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Indoor microbial air quality in Prince Mohammad Ali's museum, Giza, Egypt: A preliminary study

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ABSTRACT

The present study aims to determine the prevalence of bio–pollutants in the air at different locations inside Prince Mohammad Ali's museum, in relation to microenvironmental conditions, location characteristics, ventilation type, and human activity. Samples of Airborne bacteria, fungi and actinomycetes were collected using Andersen 2 stages sampler and particles were separated into fine (<2.5 µm) and coarse (>7µm) size ranges. Annually indoor concentrations of bacteria, fungi and actinomycetes ranged from 694–7787 CFU/m^3, 47–1985 CFU/m^3 and 0–294 CFU/m^3, respectively. Seasonally, the highest concentrations of bacteria, fungi and actinomycetes were found in spring, winter and autumn seasons, respectively. Indoor microbial fine fraction (< 2.5 µm) constituted ~ 69–76.5%, 71.5–92% and 65.6–95% for airborne bacteria, fungi and actinomycetes, respectively. Indoor/ outdoor ratios (I/O) exceeded 1 in the reception hall for bacteria, in the residence hall for fungi and in both of the reception hall and restoration laboratory for actinomycetes. The Indoor Global Index of Microbial Contamination (GIMC–CFU/m^3) exceeded the limit value of 1000 CFU/m^3 in the all sites inside the museum. Naturally ventilated locations had the worst indoor microbial quality. Temperature detrimentally affected microbial culturability, and relative humidity comparatively supported their culturability, without clear correlation pattern.

***Keywords*: B**ioaerosols, microbial index, microbial size, microclimatic factors, ventilation.

INTRODUCTION

Museums are important places to preserve, present and interpret objects and materials of cultural, religious and historical importance (Fromm, 2016). Museums are an important part in our experience of learning about cultural heritage, and contribute to the evolution and growth of our communities (Rossler, 2017). Archaeological and artistic artifacts are subject to damage and biodeterioration (Nuntiis and Palla, 2017; Avdanina and Zhgun, 2024). Physical, chemical, and biological agents lead to damage and loss of cultural heritage objects (Borrego and Perdomo, 2012; Gomoiu *et al*., 2022). Particulate matter, microorganisms and environmental conditions may cause potential risks to museum collections (Lazaridis *et al*., 2015; Meng *et al*., 2023; Zhgun, 2023).

Microorganism cause problems in the conservation of cultural heritage (Nevalainen *et al*., 2015; Avdanina and Zhgun, 2024) and many important diseases (Nazaroff, 2016; Chawla *et al*., 2023). The composition and nature of the material itself, micro –climate, quality of environment, housekeeping and hygiene determine

biodeterioration phenomena of cultural heritage materials (Sterflinger and Piñar, 2013; Avdanina and Zhgun, 2024). Bioaerosols/ air microorganisms induce biodeterioration of objects in museums and libraries (Tao *et al*., 2014; Osman *et al*., 2017; Saridaki *et al*., 2022). Microorganisms may cause serious damage to artifacts, resulting in material loss, due to acid corrosion, production of staining compounds, enzymatic degradation and mechanical stress (Abdulla *et al*., 2008; Pinzari *et al*., 2010; López-Miras *et al*., 2013; Sterflinger and Piñar, 2013; Sapkota, 2023).

The mechanism of deterioration depends on the structure of the materials on which microbes have been grown, while chemical composition of the material determines the microbial genera (Szczepanowska and Cavaliere, 2003; Saridaki *et al*., 2023). The survival and growth of microorganisms on the air and surfaces depend on microbial metabolic characteristics, ecology of the surface and microclimatic conditions. Sufficient quantity of nutrient, sufficient water activity of the substrate, appropriate surface pH, human activities and outdoor air contribute a wide range of airborne microorganisms indoors (Lazardis *et al*., 2015; Nuntiis and Palla, 2017; Saridaki *et al*., 2023).

The Prince Mohamed Ali's museum is one of the highly recommended attraction museums in Cairo. It is amazing by beauty of many wonderful works of art. It locates in district area characterized by high traffic density and many of human activities that may negatively effect on the museum's contents. Monitoring of bio-pollution is essential to study the museum environmental quality to design of effective engineering control in order to protect culture heritage. The present study aims to determine the prevalence of microorganisms in the air inside the Prince Mohammad Ali's museum in relation to microclimatic conditions, location and ventilation type.

MATERIALS AND METHODS

1. Description of sampling sites

The sampling was performed inside and outside of Al Manial/prince Mohamed Ali's museum. The sampling was carried-out at different indoor sites, differing in size, design and location, with no history of water damage. The museum is located in Al Manial district on the island of El Rawda El Nilia, Cairo (Fig. 1). This district is characterized by high traffic density, different human activities, parking and located nearby the Cairo University. The museum is characterized by its architectural of the Maghreb and surrounded by a permanent vegetation garden ~34000 m, includes rare trees and plants.

The museum consists of a number of Islamic arts, decoration and includes rare works of art. The museum includes reception hall, clock hall, mosque, hunting museum, Thorne hall, residence hall and golden hall. In the present study indoor sampling was only performed at depository, reception hall, residence hall, Thorne hall, hunting museum and restoration laboratory, due to instructions for accessibility and security regulations. Table (1) shows description of each of sampling location at the museum.

Indoor microbial air quality in Prince Mohammad Ali's museum, Giza, Egypt: A preliminary study

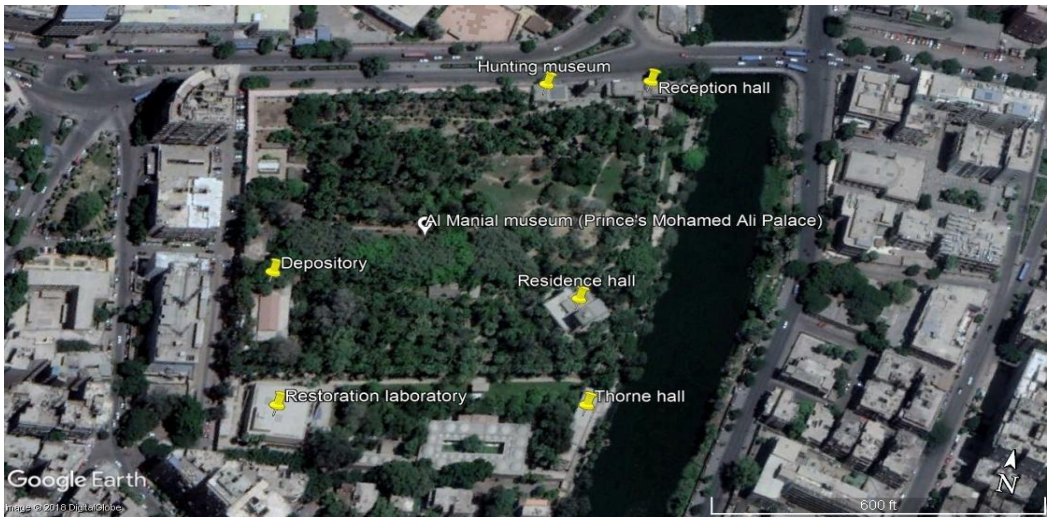

Fig. 1. Google Earth Image of Prince Mohammad Ali's Museum and the surrounding area.

Table 1. Description of sampling locations.

Site	Description	Ventilation type	Location
Reception hall	It consists of 2– floors, the upper floor comprising of 2 halls, one was designed in Shami style, and the other in Moroccan style. Its purpose was to receive official guests and contains rare antiques including carpets and Arabian furniture and tables.	Natural	Locates next to heavy traffic road
Residence hall	It was dedicated to residence of the prince, it consists of 2–floors; the ground floor was allocated to the reception and dining rooms and prince's library; however, the top floor was allocated to bed rooms.	Natural	Locates in the middle of the garden
Thorne hall	It consists of 2 floors the ground floor known as "trusteeship" and the 2nd floor includes Aubusson, and chairs coated with velvet and pictures.	Mechanical and natural	In the garden, next to river Nile
Hunting Museum	It locates along corridor next to the north wall in the vicinity of the reception hall. It was added to the museum in 1963, it displays ~1180 pieces of stuffed animals, birds, butterflies and skeletons.	Mechanical and natural	Locates next to heavy traffic area
Restoration Laboratory	Restoration laboratory is used for conservation and restoration of the collections of the museum.	Mechanical and natural	Locates at south wall, faraway from heavy traffic road
Depository	It contains a number of storage units equipped to store the artifacts.	Mechanical	Locates at the west wall, in the middle of the museum garden

2. Sampling strategy

The samples were taken during the working hours and normal human activities, between 9 AM and 2 PM, during December 2016 to June 2018, 2–3 times/ month. The samples were collected at fixed positions, at a height of ~ 1.5 m above the floor level at the center of the location/building. The comparison site (outside) sampling was collected ~5 m height on the hunting museum in order to determine background level of airborne microorganism.

Airborne environmental bacteria, fungi and actinomycetes were collected

using Andersen two–stage viable cascade impactor sampler (TE–10–160, Tisch Environmental Cleves, OH, USA). It separates particles into fine (< 2.5 µm) and coarse (>7 µm) size ranges. The sampler was operated at flow rate of 28.3 *L*/min for 5–10 min.

Trypticase soya agar supplemented with cycloheximide, malt extract agar and starch casein agar media (Hi–media laboratories, Mumbai, India) were used to collect bacteria, fungi and actinomycetes, respectively (Mouli *et al*., 2005; Sarica *et al*., 2005). Two consecutive samples were taken during each sampling event (4 plates/parameter/ location), because of short time of sampling. Short sampling time is a common problem as the representativeness of sampling decreases and variability between side by side increases (Godish and Godish, 2007).

Bacterial plates were incubated at 28^{o}C for 48 hrs. whileas, fungal and actinomycete plates were incubated at 28^{o}C for 5–7 days and 7–14 days, respectively. Positive–hole correction (Andersen, 1958) was applied to the raw colony forming unit (CFU) recorded on each plate, and by using the CFU with sampling time and flow rate, microbial concentrations were calculated as colony forming unit per cubic meter of the air (CFU/m^3).

3. Microclimatic conditions

Temperature and relative humidity were measured using a portable weather instrument (SATO, PC– 5000 TRH–II sampler) at the time of sampling. Temperature records ranged between 11–29 ^{o}C indoors and 14–34 ^{o}C outdoor. Relative humidity ranged within 24–64% indoors and 32–52% outdoor.

Relative humidity records were slightly higher in the depository, while temperature in the residence hall. No significant differences (P>0.05) were found between recorded temperature and relative humidity measurements. The Q3 (75th percentile) value showed that 25% of the relative humidity measurements exceeded 58% in the depository and 55% in the reception hall, Thorne hall and hunting museum that may trigger microbial growth and chemical reactions. Microclimate conditions indoor and outdoor are closely similar, indicating not–well controlling measures.

4. Statistical analysis

Spearman's rank correlation test was used to determine relationships between airborne microbial concentrations with microclimatic conditions. A probability of less or equal to P≤ 0.05 was considered significant.

RESULTS AND DISCUSSION

1. Overall microbial concentrations

It was obvious from Figure (2) that the monthly concentrations of airborne microorganisms ranging within 694–7787 CFU/m^3 for bacteria, 47–1985 CFU/m^3 for fungi and 0–294 CFU/m^3 for actinomycetes, indoors. Also, the highest indoor bacterial (7787 CFU/m^3) and actinomycetes (294 CFU/m^3) concentrations were found in November and fungal concentrations (1985 CFU/m^3) were found in October. However, the highest outdoor bacterial (4919.3 CFU/m^3), fungal (635 CFU/m^3) and actinomycetes (136.7 CFU/m^3) concentrations were found in April, December and November, respectively.

In the present study, the highest bacterial and actinomycetes concentrations were found in the reception hall, because the reception hall is located nearby a busy cross road and naturally ventilated that helps infiltration of outdoor contaminants. However, the highest fungal concentration was found in the residence hall (Fig.3), because fungi are mainly related to biotic

sources (residence hall is surrounded by a big plant garden).

Intensity and activity of people, and stirring dust are important factors affect indoor microorganisms (Chen and Hildemann, 2009; Saridaki *et al*., 2023). Bacteria are mainly correlated to human activities while fungi to biotic sources (Bowers *et al*., 2012; Lenart-Boron *et al*., 2016; Saridaki *et al*., 2023). Airborne bacteria were found in the highest concentrations in naturally ventilated buildings located in the vicinity of heavy traffic roads and fungi in buildings located nearby a big plant garden (Abdel Hammed *et al*., 2018). Moreover, human activities are also import sources for fungi; shedding particulate matter from clothes and suspending settled dust (Nazaroff, 2016).

The results in the present study agree and disagree with other studies worldwide. Airborne fungi in different caves ranged from 0–1519 CFU/m^3 in China (Wang *et al*., 2010) and 10^2– 10^4 CFU/m^3 at different museums in Poland (Skóra *et al*., 2015). The highest concentrations of airborne mesophilic bacteria, actinomycetes and fungi reached 860 CFU/m^3, 60 CFU/m^3 and 1,290 CFU/m^3, respectively in Jagiellonian University Museum in Kraków, Poland (Lenart-Boroń *et al*., 2016). Airborne bacteria, actinomycetes and fungi averaged 487 CFU/m^3, 65 CFU/m^3 and 90 CFU/m^3, respectively in church of Saint Katherine Monastery, Egypt (Abdulla *et al*., 2008). These variations are attributed to microbial concentrations affected by ambient air, meteorological conditions, geographic location, every day activity, type of activity, hygienic rules and ventilation (Wamedo *et al*., 2012; Saeed, 2017).

Although, there are no international standards to determine whether an indoor environment is contaminated or not, it has been suggested that environment with a microbial prevalence ≥ 1000 CFU/ m^3 should be considered contaminated (Wonder Makers Environmental, Inc., 2001; Eagle Industrial Hygiene Associates, 2004). Airborne microbial concentration should not exceed 750 CFU/m^3 (Radler de Aquino and de Góes, 2000), and 300 CFU/ m^3 should be the lower limit for fungi (Kolwzan *et al*., 2006). Parchas (2008) suggested that, fungal concentration should not exceed 100–120 CFU/m^3 or the collection should be subjected to disinfection. The Italian Ministry of cultural heritage proposed the following threshold limit values: ≤ 750 CFU/m^3 for heterotrophic bacteria and ≤ 150 CFU/m^3 for fungi (MIBAC, 1998). In the present study bacterial and fungal mean concentrations did not exceed the Polish proposals for threshold limit values 5 x10^3 CFU/m^3 for both bacteria and fungi, and 200 CFU/m^3 for actinomycetes (Górny and Dutkiewicz, 2002).

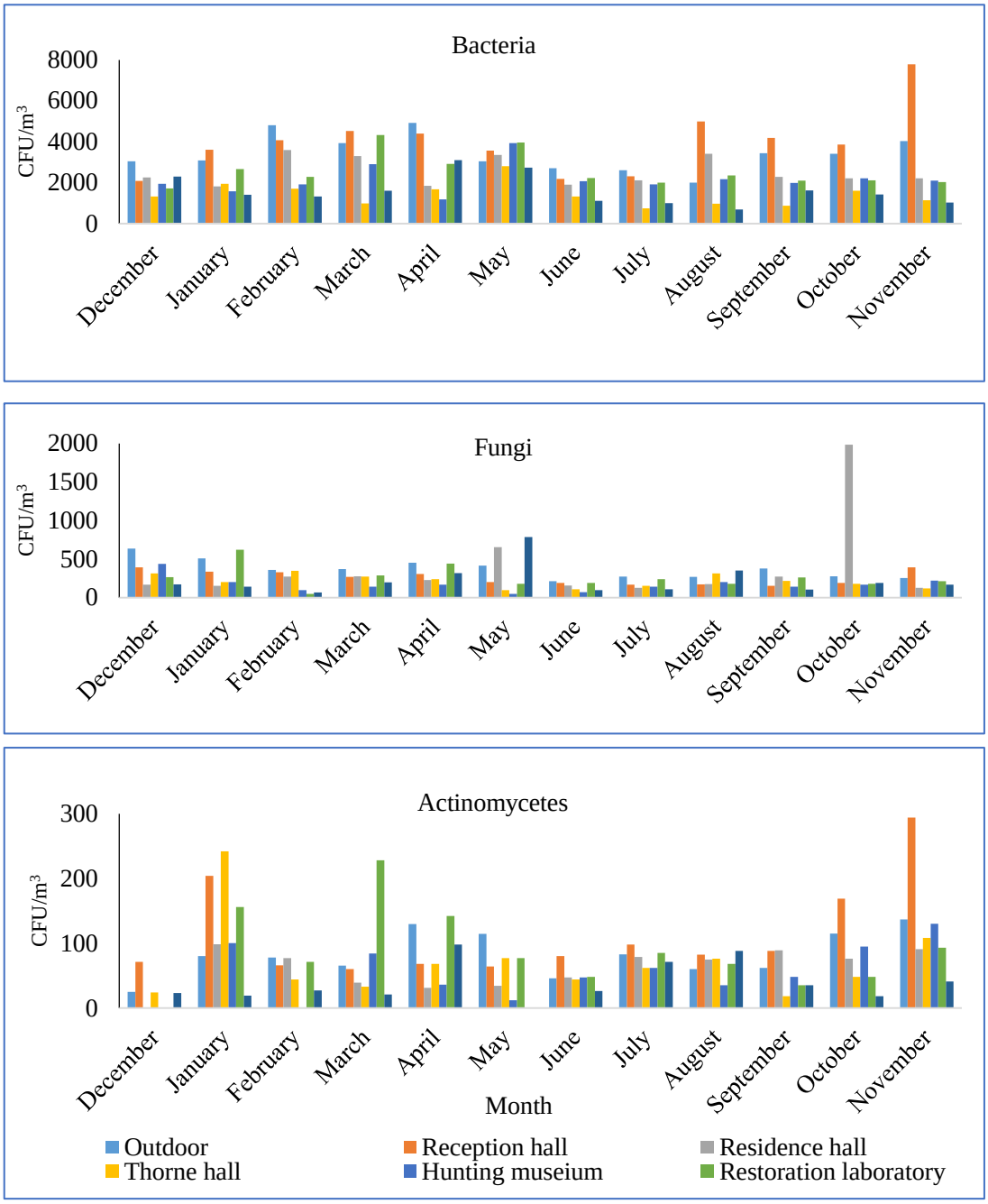

Fig. 2. Monthly variations of airborne microorganisms at Prince Mohammad Ali's museum.

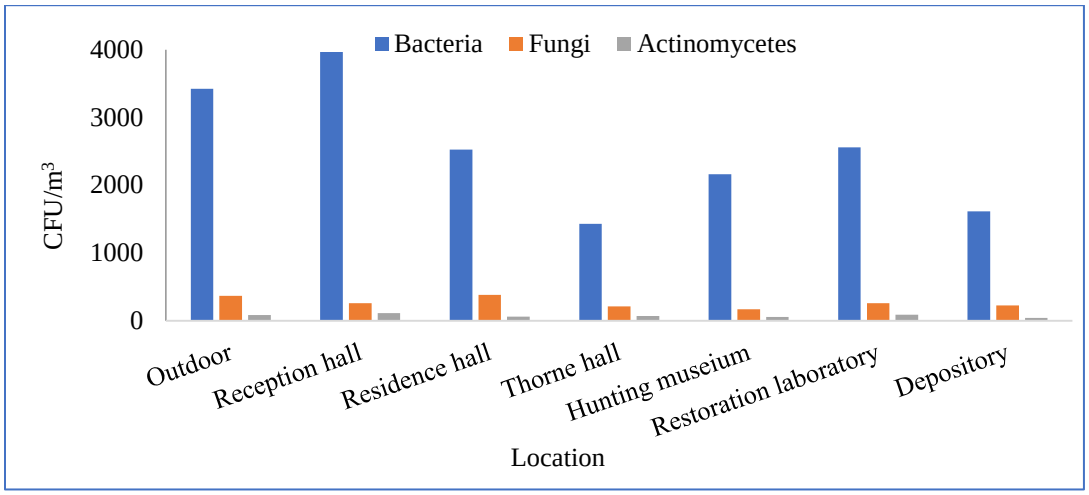

Fig. 3. The annual mean concentrations of airborne microorganisms at Prince Mohammad Ali's museum.

2. Seasonal microbial concentrations

Seasonal concentrations of airborne bacteria, fungi and actinomycetes ranged within 936–5280 CFU/m^3, 118.3–794 CFU/m^3, 23–183.6 CFU/m^3 indoors and 2445–3968.8 CFU/m^3, 251.96–500.3 CFU/m^3, 61–104.6 CFU/m^3 outdoor, respectively (Fig. 4). High microbial concentrations were found in spring, winter and autumn seasons. Spring and autumn seasons have suitable air temperature and moisture that helps microbial growth and survival. In Egypt, spring and autumn are characterized by unstable meteorological conditions and consequently high suspended particulate load. Bacteria and actinomycetes are mainly associated suspended particulate matter (Alghamdi *et al*., 2014). The highest degree of airborne actinomycetes pollution was detected in location characterized with high amounts of suspended dust, because they are a group of soil bacteria and commonly found in fodder, soil and agricultural areas (Abdel Hameed, 2007). Actinomycetes are important bio-contaminant indoors (Abdel Hameed and El Gendy, 2014), and their presence has been suggested as indicator of moisture damage (Nevalainen *et al*., 1991), and bio-contamination (ACGIH, 1989).

However, airborne fungi were found in the highest concentrations in the winter season due to high fungal biodiversity during wet months and the presence of the threshold limit of rain that is important for liberation and dissemination of fungal spores into the atmosphere. Moreover, rainfall facilitates the release and dispersion of dry spore mass (Das and Gupta-Bhattacharya, 2008).

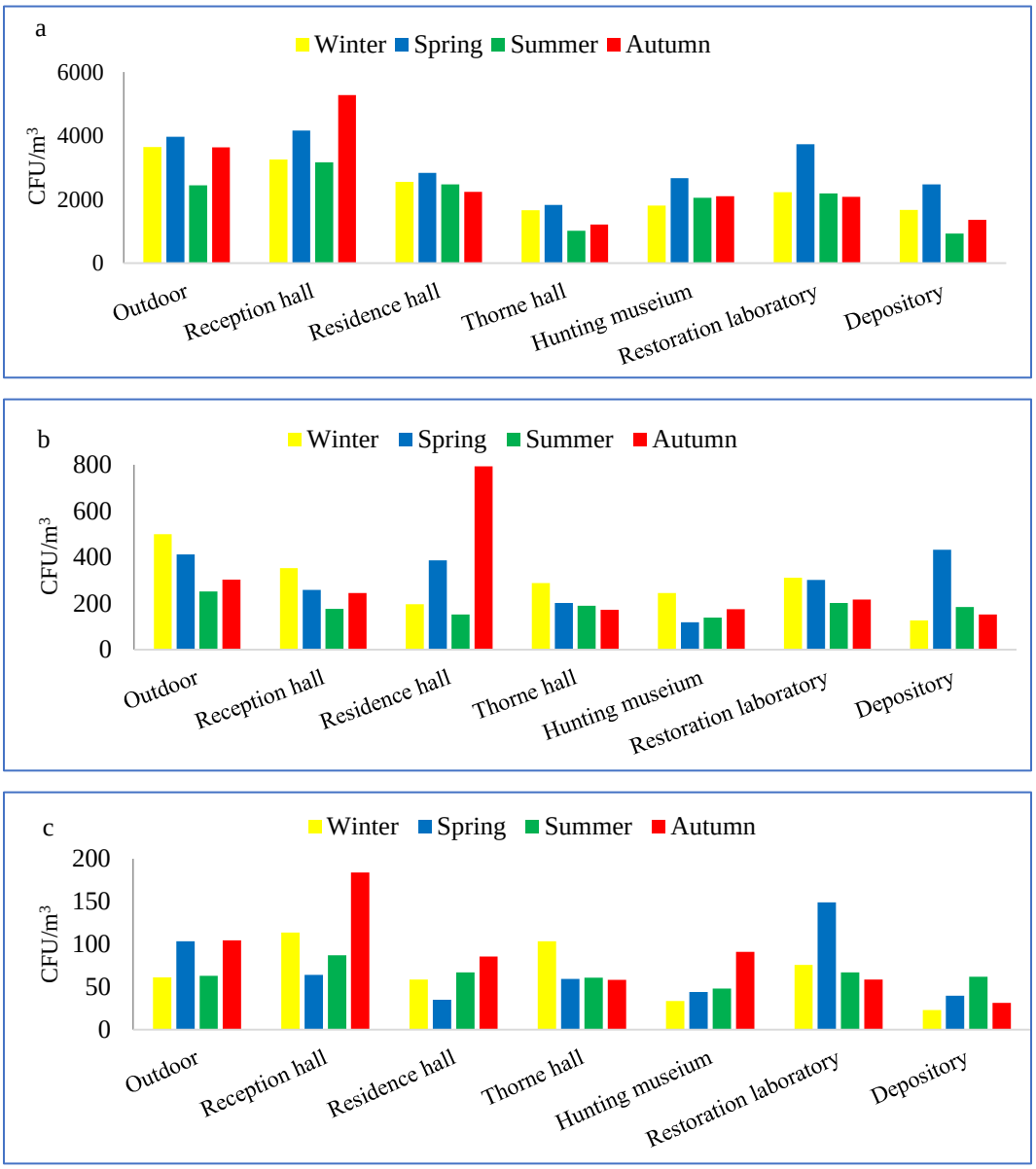

Fig. 4. Seasonal concentrations of airborne microorganisms at Prince Mohammad Ali's museum. a: bacteria; b: fungi; c: actinomycetes.

3. Microbial size fraction

Particle size affects transmission and deposition of microorganisms the air and human respiratory system (Sadyś *et al.*, 2016). Fine particle size remains airborne longer period of time, influencing on their physical and biological structures. Particle size affects some of indoor dynamics process and particle size differs greatly from place to place (Saeed, 2017).

In the current study, microbial fine fraction constituted the majority, ranging between 52–95% (Fig. 5). The highest percentages were found in the Thorne hall for bacteria (76.5%) and fungi (92.2%), and in hunting museum for actinomycetes (94.9%). Microbial

fine fraction was always higher indoor than outdoor, except in the residence hall for fungi (71.5%) and in the reception hall for actinomycetes (65.6%). This may be attributed to differences of microbial composition at each location. *Alternaria*, *Drechslera* and *Emericella* were found in higher concentrations in the residence hall than outdoor. The residence hall contains many of cellulatic material (e.g.; woods, books, paper and textile) which encourage the growth of different cellulatic fungi like: *Alternaria*, *Drechslera* and *Emericella*. Wang *et al*. (2010) found the highest concentrations of airborne fungi in size range of 2–3 µm in different caves of the MogaoGrottoes, Dunhuang, China. Fine fraction of fungi constituted the majority of size ranges ~ 82.54–94.15% indoors the Egyptian libraries (Osman *et al*., 2017). Fine fraction of fungi was high, because fungal spores are individually found in the environment and their sizes ranged between 2–8 µm in diameters. *Aspergillus*, *Penicillium* and *Cladosporium*, the common fungal spores have aerodynamic diameters ≤ 8µm (Skóra *et al*., 2015). Generally, actinomycetes have particle sizes ~1 µm, however, fine fraction of actinomycetes was found in lower percentage in the reception hall (65.6%). This may be attributed to their association with other sources. Traffic density, resuspension of settled dust, and human occupancy and activities are major factors influence indoor microbiology (Abdel Hameed and El Gendy, 2014).

The relationships between outdoor bioaerosol concentrations and the source of indoor bioaerosols can vary with particle size (Nazaroff, 2016). Bacteria are mainly related to anthropogenic activities and attached to larger particles (Schulz *et al*., 2011) and larger particles are mainly of local origin (Lighthart and Stetzenback, 1994). Generally, large particles may deposit due to gravitational forces and fine particles may deposit due to Brownian motion, contributing an important step in the process of microbial colonization of surfaces and works of art.

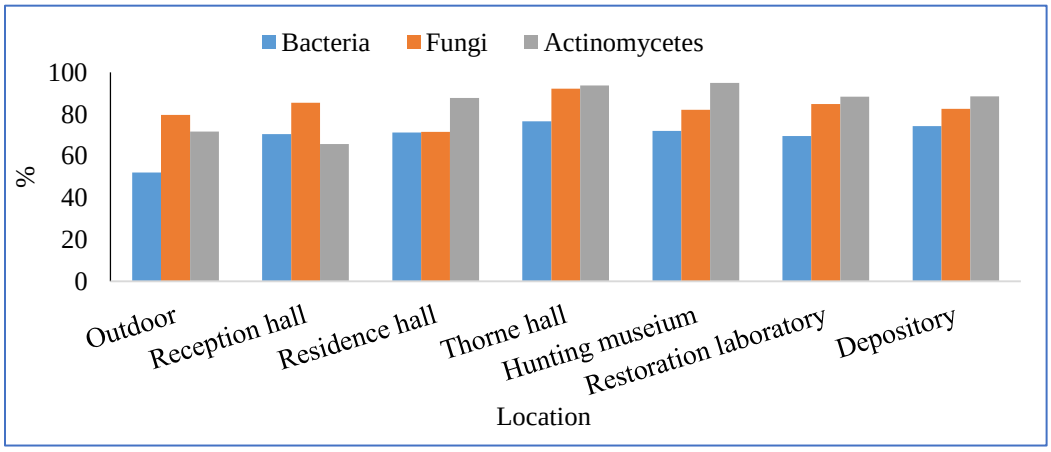

Fig. 5. The percentages of fine fraction of airborne microorganisms at the different museum locations.

4. Indoor/outdoor ratio of airborne microorganisms

Indoor/ outdoor (I/O) ratio, a relative standard, was used to document the presence or absence of indoor biologically derived contamination and differences between sampling sites as well (ACGIH, 1999). I/O ratio ranged within 1.5–2 indicates indoor environment of regular condition, and I/O ratio was >2 indicates absence of proper indoor environmental conditions (Ross *et al*., 2004). Generally outdoor environment is the main contributor of indoor air microorganisms, and people represent an it is important indoor bacterial source.

In this study, I/O ratios were >1 in the reception hall (1.2) for bacteria, in the residence hall (1.04) for fungi and in the reception hall (1.33) and restoration laboratory (1.06) for actinomycetes, (Fig. 6). The elevated indoor concentrations of bacteria and fungi indicated that the built environmental conditions are suitable for microbial growth (high humidity, bad ventilation, overcrowding and bad hygienic rules) and the presence of indoor microbial sources.

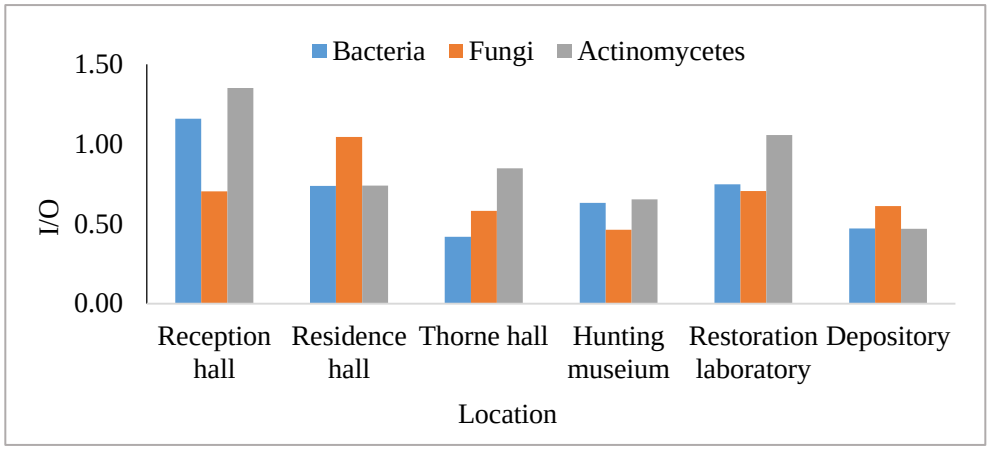

Fig. 6. I/O ratios of airborne microorganisms at the different museum locations.

5. Microbial–contamination indices

Indoor microbial contamination was determined on the basis of the total culturable counts of bacteria, fungi and actinomycetes using the following indices: Global Index of Microbial Contamination per cubic meter of air (GIMC–CFU/m^3) and Amplification Index (AI). GIMC–CFU/m^3 was calculated as the sum of the values of the total microbial counts determined for bacteria, fungi and actinomycetes in all sampling locations. AI was determined by calculating the ratio between GIMC–CFU/m^3 values measured inside each location and outside the museum.

The GIMC–CFU/m^3 values ranged from 960–8474 CFU/m^3 and 2341.6–5499.8 CFU/m^3 indoors and outdoors, respectively (Table 2). The greatest mean indoor GIMC–CFU/m^3 value was found inside the reception hall (4338.68 CFU/m^3) and the lowest in the Thorne hall (1713.78 CFU/m^3), (Fig.7).

The degree of biocontamination profile according to GIMC–CFU/m^3 values was: reception hall> outdoor>residence hall> restoration laboratory> hunting museum> depository>Thorne hall. Naturally

ventilated locations (reception hall, residence hall and restoration laboratory) had higher global index of microbial contamination than mechanically ventilated locations (hunting museum, depository and Thorne hall), (Table 1). Ventilation type can modify characteristics of indoor air. The natural ventilation increases infiltration of outdoor microorganisms and mechanical ventilation reduces infiltration of outdoor microorganisms (Borrego *et al*., 2010). The results in the present study were higher than the guidance value of GIMC–CFU/m^3 in non–industrial environments 1000 CFU/m^3 indicating a non-adequate indoor environment quality (Dacarro *et al*., 2000).

Amplification index (AI) values ranged between 0.25–2.24 (Table 2), with the greatest mean values achieved at the reception hall (1.15) indicating the presence of indoor microbial sources. The variability of microbial composition within the museum sites indicates that each site has its own ecology equilibrium, depending on location, structure, furniture, type of works of art and number of visitors (Pasquarella *et al*., 2015; Avdanina and Zhgun, 2024).

Table 2. Microbial air contamination indices.

Location	GIMC–CFU/m^3		AI	
	Range	Mean± SD	Range	Mean± SD
Outdoor	2341.6–5499.8	3874.1±916.17	–	–
Reception hall	2453–8474	4338.7±1612.31	0.69–2.24	1.15±0.46
Residence hall	2065.6–4274	2971.2±861.13	0.38–1.57	0.81±0.32
Thorne hall	960–2977.7	1713.8±579.80	0.29–0.83	0.46±0.17
Hunting museum	1384–3992	2385.3±652.95	0.25–1.12	0.66±0.24
Restoration laboratory	1992.8–4842	2907.3±888.77	0.46–1.18	0.78±0.25
Depository	1132–3515.5	1877.5±851.87	0.27–0.98	0.49±0.20

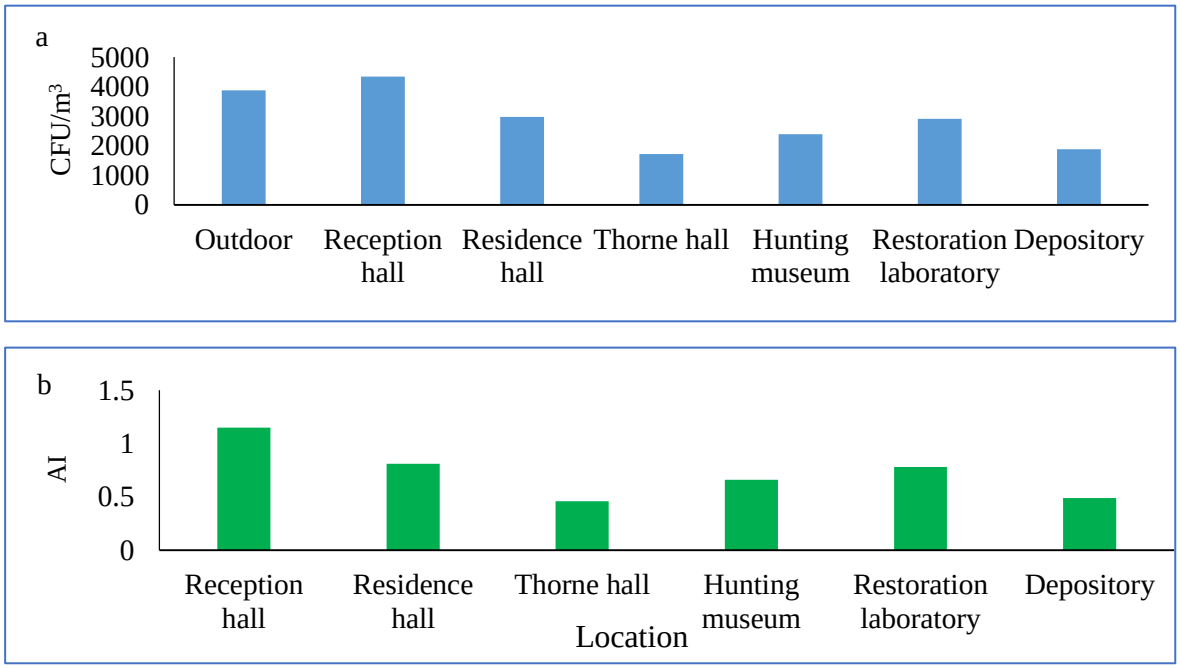

Fig. 7. Microbial air contamination indices: a) global index of microbial contamination/m^3 (GIMC–CFU/m^3), b) amplification index (AI).

6. The impact of microclimatic conditions on microbial culturability

The correlations between airborne microbial parameters and microclimatic conditions (T°C and RH%) varied regarding microbial type and location (Table 3). Generally, temperature detrimentally affected microbial culturability, and relative humidity relatively supported culturability. Moderate significant negative correlations were found between temperature and bacteria (r=- 0.59) and fungi outdoor (r=-0.68) as well as with fungi and actinomycetes indoors (r=-0.71). It is suggested that microclimatic conditions synergistically affected microbial culturability, as human activity, geographical factors and timing of microbial growth may mask the effects of microclimatic conditions on microbial culturability (Adams *et al*., 1986) and the extremes of these factors differ from place to place. Interactions of these variables may interpret the complex–correlations between microorganisms and microclimatic conditions. Generally, the current microclimatic conditions inside the Prince Mohamed Ali museum suppress microbial growth in the air and consequently on surfaces.

Table 3. Spearman's rank correlations between airborne microbial parameters and microclimatic conditions (T°C and RH%).

Location	T°C			RH%		
	Bacteria	Fungi	Actinomycetes	Bacteria	Fungi	Actinomycetes
Outdoor	– 0.59*	– 0.68*	– 0.05	– 0.01	0.29	0.04
Reception hall	– 0.11	– 0.71*	– 0.71*	0.15	0.13	0.13
Residence hall	0.06	– 0.18	– 0.02	0.16	0.12	0.39
Thorne hall	– 0.44	– 0.55*	– 0.08	– 0.16	0.37	– 0.02
Hunting museum	0.43	– 0.49	– 0.02	– 0.09	– 0.09	– 0.52*
Restoration laboratory	– 0.12	– 0.31	– 0.26	– 0.19	– 0.08	– 0.27
Depository	– 0.17	0.08	0.07	– 0.36	0.06	0.13

*$P \leq 0.05$

Conclusion

The accurate assessment of the effects of air pollution on cultural heritage requires knowledge on the level and types of biological pollutants in the air. The Global Index of Microbial contamination exceeded 1000 CFU/m^3 in all locations inside the Prince Mohammad Ali's Museum, Giza, Egypt. The reception hall had the worst microbial air quality. Outdoor environment was the main contributor of indoor microbial pollution, and ventilation type significantly affected indoor quality. The location, ventilation and human activities strongly influence prevalence of bio-pollutants in comparison to microclimatic conditions. Building air exchange is important factor for removing of bioaerosols and sometimes for accumulation of outdoor bioaerosols.

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جودة الهواء الميكروبي الداخلي بمتحف الأمير محمد علي بالجيزة، مصر: دراسة أولية

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المستخلص

تهدف الدراسة الى تقييم ملوثات الهواء البيولوجية (بكتيريا و فطريات و الأكتينوميسيتات) في متحف الأمير محمد على بالمنيل، الجيزة، و تأثرها بالعوامل المناخية ، الموقع الجغرافي، نوع التهوية و النشاط الإنساني. تم تجميع الدلائل الميكروبية السابقة خلال ساعات العمل اليومية بالمتحف ، خلال الفترة من 2016 – 2018 و ذلك باستخدام جهاز اندرسون ذو المرحلتين . تراوحت تركيزات البكتيريا و الفطريات و الأكتينوميسيتات مابين 694 – 7787 مستعمرة/م^3 ، 47 – 1985 مستعمرة/م^3 و صفر– 294 مستعمرة/م^3، على التوالي . تم رصد أعلى تركيز للبكتيريا في موسم الربيع و الفطريات في موسم الشتاء و الأكتينوميسيتات في الخريف، و شكلت نسب الدلائل الميكروبية الأقل من 2.5 ميكروميترالنسب الأعلى في الهواء الداخلى بالمقارنة بالهواء الخارجي، حيث تراوحت ما بين 65.6–95%. كان معدل تركيزات البكتيريا و الفطريات في الهواء الداخلى إلى الخارجى(I/O) أكبر من 1 عند سراي الاستقبال و الإقامة، على التوالي، بينما كانت اكبر من 1 عند سراي الإستقبال و معمل الترميم للأكتينوميسيتات. تجاوزت قيم المؤشر الشامل للملوثات الميكروبية (GIMC–CFU/m^3) النسبة المسموح بها عالميا 1000 مستعمرة /م^3 داخل المتحف. كما أوضحت النتائج أن درجة الحرارة تؤثر سلبا على حيوية الكائنات الدقيقة بينما الرطوبة النسبية من العوامل الداعمة لنمو و حيوية الكائنات الدقيقة.

الكلمات المفتاحية: الهباء الحيوي، المؤشر الميكروبي، الحجم الميكروبي، العوامل المناخية الدقيقة، التهوية.