanen, Pasanen, Jantunen, and Kalliokoski (1991) reported that the minimum air velocity at which *Cladosporium* released spores was 1 m/s, however *Aspergillus* and *Penicillium* species released great numbers of spores at 0.5 m/s. Wind velocity is an important factor for liberation and dispersion of airborne fungi. However, relative humidity and temperature gradients play an important role in both sedimentation and dispersion of fungal particles. Temperature affects spore viability and may be considered the factor which best explains the trough during hot months.

In the present investigation many of the identified airborne fungi: *Cladosporium*, *Alternaria*, *Penicillium*, *Aspergillus*, *Phoma*, *Epicoccum*, *Rhizopus* and *Mucor* can cause respiratory disorders.*Geotrichum*, *Trichophyton*, *Aspergillus fumigatus* and *Scopularopsis* are human pathogens. Otherwise *Aspergillus*, *Alternaria*, *Botrytis*, *Cladosporium*, *Fusarium*, *Helminthosporium*, *Stemphylium*, *Trichothecium* and *Verticillium* are plant pathogens.

5 Conclusion

The evaluation of airborne fungal community from all directions (vertical and horizontal) can provide more information concerning natural environmental characteristics and the impact of fungi on different orientations. Significant differences were observed between fungal counts and types on the horizontal surface compared to the vertical surfaces. Additionally, the data showed that directional sampling showed no difference with total fungal load; however, it did differ in terms of specific predominant organisms, which needs to be re-evaluated as a potential tool in city planning. Using different media allowed the isolation of large numbers of fungal types. Meteorological parameters show positive and negative effects on airborne fungal counts. Many pathogenic and allergenic fungi were found in the atmosphere, so that this survey may be useful to those particularly sensitive to these organisms.

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