Concentrations of Airborne Cultivable Fungi at a Higher Education Institution in Cartagena de Indias, Colombian Caribbean

Article *in* Aerosol Science and Engineering · August 2022

DOI: 10.1007/s41810-022-00151-8

4 authors, including:

Carolina Rubiano Labrador
Universidad Tecnológica de Bolívar
18 PUBLICATIONS **140** CITATIONS

SEE PROFILE

Rosa Acevedo-Barrios
Universidad Tecnológica de Bolívar
40 PUBLICATIONS **224** CITATIONS

SEE PROFILE

Aerosol Science and Engineering
https://doi.org/10.1007/s41810-022-00151-8

ORIGINAL PAPER

Concentrations of Airborne Cultivable Fungi at a Higher Education Institution in Cartagena de Indias, Colombian Caribbean

Carolina Rubiano-Labrador[1] · Ludys Baena De Avila[1] · Dayana Doria Posada[1] · Rosa Acevedo-Barrios[1]

Received: 11 February 2022 / Revised: 9 June 2022 / Accepted: 11 July 2022

Abstract
Bioaerosols are as small particles suspended in air that contain several microorganisms (bacteria, fungi, and viruses). These particles are studied because of the possible impacts that they have on the health of humans and animals in open and closed spaces. In this study, the presence of airborne fungi presents in a Higher Education Institution (HEI) of the city of Cartagena de Indias, Colombian Caribbean was evaluated. Over 4 months (June–October 2018), 128 fungal samples were collected using a two-stage cascade impactor, and the fungi present in these samples were counted, characterized, and identified. Bioaerosol concentrations were correlated with meteorological data from the Rafael Núñez Airport meteorological station to establish the possible influence of these factors on the presence of bioaerosols. The results obtained showed an average concentration of fungal aerosols of 123.71 ± 17.97 UFC/m^3, with the highest proportion occurring in the morning. The predominant genera were *Aspergillus* (60.8%), followed by *Penicillium* (24.5%) and *Fusarium* (9.3%). According to the correlations obtained from a multivariate analysis, the meteorological parameters did not influence the presence of microorganisms at the HEI studied; however, a possible influence of emission sources such as vegetation and industry is suggested.

Keywords Air quality · Bioaerosols · External environments · Meteorological factors · Microorganisms

1 Introduction

Bioaerosols are defined as very small particles of biological origin that are found in the air, with sizes ranging from 0.001 to 100 µm (Kim et al. 2018). These particles can be made up of live or dead microorganisms (Douwes et al. 2017), such as bacteria, viruses, fungi, and, pollen, and their metabolic products, and even insect remains (Hurtado et al. 2014). Bioaerosols are derived from natural sources such as plants, animals, people, soil, and water (Heo et al. 2014) and from anthropogenic sources such as industries, solid and liquid waste management, agriculture, livestock, and food processing (Humbal et al. 2018).

In particular, fungi are abundant and ubiquitous in nature, representing 30% of all atmospheric aerosols (El-Morsy 2006; Fröhlich-Nowoisky et al. 2016). In some cases, they can be found in high concentrations due to particular characteristics of the atmosphere (Douwes et al. 2017), such as meteorological conditions, because they influence the processes of aerosolization, transport, and deposition of aerosols (Velez-Pereira 2017). Particularly, temperature and humidity can have the greatest influence on the presence of fungal bioaerosols because they intervene in the biological activity and emission of these microorganisms (Almaguer et al. 2014; Dedesko et al. 2015; Fröhlich-Nowoisky et al. 2016). In addition, these variables can affect hydrological processes because they contribute significantly to the formation of ice cores and the condensation of clouds (Huertas et al. 2018; Hurtado et al. 2014).

The concentrations of fungal bioaerosols in the air can affect human, plant, and animal health because they cause diseases and other adverse effects (Fayad et al. 2021; Fröhlich-Nowoisky et al. 2016; Nazaroff 2016). Some species of bioaerosols are considered pathogens, as they are associated with infectious, allergic, and respiratory diseases, in addition to causing the generation of acute toxic, neurological and even cancer effects (Douwes et al. 2003). Therefore, in recent years, research has been conducted to identify fungal bioaerosols and their potential impact on biota (Douwes et al. 2017; Fröhlich-Nowoisky et al. 2016). Most of these

✉ Carolina Rubiano-Labrador
drubiano@utb.edu.co

[1] Grupo de Estudios Químicos y Biológicos, Facultad de Ciencias Básicas, Universidad Tecnológica de Bolívar, POB 130001, Cartagena de Indias D. T. y C., Colombia

studies have been conducted in indoor environments such as offices (Bręgoszewska et al. 2018; Gołofit-Szymczak and Górny 2018; Yu et al. 2018), schools (Bręgoszewska et al. 2018; Yen et al. 2020), and hospitals (Mousavi et al. 2019; Tolabi et al. 2019). Likewise, studies have been carried out in outdoor environments such as coastal areas (Huertas et al. 2018), urban centers (Liu et al. 2019; Ruíz-Fonseca and Rubiano-Labrador 2021) and open spaces in educational centers (Rodriguez-Gomez et al. 2020).

In Colombia, studies have been carried out in intramural environments such as hospitals and universities in Santa Marta and Barranquilla (Caicedo et al. 2015; Medina and De la Hoz 2018; Suarez et al. 2017; Velez-Pereira and Caicedo 2014). In the case of fungal aerosols in extramural environments, despite the relevance of their study for public health and agriculture (Ruiz-Gil et al. 2020), there have been few studies in the country, and to date, most studies have focused on landfills (Morgado 2017). In the city of Cartagena de Indias only two studies have been reported; the first sought to determine the sensitization to allergens in a local emergency room (Caraballo et al. 1998), while the second quantified and characterized the biological particulate material at the Blas El Teso beach (Huertas et al. 2018). In the case of extramural environments with a high influx of people such as universities or colleges, to date there are no studies in the city of Cartagena de Indias on their exposure to bioaerosols. Studies in this type of environment are necessary because they are important facilities associated with the environmental exposure of students, teachers and administrative staff, and where they spend a large part of their time during the week (children spend 25% of their time in school, and university students can spend more than 12 h a day) (Jo and Seo 2005; Oliveira et al. 2009). Considering the limited information that exists on fungal bioaerosols in outdoor environments in the city of Cartagena de Indias, the objectives of our study were: (1) to determine the concentration of airborne fungi present in a higher education institution (HEI), (2) to characterize the airborne cultivable fungi present in the HEI, and (3) to determine the influence of meteorological conditions on the concentrations of isolated airborne fungi.

2 Materials and Methods

2.1 Sampling Site

This study was conducted in the city of Cartagena de Indias, Colombia. This city is located in the center of the Colombian Caribbean coast, and is characterized by a semi-arid tropical climate with an average humidity of 90% and an average temperature of 31.5 °C. The climate changes several times during the year: a dry season or summer (August–November), a rainy or winter season (December–March) and a transition season (April–July) (CIOH 2010).

The sampling site was located on the roof of an academic building on the campus of a HEI (10° 22′ 13.6″ N–75° 27′ 55.5″ W), which is located south of the city in the Carlos Vélez Pombo Industrial and Technological Park. In this industrial park, there are storage warehouses and companies related to the supply of materials and services related to the energy industry. In addition, it is characterized by a high presence of vegetation and green areas. The building selected as the sampling point was located in the most vegetated area of the institution. The locations of the sampling sites are shown in Fig. 1. This location was selected because of its accessibility and favorable wind current conditions.

The sampling instruments were located at an approximate height of 1.5 m, which corresponds to the average height of human respiration (Camargo et al. 2011). In this study, a systematic demonstration was used, since the samples were taken in the same period of time during the 16 sampling campaigns. The bioaerosol sampling was carried out in duplicate once a week between June and October 2018 (16 sampling campaigns), and the samples were collected in the morning (9h00–10h00) and afternoon (13h00–16h00). During the sampling period, 128 samples were collected. The methodology proposed by Huertas et al. (2018), who have carried out studies in outdoor environments such as coastal areas. The meteorological data (temperature, precipitation, wind speed and humidity) were obtained from the platform of the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM), which correspond to the main synoptic station located at the Rafael Núñez Airport.

2.2 Sampling Methods

Bioaerosol sampling was performed using a two-stage viable Andersen cascade impactor with a flow rate of 28.3 L/min. This device has a design that allows it to simulate the functioning of the human respiratory system, sucking in the air from the environment, and allowing the impaction of the particles in each of stage. Each stage was designed to capture a range of particles with a defined aerodynamic size range. In stage 1, particles with a diameter greater than 7 µm were captured, representing the area of the nasal cavity of the human respiratory system; in stage 6, particles with a diameter of approximately 2 µm were captured, which could enter the area of the primary bronchi or alveoli of the respiratory system (Huertas et al. 2018).

Previously, a pre-sampling test was carried out to determine the appropriate time to collect the samples, considering: (i) the growth of microorganisms without overlapping colonies and (ii) the appropriate time to identify the growth of microorganisms in the laboratory. The optimal sampling time was 8 min. Cultivable fungi samples were collected

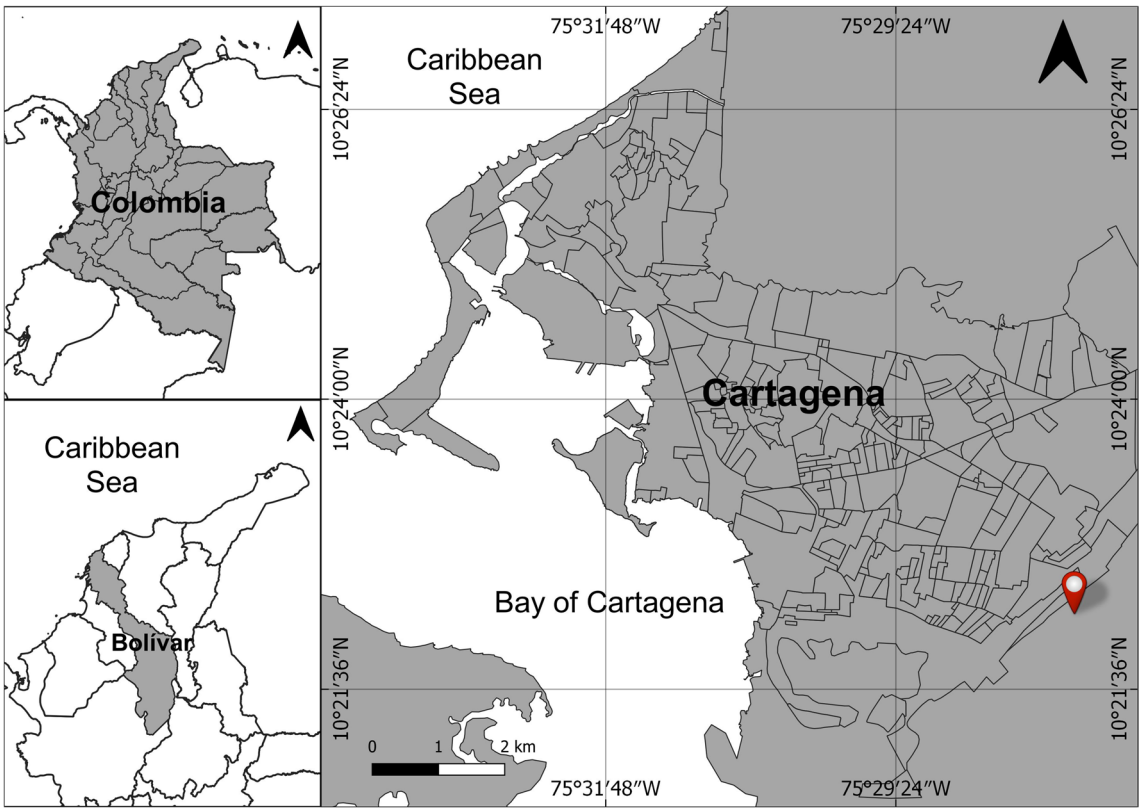

Fig. 1 Location of the sampling site (HEI) in Cartagena de Indias

in 9.0 cm Petri dishes containing Sabouraud agar and were incubated at 26 °C for 8 days.

2.3 Counting and Identifying Fungal Bioaerosols

The fungal genera were identified based on their macro (color, texture and shape) and microscopic (hyphae, conidiophores and ascospores) characteristics using standard taxonomic keys (Koneman 2008; Vos et al. 2009). The colony-forming units (CFU) were counted according to the formula proposed by Caicedo et al. (2015):

$$\frac{\text{CFU}}{\text{m}^3} = \frac{\text{Colony forming units}}{\text{Air volume}},$$

where the air volume is calculated as the product of the pumping flow rate and sampling duration.

2.4 Statistical Analyses

In the present work, statistical analyses were performed using the Statgraphics software (version 16). The fungal concentrations were evaluated at 95% confidence intervals. Comparisons were made between samples collected in the morning and afternoon during each week (average concentration obtained for each campaign). Pearson's correlation coefficient (r) was used to determine the correlation between the concentrations of bioaerosols and meteorological variables.

3 Results and Discussion

3.1 Airborne Culturable Fungi Concentration

The average concentration of fungi was 123.71 ± 17.97 CFU/m^3 during the 4 months of sampling. The minimum value was presented in week 2 of sampling with 44.17 CFU/m^3, in the morning, and the maximum value in week 7 with 247.35 CFU/m^3, at the same time. Figure 2 shows the results of the concentration (CFU/m^3) in the HEI and its area of influence during the 16 monitoring campaigns. There have been few studies on bioaerosols carried out in the same sampling area as in this study (coastal zone). To date, studies have been conducted on the beaches of the city of Cartagena de Indias (Huertas et al. 2018), in a sanitary landfill in the city of Santa Marta (Velez-Pereira and Camargo 2011), and in the coastal city of Mérida, Mexico (Rodriguez-Gomez et al. 2020). The concentrations found in our study were lower than those reported in these previous reports.

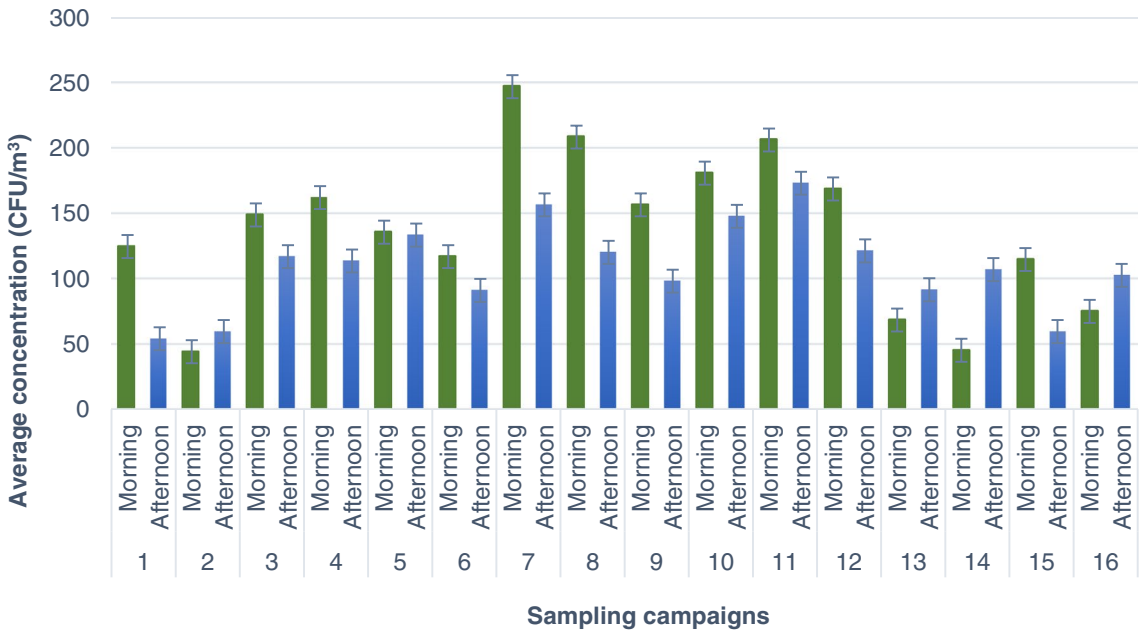

Fig. 2 Average concentration of fungi by times and sampling campaigns at a HEI in Cartagena de Indias, Colombia

However, it is important to note that the sampling location was different in each study; therefore, this may be a factor that can influence the differences in the concentrations. In addition, there are other factors that may influence the results, such as the various natural or anthropogenic emission sources and the different meteorological variables or climatic conditions of each place.

In the case of the values registered by campaign and sampling times, a higher concentration was reported in the morning in 11 of the 16 campaigns. This trend may be related to wind speed since a lower average speed was recorded in the morning (8.75 km/h) than in the afternoon (16.18 km/h). These results coincide with reported by Huertas et al. (2018) who quantified the concentrations of fungi on a beach in Cartagena de Indias and can be explained by the influence of sea and land breezes on the wind patterns in coastal areas. Moreover, high wind can act as a spore dilution factor, and could reduce the concentration of fungal spores (Fayad et al. 2021).

3.2 Characterization and Identification of Fungi Bioaerosols

During the 16 sampling campaigns, 128 samples were collected, from which 11 fungi were identified and characterized (Table 1). According to the results obtained, it was determined that the isolated fungal strains belonged mainly to the *Ascomycota* phylum (82%), followed by *Mucoromycota* (9%) and *Basidiomycota* (9%). The dominance of the phylum Ascomycota coincides with that reported by Shelton et al. (2002), Shin et al. (2015) and Valsan et al. (2015), and may be related to rapid growth and intense sporulation on standard agar media (Pashley et al. 2012).

The main genera of airborne fungi present in the air of the HEI were *Aspergillus* (1607.8 CFU/m^3), *Penicillium* (649.3 CFU/m^3), *Fusarium* (247.3 CFU/m^3), *Alternaria* (97.2 CFU/m^3), and *Mucor* (8.8 CFU/m^3) (Fig. 3). Regarding the frequency of appearance of the fungi according to time, it was determined that all the identified genera appeared at both times (morning and afternoon) (Fig. 4) Araujo et al. (2013). *Aspergillus* sp. was the most common fungal genus represented by two species: *Aspergillus niger* and *Aspergillus flavus*. This genus reached its maximum concentration in the afternoon. *Aspergillus* is a saprophytic filamentous fungus widely distributed worldwide, and some of the species of this genus are infectious agents that cause different syndromes that affect the respiratory tract (Belizario et al. 2021; Navale et al. 2021). The presence of *Aspergillus* sp. is very common in the air because of its versatility to adapt to environmental changes (Fayad et al. 2021), and it has been previously reported in studies on bioaerosols (Fayad et al. 2021; Huang et al. 2002; Huertas et al. 2018; Madhwal et al. 2020). In addition, this genus has been reported to be highly abundant in tropical and subtropical regions (Fayad et al. 2021).

Penicillium sp. was the second most predominant genus, and its frequency was similar in the two sampling campaigns evaluated. This genus is abundant and frequent in nature, and some species are associated with keratitis, otomycosis, pneumonia, and endocarditis (Egbuta et al. 2017). Previous

Table 1 Phenotypic characterization of isolated fungi

Code	Morphology	Macroscopic description	Phylum	Family	Genus	Related species
H1	Septate hypha, profusely branched, globose and wrinkled conidia	Colony with cottony texture and black aerial conidia	*Ascomycota*	*Trichocomaceae*	*Aspergillus*	*Aspergillus niger*
H2	Septate hypha with simple conidiophores	Yellow colony with white center and cottony texture	*Ascomycota*	*Nectriaceae*	*Fusarium*	*Fusarium* sp.
H3	Septate hypha, young conidia rounded at the base	Dark green cottony colony	*Ascomycota*	*Pleosporaceae*	*Alternaria*	*Alternaria* sp.
H4	Non-septate hypha, conidia formed from conidiophore	Colony with black filaments with white edges, and with a cottony texture	*Ascomycota*	*Trichocomaceae*	*Aspergillus*	*Aspergillus* sp.
H5	Hyphae not septate, hyaline, thin, conidia round	Green colony with white edges and cottony texture	*Ascomycota*	*Trichocomaceae*	*Penicillum*	*Penicillum* sp.
H6	Septate hypha, globose conidia, bluish green	Green colony with white edges and cottony texture	*Ascomycota*	*Trichocomaceae*	*Aspergillus*	*Aspergillus flavus*
H7	Hypha septate, hyaline, broad	Brown cologne and cottony texture	*Mucoromycota*	*Mucoraceae*	*Mucor*	*Mucor* sp.
H8	Septate hypha, slender conidia, and micro conidia on the sides of the hyphae	White colony with beige center and cottony texture	*Ascomycota*	*Arthrodermataceae*	*Microsporum*	*Microsporum* sp.
H9	Septate hypha, slender conidia, and micro conidia on the sides of the hyphae	Green color cologne and black reverse, with velvety texture	*Ascomycota*	*Davidiellaceae*	*Cladosporium*	*Cladosporium* sp.
H10	Slender septate hypha, hyaline conidia	Yellow colony with cottony texture	*Ascomycota*	*Eurotiomycetes*	*Paecilomyces*	*Paecilomyces* sp.
H11	Septate hypha, presence of blastoconidia	Branched salmon colony	*Basidiomycota*	*Sporidiobolaceae*	*Rhodotorula*	*Rhodotorula* sp.

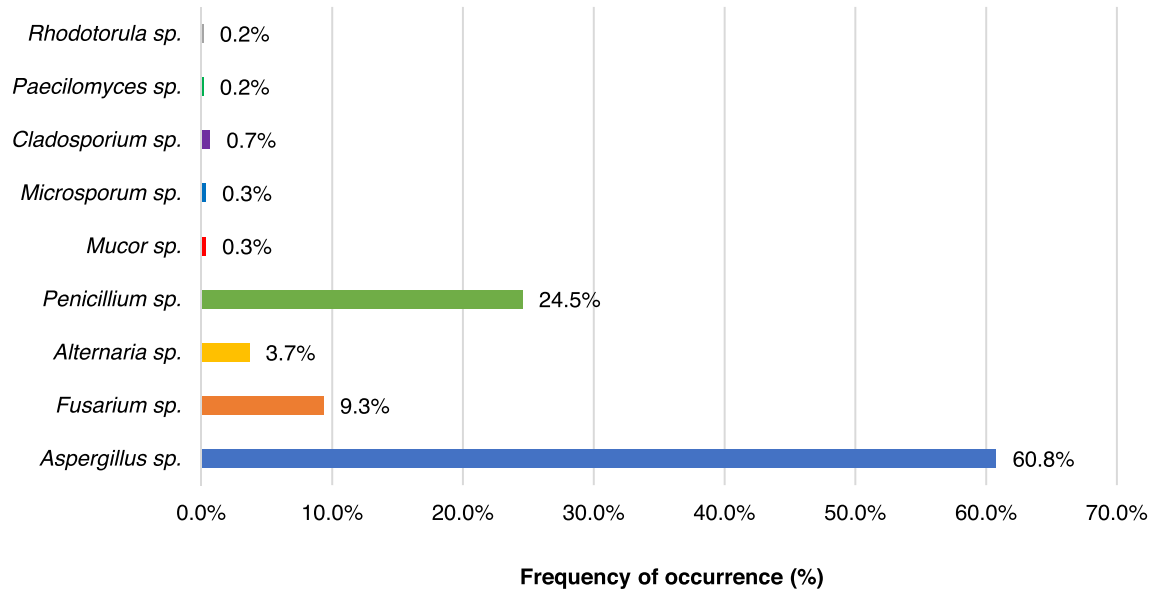

Fig. 3 General frequency of fungal genera identified in the air of the higher education institution (HEI)

studies have reported *Penicillium* sp. as a fungal aerosol abundant in outdoor environments both in winter and summer, as its spores can grow under different meteorological conditions (El-Morsy 2006; Faridi et al. 2015; Lee and Chang 2000; Pashley et al. 2012; Rodriguez-Gomez et al. 2020; Spicer and Gangloff 2005). *Fusarium* sp., which was

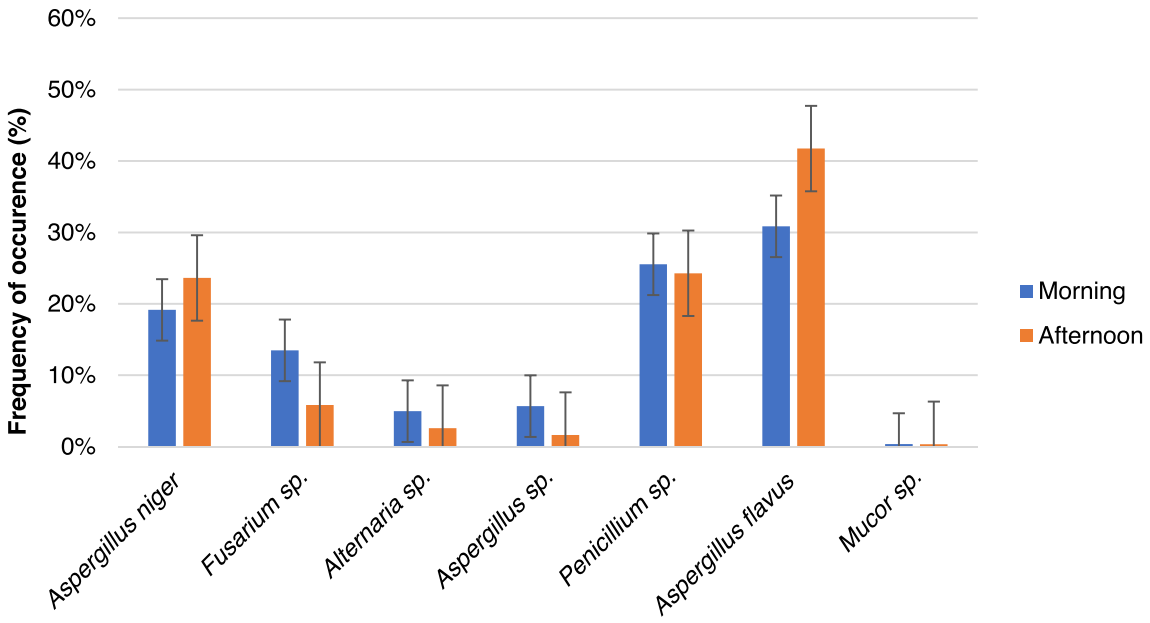

Fig. 4 Frequency of fungal bioaerosols occurrence in the morning and afternoon

the third most frequent genus in this study, is a group of filamentous fungi widely distributed in soil and plants; they are considered opportunistic due to their ability to grow at high temperatures, and can cause systematic infections in immunocompromised patients, and some produce toxins that affect humans and animals (Georgiadou et al. 2014). These results coincide with those of previous studies in which the genus *Fusarium* has been considered as an outdoor-relevant group (Huertas et al. 2018; Nageen et al. 2021; Oliveira et al. 2009; Rodriguez-Gomez et al. 2020).

The genus *Alternaria* is a ubiquitous genus of fungi, which is associated with a wide variety of substrates, including seeds, plants, agricultural products, animals, soil, and the atmosphere (Woudenberg et al. 2013). Some species of this genus can be plant pathogens, causing great losses in a wide range of crops, and can also have negative health effects in humans (Woudenberg et al. 2013). *Alternaria* spp. are commonly found in the air, and their presence in outdoor environments has previously been reported (El-Morsy 2006; Faridi et al. 2015; Fayad et al. 2021; Hosseini et al. 2021; Nageen et al. 2021; Rodriguez-Gomez et al. 2020). On the other hand, the species of the genus *Mucor* are very frequent in nature, they are found in a great variety of substrates, but more frequently they are associated with humid environments. The spores of this genus, which are emitted in large quantities, have a strong moisture absorption capacity, and a high level of adherence to various surfaces, and can be dispersed in humid air (Morin-Sardin et al. 2017). This genus has been reported in previous studies of airborne fungi (El-Morsy 2006; Fayad et al. 2021; Huertas et al. 2018; Niazi et al. 2015).

3.3 Analysis of Meteorological Conditions and Bioaerosols Concentrations

In this study, three meteorological variables were monitored in parallel: temperature (°C), relative humidity (%) and wind speed (km/h). The behavior of these variables during the four months of sampling is shown in Fig. 5 and Table 2 presents the results of the statistical analysis performed.

The relative humidity values ranged between 80 and 90%, while the temperature remained in the range of 28–33 °C, and the speed of the wind, ranged between 5 and 20 km/h, the meteorological variable being more fluctuation. Based on the information in Table 2, it can be inferred that the meteorological variables, temperature, and relative humidity maintain a high consistency in their data because the standard deviation and coefficient of variation values are low, indicating that there is little dispersion in the data of these variables. Likewise, it is observed that there are no significant differences between the minimum and maximum values of these variables. Regarding the linear correlation coefficients of the analyzed variables, a low negative relationship was determined between temperature and the concentration of fungal bioaerosols ($r = -0.1$). Similarly, a low correlation between wind speed and fungal concentration was observed ($r = -0.11$). In addition, a low positive correlation was found between relative humidity and fungal concentration ($r = 0.18$).

The low correlation between relative humidity and bioaerosol concentrations determined here coincides with the studies carried out by Fayad et al. (2021), Jianhua et al. (2015) and Zhong et al. (2016), who reported that relative

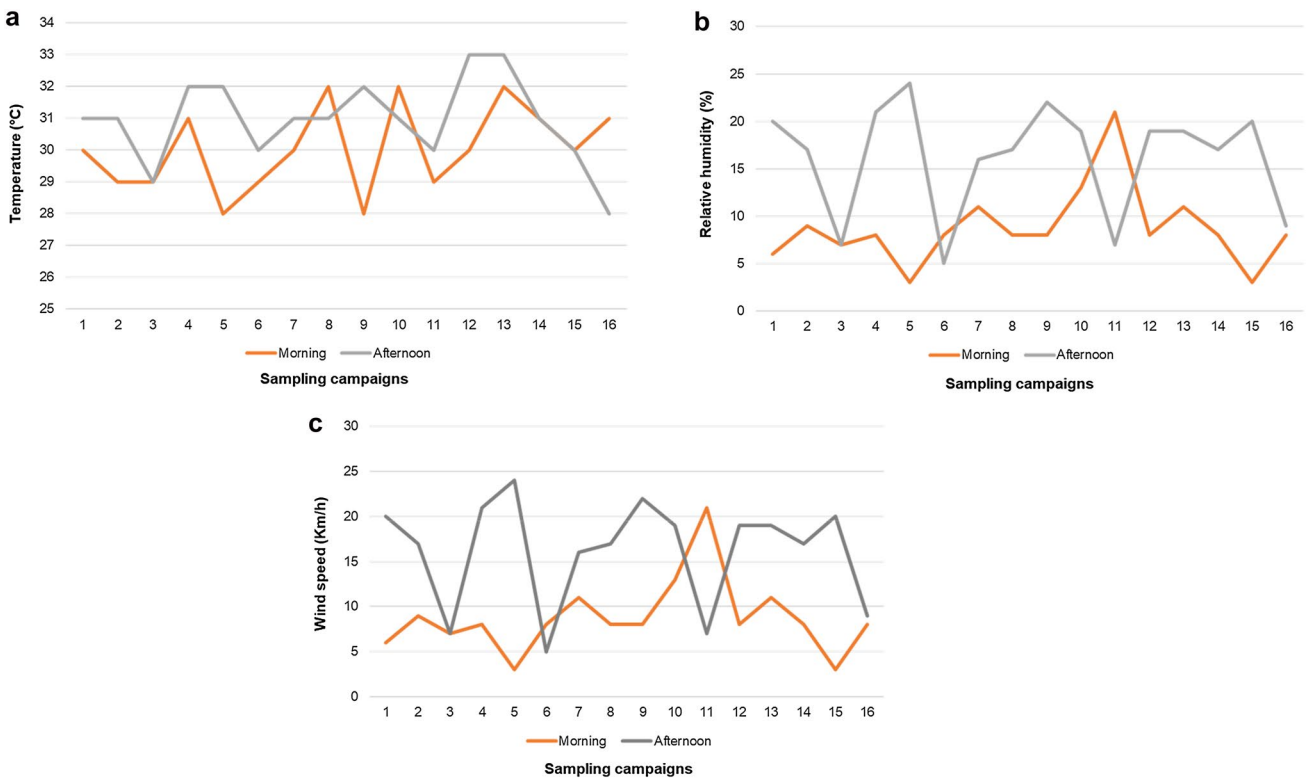

Fig. 5 Behavior of meteorological variables during the sampling period. Bars represent a 95% confidence interval. **a** Temperature (°C), **b** relative humidity and **c** wind speed

Table 2 Statistical features of the analyzed variables

Variable	Average	Standard deviation	Variation coefficient (%)	Minimum	Maximum	Pearson's coefficient	*P* value
Average concentration of fungi (CFU/m^3)	123.71	49.84	40.29	42	247.4	NA	NA
Temperature (°C)	30.5	1.39	4.56	28	33	− 0.10	0.68
Relative humidity (%)	74.5	5.95	7.98	63	85	0.18	0.48
Wind speed (km/h)	12.47	6.27	50.31	3	24	− 0.11	0.3

humidity and the microbiological activity of bioaerosols were not significantly correlated. Therefore, the results obtained in our study suggest that fungal activity was not affected by relative humidity in the range of 66–85%. Wind is a factor that can influence bioaerosols, depending on the speed and direction. Wind speed is associated with the release and dispersal of spores; however, this effect varies with intensity and height (Li et al. 2011). In this study, a negative correlation between wind speed and concentration was found because fungal concentrations were higher in the morning when wind speeds were lower. These results coincide with those reported by Jones and Harrison (2004), who indicated that fungal concentrations increase when wind speed increases from 0.5 to 1 m/s but decrease when the wind speed increases to 5 m/s, probably as a result of the depletion of the source. A low negative correlation was found between fungal concentration and temperature. These results have been reported in previous studies, in which no correlation was found between the concentration of fungi and temperature (Huertas et al. 2018; Rodriguez-Gomez et al. 2020). According to Camargo et al. (2011), this behavior may be associated with the stress processes to which fungi aerosols are subjected at high temperatures and low water content, which reduces their viability and subsequent recovery.

In this study, no correlations were observed between the meteorological variables and the concentration of bioaerosols during the sampling period, as there were no statistically significant differences between them, which indicates that the meteorological parameters had no influence

on the presence of fungal bioaerosols in the air of the HEI analyzed. Fungal concentration can also be influenced by emission sources close to the test site because the natural environment provides the substrates and habitats for their survival (Kummer and Thiel 2008; Ruzer and Harley 2004). In our study, the HEI sampling site was located within the urban settlement between the cities of Cartagena and Turbaco, which is characterized by vegetation in the tropical dry forest ecosystem (FCDS 2013; Ulloa-Delgado 2016). This vegetation, represented by the presence of vascular plants, can influence the presence, composition, and quantity of bioaerosols present in the area (Fröhlich-Nowoisky et al. 2016). On the other hand, close to the institution there are industries related to the activities of handling iron and steel, according to Gilbert and Duchaine (2009), industries related to the handling of metals can be sources of bioaerosols because these activities can favor the aerosolization of these microorganisms and guarantee their transport in the air. However, to determine the influence of the mentioned emission sources on the concentration of fungal bioaerosols, future studies based on a large-scale test are required.

4 Conclusions

In this study, the concentration of culturable fungal bioaerosols at a higher education institution in a tropical city (Cartagena de Indias, Colombia) was evaluated. The highest concentrations of fungi occurred in the morning, and the airborne fungi that occurred most frequently were related to the genera *Aspergillus*, *Penicillium* and *Alternaria*. The outdoor fungal bioaerosol concentrations in the sampling area were not influenced by meteorological conditions. Other emission sources close to the sampling point may influence the presence and concentration of fungal bioaeroles, however, future studies with broader monitoring are required, and it is suggested that their presence and concentration were due to various emission sources. This is the first study to identify airborne fungi in an HEI in the city of Cartagena de Indias. Therefore, this research constitutes a baseline for future research related to the measurement of bioaerosols in outdoor environments in the city of Cartagena de Indias, allowing the identification of microorganisms present in the area, their concentration, and their possible impact on the population.

Acknowledgements This work was funded by the Research Directorate of the Universidad Tecnológica de Bolívar.

Author contributions CRL designed the experiments, analyzed the data and wrote the paper. LBA and DDP performed the experiments. RAB contributed to the design of the experiments, analyzed the data, and critically read the manuscript. All authors read and approved the final manuscript.

Declarations

Conflict of Interest The authors declare no conflict of interest.

Ethics Approval and Consent to Participate This article does not contain any studies involving human participants or animals performed by any of the authors.

Consent for Publication All the authors have consented to publish this research.

References

Almaguer M, Aira M-J, Rodríguez-Rajo FJ, Rojas TI (2014) Temporal dynamics of airborne fungi in Havana (Cuba) during dry and rainy seasons: influence of meteorological parameters. Int J Biometeorol 58:1459–1470. https://doi.org/10.1007/s00484-013-0748-6

Araujo J, Rojas Y, Yegres F (2013) Evaluación aeromicrobiológica en la costa del puerto de La Vela de Coro, patrimonio cultural de la humanidad. Multiciencias 13:355–362

Belizario JA, Lopes LG, Pires RH (2021) Fungi in the indoor air of critical hospital areas: a review. Aerobiologia 37:379–394. https://doi.org/10.1007/s10453-021-09706-7

Brągoszewska E, Biedroń I, Kozielska B, Pastuszka JS (2018) Microbiological indoor air quality in an office building in Gliwice, Poland: analysis of the case study. Air Qual Atmos Health 11:729–740. https://doi.org/10.1007/s11869-018-0579-z

Caicedo L, Giusiano G, Alvarez M (2015) Estudio de la micota ambiental de tres edificios de laboratorios de la Universidad del Valle, Colombia, y su relación con los síntomas de alergias respiratorias que manifiestan trabajadores. Universidad Nacional del Nordeste, p 100

Camargo YC, DH M, Velez-Pereira A (2011) Emisiones atmosféricas de origen biológico, Santa Marta, Colombia

Caraballo L, Puerta L, Fernández-Caldas E, Lockey RF (1998) Sensibilización a los alérgenos de ácaros y al asma aguda en un ambiente tropical. Revista de Alergología en Investigación e Inmunología Clínica

CIOH CdIOeHdC- (2010) Clima Cartagena. CIOH, https://www.cioh.org.co/meteorologia/Climatologia/ResumenCartagena2.php

Dedesko S, Stephens B, Gilbert JA, Siegel JA (2015) Methods to assess human occupancy and occupant activity in hospital patient rooms. Build Environ 90:136–145. https://doi.org/10.1016/j.buildenv.2015.03.029

Douwes J, Thorne P, Pearce N, Heederik D (2003) Bioaerosol health effects and exposure assessment: progress and prospects. Ann Occup Hyg 47:187–200. https://doi.org/10.1093/annhyg/meg032

Douwes J, Eduard W, Thorne PS (2017) Bioaerosols. In: Quah SR (ed) International encyclopedia of public health, 2nd edn. Academic Press, Oxford, pp 210–218

Egbuta MA, Mwanza M, Babalola OO (2017) Health risks associated with exposure to filamentous fungi. Int J Environ Res Public Health 14:719. https://doi.org/10.3390/ijerph14070719

El-Morsy ELSM (2006) Preliminary survey of indoor and outdoor airborne microfungi at coastal buildings in Egypt. Aerobiologia 22:197–210. https://doi.org/10.1007/s10453-006-9032-0

Faridi S, Hassanvand MS, Naddafi K, Yunesian M, Nabizadeh R, Sowlat MH, Kashani H, Gholampour A, Niazi S, Zare A, Nazmara S, Alimohammadi M (2015) Indoor/outdoor relationships of bioaerosol concentrations in a retirement home and a school dormitory. Environ Sci Pollut Res Int 22:8190–8200. https://doi.org/10.1007/s11356-014-3944-y

Fayad RK, Al-Thani RF, Al-Naemi FA, Abu-Dieyeh MH (2021) Diversity, concentration and dynamics of culturable fungal bioaerosols at Doha, Qatar. Int J Environ Res Public Health 18:182. https://doi.org/10.3390/ijerph18010182

FCDS (2013) Análisis de conectividad de bosque seco tropical en cuatro ventanas del Caribe Colombiano. In: FCDS (ed). Fundación para la Conservación y el Desarollo Sostenible, p 71

Fröhlich-Nowoisky J, Kampf CJ, Weber B, Huffman JA, Pöhlker C, Andreae MO, Lang-Yona N, Burrows SM, Gunthe SS, Elbert W, Su H, Hoor P, Thines E, Hoffmann T, Després VR, Pöschl U (2016) Bioaerosols in the earth system: climate, health, and ecosystem interactions. Atmos Res 182:346–376. https://doi.org/10.1016/j.atmosres.2016.07.018

Georgiadou SP, Velegraki A, Arabatzis M, Neonakis I, Chatzipanagiotou S, Dalekos GN, Petinaki E (2014) Cluster of *Fusarium verticillioides* bloodstream infections among immunocompetent patients in an internal medicine department after reconstruction works in Larissa, Central Greece. J Hosp Infect 86:267–271. https://doi.org/10.1016/j.jhin.2014.01.011

Gilbert Y, Duchaine C (2009) Bioaerosols in industrial environments: a review. Can J Civ Eng 36:1873–1886. https://doi.org/10.1139/L09-117

Gołofit-Szymczak M, Górny RL (2018) Microbiological air quality in office buildings equipped with dventilation systems. Indoor Air 28:792–805. https://doi.org/10.1111/ina.12495

Heo KJ, Kim HB, Lee BU (2014) Concentration of environmental fungal and bacterial bioaerosols during the monsoon season. J Aerosol Sci 77:31–37. https://doi.org/10.1016/j.jaerosci.2014.07.001

Hosseini N, Hajizadeh Y, Nikaeen M, Hatamzadeh M (2021) Spatiotemporal variation of ambient bioaerosols in a large and industrialized metropolis of Iran and their association with PM2.5 and meteorological factors. Aerobiologia 37:105–117. https://doi.org/10.1007/s10453-020-09672-6

Huang CY, Lee CC, Li F-C, Ma YP, Su H-J (2002) The seasonal distribution of bioaerosols in municipal landfill sites: a 3-yr study. Atmos Environ 36:4385–4395. https://doi.org/10.1016/S1352-2310(02)00322-9

Huertas M, Acevedo-Barrios R, Rodríguez M, Gaviria J, Arana R, Arciniegas C (2018) Identification and quantification of bioaerosols in at tropical coastal region: Cartagena de Indias Colombia. Aerosol Sci Eng 2(4):206–215. https://doi.org/10.1007/s41810-018-0037-1

Humbal C, Gautam S, Trivedi U (2018) A review on recent progress in observations, and health effects of bioaerosols. Environ Int 118:189–193. https://doi.org/10.1016/j.envint.2018.05.053

Hurtado L, Rodríguez G, López J, Castillo JE, Molina L, Zavala M, Quintana PJE (2014) Characterization of atmospheric bioaerosols at 9 sites in Tijuana, Mexico. Atmos Environ 96:430–436. https://doi.org/10.1016/j.atmosenv.2014.07.018

Jianhua Q, Zhong X, Shao Q, Gao D, Wu L, Huang L, Ye Y (2015) Microbial activity levels in atmospheric bioaerosols in Qingdao. Aerobiologia 31(3):353–365. https://doi.org/10.13227/j.hjkx.201605074

Jo WK, Seo YJ (2005) Indoor and outdoor bioaerosol levels at recreation facilities, elementary schools, and homes. Chemosphere 61(11):1570–1579. https://doi.org/10.1016/j.chemosphere.2005.04.103

Jones AM, Harrison RM (2004) The effects of meteorological factors on atmospheric bioaerosol concentrations—a review. Sci Total Environ 326:151–180. https://doi.org/10.1016/j.scitotenv.2003.11.021

Kim K-H, Kabir E, Jahan SA (2018) Airborne bioaerosols and their impact on human health. J Environ Sci 67:23–35. https://doi.org/10.1016/j.jes.2017.08.027

Koneman E (2008) Microbiological diagnosis: text and color atlas. Editorial Médica Panamericana, Buenos Aires, Argentina

Kummer V, Thiel WR (2008) Bioaerosols—sources and control measures. Int J Hyg Environ Health 211:299–307. https://doi.org/10.1016/j.ijheh.2007.06.006

Lee SC, Chang M (2000) Indoor and outdoor air quality investigation at schools in Hong Kong. Chemosphere 41:109–113. https://doi.org/10.1016/s0045-6535(99)00396-3

Li M, Qi J, Zhang H, Huang S, Li L, Gao D (2011) Concentration and size distribution of bioaerosols in an outdoor environment in the Qingdao coastal region. Sci Total Environ 409:3812–3819. https://doi.org/10.1016/j.scitotenv.2011.06.001

Liu T, Chen LW, Zhang M, Watson JG, Chow JC, Cao J, Chen H, Wang W, Zhang C, Liu H, Zheng J, Chen N, Yao R, Xiao W (2019) Bioaerosol concentrations and size distributions during the autumn and winter seasons in an industrial city of central China. Aerosol Air Qual Res 19:1095–1104. https://doi.org/10.4209/aaqr.2018.11.0422

Madhwal S, Prabhu V, Sundriyal S, Shridhar V (2020) Distribution, characterization and health risk assessment of size fractionated bioaerosols at an open landfill site in Dehradun, India. Atmos Pollut Res 11:156–169. https://doi.org/10.1016/j.apr.2019.10.002

Medina J, De la Hoz S (2018) Evaluación del comportamiento de bioaerosoles bacterianos en la unidad de cuidados intensivos neonatal (UCIN), de una institución de salud de alta complejidad en la ciudad de Barranquilla, Atlántico. Departamento de Civil y Ambiental. Universidad de la Costa, Barranquilla, Colombia, p 114

Morgado W (2017) Evaluación de bioaerosoles fungí asociados a un relleno sanitario ubicado en el municipio de Tubara, departamento del Atlántico. Facultad de Ciencias Contables Económicas y Administrativas. Universidad de Manizales, Manizales, Colombia, p 78

Morin-Sardin S, Nodet P, Coton E, Jany JL (2017) *Mucor*: a Janus-faced fungal genus with human health impact and industrial applications. Fungal Biol Rev 31:12–32. https://doi.org/10.1016/j.fbr.2016.11.002

Mousavi MS, Hadei M, Majlesi M, Hopke PK, Yarahmadi M, Emam B, Kermani M, Shahsavani A (2019) Investigating the effect of several factors on concentrations of bioaerosols in a well-ventilated hospital environment. Environ Monit Assess 191:407. https://doi.org/10.1007/s10661-019-7559-0

Nageen Y, Asemoloye MD, Põlme S, Wang X, Xu S, Ramteke PW, Pecoraro L (2021) Analysis of culturable airborne fungi in outdoor environments in Tianjin, China. BMC Microbiol 21:134–134. https://doi.org/10.1186/s12866-021-02205-2

Navale V, Vamkudoth KR, Ajmera S, Dhuri V (2021) *Aspergillus* derived mycotoxins in food and the environment: prevalence, detection, and toxicity. Toxicol Rep 8:1008–1030. https://doi.org/10.1016/j.toxrep.2021.04.013

Nazaroff WW (2016) Teaching indoor environmental quality. Indoor Air 26:515–516. https://doi.org/10.1111/ina.12309

Niazi S, Hassanvand MS, Mahvi AH, Nabizadeh R, Alimohammadi M, Nabavi S, Faridi S, Dehghani A, Hoseini M, Moradi-Joo M, Mokamel A, Kashani H, Yarali N, Yunesian M (2015) Assessment of bioaerosol contamination (bacteria and fungi) in the largest urban wastewater treatment plant in the Middle East. Environ Sci Pollut Res 22:16014–16021. https://doi.org/10.1007/s11356-015-4793-z

Oliveira M, Ribeiro H, Delgado JL, Abreu I (2009) Aeromycological profile of indoor and outdoor environments. J Environ Monit 11:1360–1367. https://doi.org/10.1039/B820736D

Pashley CH, Fairs A, Free RC, Wardlaw AJ (2012) DNA analysis of outdoor air reveals a high degree of fungal diversity, temporal variability, and genera not seen by spore morphology. Fungal Biol 116:214–224. https://doi.org/10.1016/j.funbio.2011.11.004

Rodriguez-Gomez C, Ramirez-Romero C, Cordoba F, Raga GB, Salinas E, Martinez L, Rosas I, Quintana ET, Maldonado LA, Rosas D, Amador T, Alvarez H, Ladino LA (2020) Characterization

of culturable airborne microorganisms in the Yucatan Peninsula. Atmos Environ 223:117183. https://doi.org/10.1016/j.atmosenv.2019.117183

Ruíz-Fonseca C, Rubiano-Labrador C (2021) Perfil de bacterias y hongos aerotransportados por la lluvia horizontal de la región del Salto del Tequendama (Colombia). Gestión y Ambiente 24:1–15. https://doi.org/10.15446/ga.v24n1.92479

Ruiz-Gil T, Acuña JJ, Fujiyoshi S, Tanaka D, Noda J, Maruyama F, Jorquera MA (2020) Airborne bacterial communities of outdoor environments and their associated influencing factors. Environ Int 145:106156. https://doi.org/10.1016/j.envint.2020.106156

Ruzer LS, Harley NH (2004) Aerosols handbook: measurement, dosimetry, and health effects. CRC Press

Shelton BG, Kirkland KH, Flanders WD, Morris GK (2002) Profiles of airborne fungi in buildings and outdoor environments in the United States. Appl Environ Microbiol 68:1743–1753. https://doi.org/10.1128/AEM.68.4.1743-1753.2002

Shin S-K, Kim J, Ha S-m, Oh H-S, Chun J, Sohn J, Yi H (2015) Metagenomic insights into the bioaerosols in the indoor and outdoor environments of childcare facilities. PLoS ONE 10:e0126960. https://doi.org/10.1371/journal.pone.0126960

Spicer R, Gangloff H (2005) Establishing site specific reference levels for fungi in outdoor air for building evaluation. J Occup Environ Hyg 2:257–266. https://doi.org/10.1080/15459620590946401

Suarez P, Rivera K, Barragan R, Blanco L, Rodríguez G, Parra C (2017) Riesgo por bioaerosoles en la sala de urgencias de un hospital privado de Bogotá. In: Valle Ud (ed) VI Congreso Colombiano y Conferencia Internacional CASAP, Cali, Colombia, p 384

Tolabi Z, Alimohammadi M, Hassanvand MS, Nabizadeh R, Soleimani H, Zarei A (2019) The investigation of type and concentration of bio-aerosols in the air of surgical rooms: a case study in Shariati hospital, Karaj. MethodsX 6:641–650. https://doi.org/10.1016/j.mex.2019.03.016

Ulloa-Delgado G (2016) Aspectos ecológicos del bosque seco tropical en el Caribe colombiano. In: Natural TICFP (ed) Tropenbos Internacional Colombia & Fondo Patrimonio Natural, Bogotá, Colombia

Valsan AE, Priyamvada H, Ravikrishna R, Després VR, Biju CV, Sahu LK, Kumar A, Verma RS, Philip L, Gunthe SS (2015) Morphological characteristics of bioaerosols from contrasting locations in southern tropical India—a case study. Atmos Environ 122:321–331. https://doi.org/10.1016/j.atmosenv.2015.09.071

Velez-Pereira A (2017) Modelación espacio-temporal de polen y esporas de hongos aerovagantes de Catalunya (1994–2015). Tesis de Maestría. Universitat Autònoma de Barcelonaz

Velez-Pereira A, Caicedo Y (2014) Análisis de los factores ambientales y ocupacionales en la concentración de aerobacterias en unidades de cuidado intensivo del hospital universitario Fernando Troconis, 2009 Santa Marta, Colombia. Cuidarte 5:595. https://doi.org/10.15649/cuidarte.v5i1.108

Velez-Pereira A, Camargo YC (2011) Evaluacion de la concentracion de bioaerosoles fungí asociados al relleno aanitario Palangana, Santa Marta-Colombia. In: Norte Ud (ed) I Simposio Iberoamericano de Ingeniería de Residuos, Santa Marta, Colombia

Vos P, Garrity G, Jones D, Krieg NR, Ludwig W, Rainey FA (2009) Bergey's manual of systematic bacteriology. Springer, New York

Woudenberg JHC, Groenewald JZ, Binder M, Crous PW (2013) *Alternaria* redefined. Stud Mycol 75:171–212. https://doi.org/10.3114/sim0015

Yen Y-C, Yang C-Y, Wang T-N, Yen P-C, Ho C-K, Mena KD, Lee T-C, Chen K-S, Lin Y-C, Chen P-S (2020) Household airborne endotoxin associated with asthma and allergy in elementary school-age children: a case–control study in Kaohsiung Taiwan. Environ Sci Pollut Res 27:19502–19509. https://doi.org/10.1007/s11356-020-07899-x

Yu H, Mui K, Wong L (2018) Numerical simulation of bioaerosol particle exposure assessment in office environment from MVAC systems. J Comput Multiph Flows 10:59–71. https://doi.org/10.1177/1757482X17746919

Zhong X, Qi J, Li H, Dong L, Gao D (2016) Seasonal distribution of microbial activity in bioaerosols in the outdoor environment of the Qingdao coastal region. Atmos Environ 140:506–513. https://doi.org/10.1016/j.atmosenv.2016.06.034