Carbon content of common airborne fungal species and fungal contribution to aerosol organic carbon in a subtropical city

Jessica Y.W. Cheng¹, Chak K. Chan², C.-T. Lee³, Arthur P.S. Lau^{1*}

¹Institute for the Environment,

²Department of Chemical and Biomolecular Engineering,
Clear Water Bay, Kowloon, Hong Kong.

³ Graduate Institute of Environmental Engineering, National Central University
Jhongli, Taoyuan, Taiwan.

*Corresponding author

Abstract

Interest in the role and contribution of fungi to atmospheric aerosols and processes grows in the past decade. Substantial data or information such as fungal mass or carbon loading to ambient aerosols is however still lacking. This study aimed to quantify the specific organic carbon content (OC per spore) of eleven fungal species commonly found airborne in the subtropics, and estimated their contribution to organic carbon in aerosols. The specific OC contents showed a size-dependent relationship ($r=0.64$, $p<0.05$) and ranged from 3.6 to 201.0 pg carbon per spore or yeast cell, giving an average of 6.0 pg carbon per spore (RSD 51%) for spore or cell size less than 10 μm . In accounting for natural variations in the composition and abundance of fungal population, weighted-average carbon content for field samples were adopted using the laboratory determined specific OC values. An average of 5.97 pg carbon per spore (RSD 3.8%) was enumerated from 28 field samples collected at the university campus. The mean fungal OC concentration was 3.7, 6.0 and 9.7 ng m^{-3} in $\text{PM}_{2.5}$, $\text{PM}_{2.5-10}$ and PM_{10} , respectively. These corresponded to 0.1%, 1.2% and 0.2% of the total OC in $\text{PM}_{2.5}$, $\text{PM}_{2.5-10}$ and PM_{10} , respectively. In the study period, rain provided periods with low total OC but high fungal prevalence and fungi contributed 7 to 32% OC in $\text{PM}_{2.5-10}$ or 2.4 to 7.1% OC in PM_{10} . More extensive studies are deserved to better understand the spatial-, temporal- and episodic dependency on the fungal OC contribution to the atmospheric aerosols.

Keywords: Fungal carbon, Organic carbon, Fungal contribution, Weighted-average carbon content, Subtropics

1. Introduction

Organic carbon (OC) constitutes a significant fraction of atmospheric aerosols. Depending on geographical locations, OC accounts for 10 – 20% of the total PM₁₀ mass (Offenberg and Baker, 2000; Etyemezian et al., 2005; Lin and Tai, 2001; Kim et al., 2000; Viidanoja et al., 2002), and as high as 40% of both PM_{2.5} and PM₁₀ aerosols in the Amazonian area (Graham et al., 2003). In Hong Kong, OC contributes about 7 – 26% of the mass of PM₁₀ materials (Cao et al., 2003; Ho et al., 2002; Yu et al., 2004). The OC fraction of PM_{2.5} materials is even higher and levels as high as 80% have been reported (Ho et al., 2002). The identification and quantification of the OC provides essential information on sources (anthropogenic and biogenic) and profiles of emissions. Detailed speciation of the organic compounds and their size distribution provides invaluable information on health implications and roles of OC in the atmospheric processes and reactions. However, substantial amounts of atmospheric OC remain uncharacterized and unidentified (Neusüss et al., 2000; Saxena and Hildemann, 1996).

Microbiological substances are conventionally considered as a minor OC source of aerosols. However, recent studies reported that primary biological aerosol particles (PBAP), which include pollen, bacteria, fungal spores, algae, and protozoa, can contribute a significant fraction in number concentrations of total aerosol particles (Mattias-Maser et al., 1999). It can amount to 20% and 30% depending on locations (Mattias-Maser and Jaenicke, 1995). Jaenicke (2005) even reported that cellular particles compose up to about 50% of total particles in a semi-rural location. Elbert et al. (2007) calculated that fungal spores accounted for an average of 35% of the PM₁₋₁₀ mass in Amazonia. Therefore, PBAP can be a significant source of OC. Up to date, only one study has reported on the bacterial contribution (0.03%) to total organic aerosol in the atmosphere by measuring the number concentration and applying the carbon conversion factor of 17 fg carbon per cell derived from limnological studies (Bauer et al., 2002a). Fungi and fungal spores are believed to make a higher contribution to the OC due to their larger size relative to bacteria. Bauer et al. (2002b) reported an average of 13 pg carbon per fungal spore. Using this value, Bauer et al. (2002b) estimated a 2.9 to 5.4 % contribution of the fungal OC to the total OC in wintry season at Mt. Rax, Austria. Indirect estimation of fungal carbon was also reported by Womiloju et al. (2003) through analyzing the profile characteristics of glycerophospholipids and their concentrations. They estimated that fragments of fungi and pollens collectively accounted for 12 – 22% of the total OC in the fine particulates (PM_{2.5}). Intact fungal spores and pollens may therefore have higher contribution to atmospheric organic carbon compared with bacteria. Due to the larger sizes of pollen (20 to 100 µm), most pollens will be selectively excluded by standard

aerosol sampler inlets in the field. Fungal spores will be dominant over pollen in particulates of inhalable range ($< 10 \mu\text{m}$) (Glikson et al., 1995). Although aerodynamic sizes of common airborne fungal spores were greater than $2.6 \mu\text{m}$ (Lee et al., 2006a) and associated with the coarse particulates ($\text{PM}_{2.5-10}$), smaller spores and fragments of spore or fungal mycelia are also present in a significant fraction ($\sim 30\%$) in the fine particulates ($\text{PM}_{2.5}$) (Cheng et al., 2008b; Fang et al., 2005). Understanding fungal contribution to the OC and their size distribution will certainly facilitate better comprehension on their role and impact on atmospheric processes. Both studies of Bauer et al. (2002b) and Womiloju et al. (2003) based their estimates of fungal carbon on fungal spore count collected from the field. However, only three impinger samples and one composite filter sample for each site (total three sites) were analyzed in Bauer et al. (2002b) and Womiloju et al. (2003) study, respectively. The sampling in both studies was yet insufficient for conclusive statement. Moreover, both studies were conducted in temperate zone; no study has been reported in the subtropics, where the climatic conditions favor fungal proliferation all year-round. The aim of this study was to assess the in situ fungal loading in terms of fungal carbon contribution with the weighted-average conversion factor approach demonstrated in our previously reported ergosterol studies (Cheng et al., 2008a, b). This paper reports the quantification of the specific organic carbon content (OC content of a spore or yeast cell) of common airborne fungi collected in the subtropics and estimates the fungal contribution to the OC in both $\text{PM}_{2.5}$ and PM_{10} in a subtropical city, Hong Kong.

2. Materials and Methods

2.1 Determination of the specific organic carbon content

The carbon contents of the common spores/yeast cells collected were analyzed. These covered *Alternaria* sp., *Aspergillus niger*, *Candida* sp., *Cladosporium* sp., *Paecilomyces* sp., *Rhodotorula* sp. and five species of *Penicillium*, including *P. chrysogenum*. Fungal spore and yeast cell suspensions were first prepared after their parental colonies had been cultured on Malt Extract Agar (MEA) at 28°C for 14 days as described in Cheng et al. (2008a). Aliquots of suspensions were dried at 50°C in ceramic sample boats, which were thermally pretreated at 900°C to remove any residual carbon.

Each sample boats were then combusted at 900°C in a total carbon content (TOC) analyzer (Shimadzu, TOC-5000), equipped with a solid sample module (SSM-5000A). Pure oxygen was used as the carrier gas with a flow-rate of 500 ml min^{-1} and a pressure at 2 kg cm^{-2} . Carbon dioxide resulting from the combustion was dehumidified and sent to a non-dispersive infrared (NDIR) detector, which output an analog signal to generate a peak. The areas of peaks were calibrated with the carbon

content of D-(+)-glucose (anhydrous, RDH) standards.

To compensate for intrinsic biological variations within individual species or strains, the specific OC content was determined with a linear regression between the carbon content and the number of spores or cells used. At least five independent batches of each type of spore or cell were prepared for the analyses. In each batch, the spore or cell number concentration was first determined by microscopic counting with hemacytometer (Cheng et al, 2008a). The amount of spores was controlled by applying different volumes from the batch for the OC measurement. Four different aliquots of spores were measured from each batch. This generated 20 data points for the regression analysis. The slope of the regression line provided the specific OC content of the species or strain studied. The 95% confidence levels were determined at the same time.

2.2 Air sampling

The studied region, Hong Kong (22.12°N, 114.08°E), is located in the subtropics on the south eastern coast of the Asiatic mainland with an annual average temperature of 23.0°C. Atmospheric aerosol samples were collected on the rooftop of a residential building in the campus of the Hong Kong University of Science and Technology (HKUST) on the east side of Hong Kong during November 2005 to April 2006. The samples were collected by a high volume sampler (Graseby, GMWT 2200) equipped with a PM₁₀ size-selective inlet (Graseby, Model 1200) and an impactor with a cut-off aerodynamic diameter at 2.5 µm (Graseby, Model 231-F). Six viable samples were collected in parallel with each filter sample. A total of 28 filter samples were collected. Details of sampling were described in Cheng et al. (2008b).

2.3 Quantification of carbon contents in aerosol samples

The filter samples were analyzed for OC and elemental carbon (EC) using DRI 2001 OC/EC Carbon Analyzer following IMPROVE thermal-optical reflectance (TOR) protocol (Chow and Watson, 2002). Punches of samples were heated stepwise at temperatures of 120°C, 250°C, 450°C and 550°C in pure helium atmosphere, and 550°C, 700°C and 800°C in 2% oxygen and 98% helium atmosphere. The carbon that evolved at each temperature was oxidized to carbon dioxide, and then reduced to methane for quantification with a flame ionization detector. Reflectance of each filter sample was monitored during the process and OC/EC spilt was set when the reflectance returned to its initial value. The carbon evolved prior to the spilt was considered as OC and the carbon evolved after the spilt was considered as EC.

2.4 Comparison of TOC system and TOR protocol

TOR is a very common method employed for determination of the OC concentrations in filter samples as the protocol has a correction for pyrolyzed OC due to the charring phenomenon in the heating process (Cao et al., 2005; Kim and Hopke, 2005; Hwang and Hopke, 2007; Brown et al., 2007). However, it is not the optimal approach for analyzing the OC contents in fungal spores directly. Though fungal spores can be transferred to a filter for TOR analysis, the evenness in spreading the spores on the filter is not guaranteed and there will be inevitable error due to transfer loss. Direct measurement of the organic carbon content is achieved with direct combustion in TOC analyzer. The total OC content of filter samples can also be quantified with the TOC analyzer; however, the organic and elemental portion of the carbon cannot be differentiated for the filter sample. Therefore, the OC in filter samples were analyzed with the TOR protocol while the fungal spores were quantified with the TOC analyzer. As the OC data from the two analytical approaches were cross compared, the consistency of the two approaches is important. This was tested by subjecting the filter samples to both approaches for total carbon analysis. Filters were cut into pieces and combusted in the TOC analyzer as that of the fungal spores. The results were compared with the total carbon contents (TC which was the sum of EC and OC) measured by the TOR protocol. Paired t-tests with $\alpha=0.05$ were used to evaluate the differences between the results of total carbon contents in filter samples measured by the TOC system and the TOR protocol.

2.4 Fungal contributions to atmospheric OC

In estimating the fungal contribution to the OC in atmospheric aerosols, the most general approach is to multiply an average spore OC value by the total number of spores in a finite volume. In this study, the weighted-average carbon conversion factor was adopted as in our previous study for ergosterol (Cheng et al., 2008a, b). The weighted-average carbon conversion factor was defined as the equivalent OC content per spore, and its derivation accounts for both the distribution of various fungal genera and species, as well as their relative abundance in the atmosphere. In the derivation, the specific OC contents summarized in Table 1 were used for *Aspergillus*, *Candida*, *Cladosporium*, *Fusarium*, *Paecilomyces* and *Rhodotorula* genera. The OC content of the *Penicillia* was assumed to be the average of the OC contents of the five species measured in this study in accounting for their diversity in the ambient air. The OC contents of unidentified and non-sporulating fungi were assumed to be average of OC contents listed in Table 1. *Alternaria* was excluded in the derivation as it was not likely to be collected in PM₁₀ due to its large spore size (10 – 12.5 μm x 20 – 30 μm). With these assumptions, the weighted-average carbon conversion factor was derived as followed:

$$\text{Weighted - average carbon conversion factor} = \sum_i f_i C_i$$

where C_i = specific organic carbon content spore of i th species

f_i = number fraction of i th species in the ambient air

The fungal carbon contributing to the atmospheric aerosol was then calculated by

$$OC_{fungi} = n \sum_i f_i C_i$$

where OC_{fungi} = total fungal organic carbon content in the ambient air

n = total number of spores (both culturable and non-culturable) in the ambient air

$$\sum_i f_i C_i = \text{weighted - average carbon conversion factor}$$

3. Results and Discussion

3.1 TOC vs. TOR

Results of paired t-tests ($\alpha = 0.05$) showed that there was no significant difference (p-value < 0.001) between the total carbon contents measured by TOR protocol and TOC system (Fig. 1). This agrees with the finding of Schmid et al. (2001). Since fungal spores do not contain any EC, the total carbon contents of spores can thus be taken as the organic carbon content of the fungi.

3.2 OC contents in fungal spores/yeast cells

Based on the assumption that each spore or cell of a fungal species contains the same amount of OC, the specific OC content (with the 95% confidence interval) of each studied species was determined from the slope of the regression analysis of OC content against the number of spores. Figure 2 shows one example of such linear regressions. The specific OC contents for the 11 tested species are summarized in Table 1. *Alternaria* spores had the highest specific OC content of 201.0 pg carbon per spore, and those of the rest lied in a narrow range of 3.6 to 13.0 pg carbon per spore or yeast cell. The size of *Alternaria* spores is very large with a dimension of 10 to 12.5 μm by 20 to 30 μm compared with the others (Table 1) and will not be collected with PM_{10} inlet. Thus, excluding *Alternaria*, the average value of OC contents of the ten studied species is 6.0 pg carbon per spore.

There is only one comprehensive study reported for the carbon contents in airborne fungal spores (Bauer et al., 2002b). Spore carbon contents of nine species from three genera, *Aspergillus*, *Cladosporium* and *Penicillium*, were measured and the

carbon content ranged from 5.2 to 23 pg carbon per spore with an average of 13 pg carbon per spore (RSD 46%), which is higher than the 6 pg carbon per spore (RSD 51%) reported in this study. The discrepancies may be due to the inter- and intra-specific differences among tested species. Nine species from three genera were covered in Bauer et al's (2002b) study while 10 species from 6 genera were analyzed and used for the average calculation in this study.

Despite the difference in the average carbon content, the specific carbon content of similar species tested in Bauer et al's study (2002b) and this one did show good agreement. Spore of *Aspergillus niger* had a specific carbon content of 13.0 pg carbon per spore (95% confidence interval: 9.6 – 16.4 pg carbon per spore or RSD 13.2%) in this study, which agreed well with the 10 pg carbon per spore (RSD 24%) reported by Bauer et al. (2002b). The 201 pg carbon per spore (95% confidence interval: 161.9 – 204.2 pg carbon per spore or RSD 9.9%) of *Alternaria sp* reported in this study is also comparable with the 292 pg carbon per spore (RSD 15%) of *Alternaria alternata* reported by Bauer et al. (2002b).

The overall size dependency of fungal spore OC is also observed in both studies. Spores or yeast cells with similar size possess similar specific carbon content regardless of genera as shown by the five *Penicillia* and *Candida sp.* (Table 1). In fact, the specific OC content is significantly correlated to size (correlation coefficient: 0.64, $\alpha < 0.05$). This size dependency was, however, not observed in the specific ergosterol content reported by Cheng et al. (2008a). Ergosterol is a membrane sterol. Hence its amount depends on the total surface area of cell and internal membranes, which cannot be easily assessed from the physical metrics. On the other hand, carbon is distributed throughout the whole volume of the fungal spore, in terms of structural components, biomolecules, metabolites...etc. The carbon content of the spores therefore shows more dependency on size metrics as demonstrated from the results of this study.

3.3 Carbon concentrations in the atmospheric aerosols

The total carbon concentration in the 28 PM₁₀ samples quantified by TOR protocol is summarized in Table 2, it ranged from 4.0 to 16.4 $\mu\text{g m}^{-3}$. The OC constituted an average of 5.1 $\mu\text{g m}^{-3}$ (range: 2.4 – 9.6 $\mu\text{g m}^{-3}$, s.d.: 2.0 $\mu\text{g m}^{-3}$), of which, an average of 4.6 $\mu\text{g m}^{-3}$ and 0.6 $\mu\text{g m}^{-3}$ (correspondingly to 88% and 12% of the total OC) was associated with the fine (PM_{2.5}) and coarse (PM_{2.5-10}) particulates, respectively. The results are comparable with those measured at Hok Tsui, a rural area which is considered as a background monitoring station of Hong Kong. Ho et al. (2003) and Cao et al. (2003) reported 5.62 and 9.1 $\mu\text{g m}^{-3}$ of OC at Hok Tsui, respectively. The relative low OC level is characteristic of the site with low industrial

activities, low traffic load and sparse population density.

3.4 Fungal contributions to atmospheric OC

The top three most prevalent fungal genera collected in this study were *Cladosporium*, *Penicillium* and *Aspergillus*, however, their relative contributions varied among samples (Table 3). Culturability is a major concern in viable sampling. Only a small fraction (0.001 to 30%) of the total microorganisms can be recovered from viable sampling (Peccia and Hernandez, 2006; Lee et al., 2006b). Despite variations in the distribution of the fungal species, the relative fungal compositions were comparable with results of another study which collected the total spore, followed by microscopic counting and identification for outdoor airborne fungi in Hong Kong (Chan, 2006). Thus, the number concentration from the viable sampling in this study might be much underestimated; the relative compositional distribution is believed to be representative of the ambient air. The corresponding weighted-average carbon conversion factors (section 2.4 in Materials and Methods) are summarized accordingly in Table 3. The weighted-average carbon values show a high consistency ranging from 5.20 to 6.34 pg carbon per spore with an average of 5.97 pg carbon per spore (s.d. 0.22 or RSD 3.8%, n=28) regardless of variations in fungal contributions. Despite this value is very close to the simple average value of 6.0 pg carbon per spore (s.d. 3.0 or RSD 51%) determined from the common airborne species (Table 1), the weighted-average approach provides dataset with less variability (RSD 3.8% vs. 51%). The natural variability in fungal composition and abundance has probably been taken care of through the weighted averaging process. The value of 5.97 pg carbon per spore can thus be taken as the general conversion factor for future calculation and application.

In determining the fungal carbon contributing to the total aerosol OC, the total number of spores (n) can be obtained by direct field measurement through spore sampling or viable sampling. Alternatively, the total spore concentration was estimated from the ergosterol measurement with their corresponding weighted-average ergosterol content (Cheng et al., 2008b). We adopted the later approach in this study to minimize the underestimation due to sampling loss and recovery issues commonly encountered and reported in the spore or viable sampling (Niemeier et al, 2006; Lappalainen, 1996). The later approach also allows parameters to be analyzed source from the same filter avoiding the spatial and temporal variations between different sampling instrumentations and protocols so that systematic error, if there is any, remains constant. The estimated spore number concentrations, as well as the calculated fungal OC and their corresponding contributions to the total aerosol OC ($OC_{\text{fungi}}/\text{Total } OC_{\text{aerosol}}$) in $PM_{2.5}$, $PM_{2.5-10}$ and PM_{10} ($PM_{2.5} + PM_{2.5-10}$) are

summarized in Table 3.

The estimated fungal OC in the PM₁₀ of the 28 samples ranged from 1.6 to 25.3 ng m⁻³ with an average of 9.7 ng m⁻³. An average of 6.0 ng m⁻³ and 3.7 ng m⁻³ of the fungal OC was associated with PM_{2.5-10} and PM_{2.5}, respectively (Table 3). The results were lower than those reported in Austria with an average >200 ng m⁻³ (n=10) at both suburban and urban sites (Bauer et al., 2008) but comparable with those estimated by Bauer et al. (2002a) at Mt. Rax, Austria during low biogenic emission period (mean: 16 ng m⁻³, n = 3). In terms of the fungal contribution to the total aerosol OC (OC_{fungi}/Total OC_{aerosol}), averages of 0.2%, 0.1% and 1.2% were estimated in the PM₁₀, PM_{2.5} and PM_{2.5-10}, respectively (Table 3). These are far less than the corresponding 18%, 2.5% and 60% in total PM₁₀, PM_{2.0} and PM_{2.0-10} at the suburban site in Austria reported by Bauer et al. (2008). The discrepancy between the two studies, however, can be justified by the following three factors: the spore carbon content value (5.97 pg m⁻³ in this study vs. 13 pg m⁻³ in Bauer et al. (2008), ca. 2-fold difference); the total aerosol OC content (5 µg m⁻³ in this study vs. 3 µg m⁻³ in Bauer et al. (2008), ca. 2-fold difference); and the spore number concentration (10² to 10³ in this study vs. 10³ to 10⁴ in Bauer et al. (2008), ca 10-fold difference) used for the estimation in the two studies. A rough estimation from these differences already gives 40-fold difference in the estimation of the fungal contribution. If this 40-fold difference is considered, the 0.2%, 0.1% and 1.2% will be translated to 8%, 4% and 48% contribution in the total PM₁₀, PM_{2.5} and PM_{2.5-10}, respectively. These values will be more comparable to those (18%, 2.5% and 60%) of Bauer et al. (2008) study. While close agreement in the spore carbon content is observed in these two studies, the total aerosol carbon content and total spore number concentration are highly spatial and temporal dependent factors as exemplified by the data collected after the heavy rainfall (Table 4).

High fungal prevalence or count is commonly observed after heavy rain (Das and Gupta-Bhattacharya, 2008; Mitakakis et al., 2001; Allitt, 2000). Apart from the 28 sets of samples described above, 3 other sets of samples were collected during late April to early May 2006 when rain was frequent. The contribution of the fungal carbon to the total OC is increased up to 32% in PM_{2.5-10} or 7.1% in PM₁₀ after rain (Table 4). Rain removes some particulates by wet deposition and hence lowering the total aerosol OC content to the range of 1.7 to 2.6 µg m⁻³, which is about half of the other 28 dataset. Although rain also removes fungal spores, high fungal concentrations after rain is a common phenomenon coherently reported in literatures. Gottwald et al. (1997) studied the released of fungal spores in a controlled environmental chamber and found that continuous rain resulted in an increase in spore concentration until depletion of spores. Arseniuk et al. (1998) found that spores were released by *Phaeosphaeria* on days when rainfall exceeded 1mm or when there was

prolonged dew. Pinkerton et al. (1998) found that spore concentration was correlated significantly with precipitation and wetness, but not with temperature or wind speed. Battarbee et al. (1997) reported an increase in number concentration of fungal spores from 1 – 4% of the total particulates before rain to 23 – 27% after rain. These authors suggested that rainfall promoted spore growth, increasing the size of the source, and rain stimulated sporulation and spore dispersal (Jones and Harrison, 2004). In addition, falling raindrops assisted aerosolization of spores on leaf surface by vibration. These enhancing effects on fungal sporulation and dispersion out-balance the wet deposition effect on the fungal spores comparing with other aerosols. The natural event of rain thus provides comparable conditions (low aerosol OC content and high spore number concentration) to those of Bauer et al. (2008). Under such similar conditions, the magnitude of fungal contribution determined in this study is in good agreement with those reported by Bauer et al. (2008), as well as with the number concentration contribution reported by Mattias-Maser and Jaenicke (1995). Results reported here also imply that fungi can be a major OC contributor in tropics and subtropics where raining season and heavy rain are prominent. Despite the apparent variation in the relative contribution of the fungi to the total aerosol OC between the two studies, fungi can be a significant OC contributor to atmospheric aerosols (particularly in coarse particulates $PM_{2.5-10}$) is consensual although extent of its contribution is spatial-, temporal- or event-dependent. The growing evidence and knowledge on the fungal role in atmospheric aerosols deserve more attention for their studies.

4. Conclusion

The specific carbon content of 10 common airborne fungal species with aerodynamic size less than 10 μm in a subtropical city was determined in the range of 3.6 – 13.0 pg per spore, giving a mean of 6.0 pg per spore with a RSD of 51%. In accounting for the natural variations in composition and abundance, weighted-average approach was adopted to generate the general carbon conversion factor of 5.97 pg carbon per spore (RSD 3.8%) determined from 28 field collected samples. The fungal carbon contributed an average of 0.1, 1.2 and 0.2% of the total OC in $PM_{2.5}$, $PM_{2.5-10}$ and PM_{10} , respectively. These values are much lower than those reported in Austria by Bauer et al. (2008). The discrepancy is accountable by the higher total OC level and lower fungal prevalence between the two studies. Nevertheless, comparable fungal contribution (7 to 32% of $PM_{2.5-10}$) were captured after three raining events which provided high fungal concentration with low total OC level comparable to conditions reported by Bauer et al. (2008). Results of this study add supporting evidence that fungi constitute a non-negligible portion in atmospheric aerosols in tropics and subtropics, their roles in aerosol compositions and atmospheric processes deserve

more detailed studies.

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Figure 1: Compatibility of TOC system and TOR protocol

Figure 2: Determination of the OC content of *Cladosporium sp.* spore by linear regression. Dotted lines represent the 95% confidence interval.

Table 1: Carbon contents of different fungal species

Fungal species	Carbon content pg carbon per spore or yeast cell	95% confidence interval pg carbon per spore or yeast cell	RSD (%)	Approximate size major x minor axis (μm x μm) ^a
<i>Alternaria</i> sp.	201.0	161.9 – 240.2	16.8	10 – 12.5 x 20 – 30
<i>Aspergillus niger</i>	13.0	9.6 – 16.4	20.9	4 – 7.5 in diameter
<i>Candida</i> sp.	4.0	3.3 – 4.7	15.1	2 – 4 in diameter
<i>Cladosporium</i> sp.	6.5	5.2 – 7.8	15.1	2.5 – 4 x 5 – 7.5
<i>Paecilomyces</i> sp.	9.5	7.9 – 11.1	13.4	4 – 6 x 6 – 8
<i>Penicillium chrysogenum</i>	5.5	4.1 – 6.7	13.6	2.5 – 4 in diameter
<i>Penicillium</i> sp. (A)	3.6	2.5 – 4.7	15.1	2.5 – 4 in diameter
<i>Penicillium</i> sp. (B)	4.0	3.0 – 5.1	17.7	2.5 – 4 in diameter
<i>Penicillium</i> sp. (C)	4.3	2.5 – 6.2	14.1	2.5 – 4 in diameter
<i>Penicillium</i> sp. (D)	3.8	2.3 – 5.3	22.2	2.5 – 4 in diameter
<i>Rhodotorula</i> sp.	5.8	4.3 – 7.3	14.0	2.5 – 4 x 5 – 7.5

^a: Cheng et al. (2008a)Table 2: The carbon concentrations in collected aerosols, $\mu\text{g m}^{-3}$ (n = 28)

		Average Concentration	Range	standard deviation
PM _{2.5}	OC	4.6	1.8-8.5	1.9
	EC	3.2	1.5-7.7	1.4
PM _{2.5-10}	OC	0.6	0.3-1.3	0.2
	EC	0.2	0.1-0.4	0.1
PM ₁₀	OC	5.1	2.4-9.6	2.0
	EC	3.4	1.6-7.9	1.5

Table 3: Summary of fungal contribution to atmospheric OC of each filter sample collected in the study

sample number	culturable fungi (%)			weighted-average carbon	estimated spore concentration (spore m ⁻³) ^b			fungal OC (ng m ⁻³) ^c			fungal contribution (%) ^d		
	<i>Cladosporium</i>	<i>Penicillium</i>	<i>Aspergillus</i>	conversion factor ^a	PM _{2.5}	PM _{2.5-10}	PM ₁₀	PM _{2.5}	PM _{2.5-10}	PM ₁₀	PM _{2.5}	PM _{2.5-10}	PM ₁₀
1	51.3	33.2	1.5	5.77	273.4	326.7	600.1	1.6	1.9	3.5	0.07	0.50	0.14
2	41.9	45.5	3.3	5.63	346.6	1179.6	1526.2	2.0	6.6	8.6	0.10	1.60	0.36
3	53.3	28.1	8.3	6.34	424.2	2371.9	2796.1	2.7	15.0	17.7	0.11	4.38	0.65
4	59.1	23.0	2.3	6.04	1447.9	2140.4	3588.3	8.7	12.9	21.7	0.23	1.63	0.46
5	58.0	30.3	1.7	5.87	1416.9	1180.0	2597.0	8.3	6.9	15.2	0.14	1.59	0.25
6	23.2	51.5	0.0	5.20	730.6	287.0	1017.6	3.8	1.5	5.3	0.06	0.20	0.08
7	63.9	24.6	0.0	5.88	1135.5	1351.1	2486.6	6.7	7.9	14.6	0.08	0.70	0.15
8	24.9	42.5	7.0	5.86	213.6	347.2	560.8	1.3	2.0	3.3	0.02	0.34	0.06
9	47.9	18.8	0.0	5.90	408.8	344.2	752.9	2.4	2.0	4.4	0.04	0.37	0.07
10	50.1	25.6	1.2	5.88	210.3	165.9	376.2	1.2	1.0	2.2	0.03	0.22	0.04
11	60.9	15.5	0.0	6.00	1767.6	812.9	2580.5	10.6	4.9	15.5	0.14	0.66	0.18
12	54.4	17.3	0.0	5.96	523.0	3721.2	4244.2	3.1	22.2	25.3	0.06	4.56	0.45
13	49.3	18.4	4.7	6.25	271.1	246.2	517.3	1.7	1.5	3.2	0.04	0.33	0.07
14	72.4	20.6	1.3	6.08	1249.4	1585.9	2835.3	7.6	9.6	17.2	0.10	2.67	0.21
15	47.8	39.4	3.5	5.78	504.7	600.4	1105.1	2.9	3.5	6.4	0.09	0.87	0.17
16	62.9	21.5	0.7	5.98	414.8	401.3	816.1	2.5	2.4	4.9	0.05	0.51	0.09
17	75.2	11.8	2.3	6.32	1074.8	2091.3	3166.1	6.8	13.2	20.0	0.15	2.83	0.39
18	68.7	18.0	0.8	6.07	1035.3	1470.7	2506.1	6.3	8.9	15.2	0.09	1.37	0.21

19	71.2	18.4	0.3	6.04	362.1	539.2	901.3	2.2	3.3	5.4	0.06	0.53	0.13
20	67.4	14.1	0.3	6.11	357.1	579.0	936.1	2.2	3.5	5.7	0.07	0.93	0.16
21	62.7	19.5	0.0	5.96	484.2	550.9	1035.1	2.9	3.3	6.2	0.04	0.26	0.07
22	75.7	11.6	0.5	6.20	313.7	608.9	922.6	1.9	3.8	5.7	0.04	0.62	0.10
23	42.4	27.8	1.2	5.80	275.1	405.9	681.0	1.6	2.4	3.9	0.06	0.61	0.13
24	41.0	16.8	2.4	6.07	310.2	369.8	680.0	1.9	2.2	4.1	0.04	0.37	0.08
25	44.2	9.2	1.0	6.13	129.7	134.9	264.6	0.8	0.8	1.6	0.02	0.15	0.04
26	39.8	20.1	3.1	6.12	363.7	345.2	708.8	2.2	2.1	4.3	0.07	0.27	0.11
27	41.0	16.9	0.0	5.90	434.8	889.3	1324.2	2.6	5.3	7.8	0.10	1.30	0.27
28	18.3	6.0	0.0	5.99	929.7	2774.8	3704.5	5.6	16.6	22.2	0.31	1.97	0.84
average				5.97 (s.d. 0.22)				3.71	5.98	9.69	0.09	1.16	0.21
max				6.34				10.61	22.18	25.30	0.31	4.56	0.84
min				5.20				0.79	0.83	1.62	0.02	0.15	0.04

^a: Calculated by weighted average carbon conversion factor = $\sum_i f_i C_i$

^b: Estimated by using conversion factor of 0.191 pg ergosterol/spore (Cheng et al., 2008b)

^c: Calculated by $OC_{fungi} = n \sum_i f_i C_i$

^d: fungal contribution = $\frac{\text{fungal organic carbon}}{\text{total organic carbon in atmospheric aerosol}}$

Table 4: Fungal contribution to OC during the period with frequent raining

sampling date	fungal OC (ng m ⁻³)			total OC (µg m ⁻³)			fungal contribution (%)			Rainfall (mm) ^a
	PM _{2.5}	PM _{2.5-10}	PM ₁₀	PM _{2.5}	PM _{2.5-10}	PM ₁₀	PM _{2.5}	PM _{2.5-10}	PM ₁₀	
23-24 Apr 06	5.7	121.8	127.5	1.4	0.4	1.8	0.4	32.0	7.1	187.5
7-8 May 06	16.1	48.7	64.8	2.0	0.6	2.7	0.8	7.5	2.4	348.0
9-10 May 06	31.7	84.7	116.3	1.3	0.4	1.8	2.3	21.0	6.6	234.7

^a: The total rainfall on the sampling day and the last six days before sampling