INTERNATIONAL JOURNAL OF ADVANCED SCIENTIFIC RESEARCH AND INNOVATION

Online ISSN: 2785-9541

Volume 7, Issue 1, 2024, 17 – 46

Print ISSN: 2785-9533

A Study of the Environmental Conditions at the Egyptian Geographic Society Museum in Cairo and Their Impact on Archaeological Leather

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Abstract:

This study encompasses the systematic monitoring of environmental parameters affecting the conserved leather artifacts within the Cairo Hall (Craft and Industries) of the Egyptian Geographical Society Museum on El Qasr El-Ainy Street in Cairo. The investigation entails the comprehensive surveillance and quantification of temperature and relative humidity over two distinct phases: a four-week observation during the winter season (comprising the initial phase) followed by an additional four-week scrutiny during the summer season (comprising the subsequent phase). This stratified approach is adopted to capture the variances in temperature and relative humidity between the external ambient atmosphere and the internal museum environment, which qualitatively impacts the archaeological holdings. Concurrently, continuous monitoring and meticulous tracking of fluctuating temperature and humidity levels across discrete temporal epochs are conducted, supplemented by the quantification of airborne pollutant gases, particulate matter, and suspended dust. Methodologically, air and suspended dust samples are collected over consecutive two-month intervals within the museum premises. Additionally, a Petri dish is deployed within the vitrine housing the archaeological sandal under investigation, while four exposed Petri dishes containing a nutritive substrate are positioned open within the museum atmosphere for a duration of four hours to delineate the presence of airborne fungi. Concurrently, biological swabs are obtained from an archaeological leather sandal preserved at the Egyptian Geographical Society Museum. Collectively, the findings underscore the inhospitable nature of the indoor museum environment for the preservation or storage of archaeological artifacts, particularly leather-based specimens.

***Keywords**: Leather sandal, temperature, relative humidity, pollution, Fungi.*

Introduction

The Egyptian Geographical Society stands as the second largest and most venerable scientific and cultural establishment in Egypt, following the Egyptian Scientific Institute. Its inception dates back to 1875, under the auspices of Khedive Ismail. The Society's current domicile, an ancient edifice nestled within the precincts of the People's Assembly and the

Online ISSN: 2785-9541 **Volume 7, Issue 1, 2024, 17 – 46** Print ISSN: 2785-9533

Constitutional Hall in Cairo, adjacent to the Egyptian Museum in Tahrir Square, was graciously bestowed upon it. Originally erected in 1865 by Khedive Ismail as an educational institution for the instruction of the Khedive's daughters, this historic edifice assumed the mantle of the Geographical Society's headquarters in 1922. Registered as an Islamic antiquity in 1995, the structure encompasses four capacious museum chambers, encompassing spaces dedicated to map and historical image archives, the Suez Canal exhibition hall, the Africa Museum, and the Cairo Museum's (Customs and Traditions) expanse. Within the confines of the Cairo Museum (Customs and Traditions) lies an array of singular archaeological and historical artifacts, emblematic of Egypt's folkloric heritage spanning the 18th and 19th centuries. These relics were meticulously curated by the Geographical Society, sourced from urban Cairo, rural villages, and hinterlands, safeguarding against the erosion of cultural patrimony in the wake of modernization. Furthermore, the repository houses a selection of seminal archaeological specimens, generously bequeathed by Egyptian royal progenitors, augmenting the museum's scholarly and cultural cachet [14].

The majority of the archaeological artifacts housed within the Egyptian Geographical Society Museum, particularly organic substances, are subject to a multitude of deteriorative processes stemming from unfavorable environmental conditions for their preservation or storage. This susceptibility arises from exposure to various deleterious agents, including relative humidity (RH), temperature (C°), and airborne pollutants, which constitute primary catalysts for the accelerated degradation and deterioration of these artifacts, notably leather, parchment, and paper [22].

Additionally, the geographical location of the Egyptian Geographical Society Museum, situated proximate to the Egyptian Museum in Tahrir Square, Cairo, exacerbates this predicament. The locale is characterized by vehicular congestion and dense traffic, emitting vehicular exhaust replete with pollutants, alongside atmospheric contaminants emanating from industrial processes and agricultural practices [7], These pollutants infiltrate the museum premises from external sources, facilitated by the exchange of indoor /outdoor air from open windows, doors, and inadequate ventilation systems [21], Moreover, certain pollutants may originate from materials utilized within the museum [15]. Furthermore, the ingress of pollutants such as dust and suspended particulate matter is facilitated by visitors, through the inadvertent transfer via their footwear and garments, compounded by biological residues such as leather and hair fragments, among others [26], The impeded air circulation within the museum premises, coupled with the absence of centralized air conditioning or air purification systems, engenders the accumulation of pollutants and particulate matter over time [24], The attendant risk posed by these pollutants is heightened by fluctuations in temperature and relative humidity in the ambient atmosphere. Notably, the majority of pollutants deleterious to archaeological artifacts precipitate chemical reactions [10, 11, 21], readily transitioning into acidic states within the ambient milieu. Acidic species in gaseous and vapor forms represent injurious compounds, rendering materials susceptible to acidic degradation, with archaeological leather being particularly predisposed to damage. The potential loss of invaluable insights into this significant heritage underscores the imperative for environmental interventions to mitigate such degradation processes [24].

Online ISSN: 2785-9541 **Volume 7, Issue 1, 2024, 17 – 46** Print ISSN: 2785-9533

A plethora of studies and research endeavors delve into the issue of indoor air pollution within museum environments, encompassing a spectrum of pollutants including organic and inorganic compounds, particulate matter, and gaseous emissions, and their potential adverse impacts on archaeological artifacts [2, 8, 20, 29, 31, 32].

Moreover, variations in temperature, relative humidity, and human activities exert notable influences on the proliferation and metabolic activity of fungi within indoor settings [5, 18, 25], thereby facilitating fungal growth within museum environments, whether airborne or on material surfaces [18, 25].

Consequently, safeguarding this invaluable cultural heritage in defense of the fundamental rights of future generations emerges as a critical imperative. Recognition of the deleterious factors at play and the implementation of proactive measures against these factors constitute primary steps toward the preservation of this significant heritage [28].

Hence, the focus of this study lay on assessing the environmental conditions within the Cairo Hall (Crafts and Industries) at the Egyptian Geographic Society. This entailed the meticulous monitoring and measurement of various ambient environmental parameters, including temperature, relative humidity, total suspended particulates, inhalable dust, and inorganic particulate matter. Furthermore, it encompassed the evaluation of museum pollutants such as ammonia (NH_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), formaldehyde (HCHO), and volatile organic compounds. Additionally, the study scrutinized fungal contamination of indoor air within the museum premises, juxtaposing these findings with data obtained from swabs taken from an ancient leather sandal preserved in the same locale. The overarching aim was to delineate the potential risks posed by these factors to preserved leathers and to ascertain compliance with recommended thresholds stipulated by relevant authorities.

Experimental

Monitoring and measuring temperature and relative humidity:

Temperature and relative humidity levels were meticulously monitored and measured within the Cairo Hall (Crafts and Industries), the repository of the archaeological artifact under scrutiny, located at the Egyptian Geographic Society Museum. This surveillance spanned four weeks during the winter season (constituting the initial phase of the study) and an additional four weeks during the summer season (constituting the subsequent phase of the study). Specifically, data collection occurred from November 26, 2022, to December 27, 2022, and from July 11, 2023, to August 31, 2023. The primary objective was to maintain continuous vigilance over the dynamic variations in temperature and relative humidity across these distinct temporal intervals. This endeavor was facilitated by the utilization of a Testo brand digital Data Logger, model 175H1, sourced from the Institute of Measurement and Standardization in Cairo.

The apparatus was meticulously calibrated to record measurements at thirty-minute intervals throughout the diurnal cycle, ensuring a total of 48 readings per day. Subsequently, the daily maximum and minimum values for both relative humidity and temperature were

Online ISSN: 2785-9541 **Volume 7, Issue 1, 2024, 17 – 46** Print ISSN: 2785-9533

meticulously documented, alongside the respective weekly maximum and minimum values, in addition to the calculated rate of change between the two ratios.

Monitoring gases and measuring pollution concentrations:

The assessment of pollutant gas concentrations within the Cairo Hall (Crafts and Industries) at the Egyptian Geographic Society Museum in Cairo was conducted. This involved employing an air sampling apparatus positioned at the designated study site, comprising an air pump connected to bottles containing calibration solutions. The mechanism operated by extracting air samples through the air pump, which then traversed filters before being channeled through tubes linked to bottles housing specialized chemical solutions tailored to each gas type requiring concentration determination. Samples were gathered at 24-hour intervals, with air volume quantification facilitated by a "Flow Rota meter" device, followed by subsequent measurement computations.

Fig. 1. depicts the apparatus utilized for the chemical extraction of air samples contaminated by methods endorsed both internationally and locally at the study site.

The concentration of sulfur dioxide (SO_2) was assessed through the application of the colorimetric method developed by "West and Geak," alternatively referred to as the "spectrophotometric" method. This methodology is renowned for its precision, yielding results within the concentration range of (0.005 to 5) parts per million [18].

This method relies on the absorption of sulfur dioxide (SO_2) from the ambient air and its subsequent stabilization within a solution of sodium tetra chloromercurate II, forming "Dichlorosulfitomercurate II" (the calibration solution). The practical analysis of sulfur dioxide gas involves extracting 5.0 mL of the calibration solution and subsequently adding 5 mL of Acid-Bleached pararosaniline Hydrochloride solution and 10 mL of formaldehyde solution into test tubes. Following thorough mixing, the solution is allowed to stand for 30

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minutes. Subsequently, the intensity of the resulting color spectrum of the methylsulfonic acid pararosaniline compound is measured using a spectrophotometer set at 560 nanometers. Finally, the concentration is determined by reference to the calibration curve, expressed in $\mu g/m^3$.

The concentration of nitrogen dioxide (NO_2) was assessed employing the methodology pioneered by Jacobs and Hochheiser, subsequently enhanced by Saltzman. This technique hinges upon the absorption of nitrogen dioxide gas from the atmosphere and its introduction into a calibration solution comprising sodium arsenite and sodium hydroxide (NaOH).

The concentration of nitrite ions is assessed through a standardized procedure involving the extraction of 10 mL of the calibration solution. Subsequently, 1 mL of hydrogen peroxide solution, 10 mL of sulfanilamide solution, and 1.4 mL of N-(1-naphthyl)-ethylenediamine dihydrochloride (NEDA) are added to the extracted solution. Following thorough mixing, 50 mL of distilled water is introduced. Additionally, an empty sample is prepared by adding 10 mL of unexposed absorbent. The absorbance curves for both the collected samples and the empty absorbent are then measured at a wavelength of 540 nanometers. Absorbance intensity is recorded at 10-minute intervals and juxtaposed with the standard curve generated using a sodium nitrite solution. By quantifying the volume of air collected during sampling, the concentration of nitrogen dioxide gas is estimated in $\mu g/m^3$.

Ammonia gas (NH_3) concentration was determined through the collection of samples in a diluted sulfuric acid solution. The "Nessler's Reagent" method was then applied for measurement, prepared as follows:

Potassium iodide (50 g) is dissolved in 50 mL of distilled water, followed by the gradual addition of a saturated solution of mercuric chloride (60 g per 1 L of distilled water) with continuous stirring until a clear precipitate forms, which is discernible. Subsequently, 400 mL of a calcium hydroxide solution, previously prepared by dissolving 248 g of calcium hydroxide in 500 mL of distilled water, is added. The solution is then brought to a final volume of 1 L with distilled water and allowed to stand for 24 hours prior to use. The reagent exhibits a yellow color in the presence of ammonia, and the color intensity is measured using a spectrophotometer at a wavelength of 460 nanometers.

The concentration of ammonia (NH_3) is calculated utilizing a standardized curve prepared with a standard solution of ammonium chloride. By quantifying the volume of air collected during sampling, the concentration of ammonia gas is estimated in $\mu g/m^3$ [20].

Monitoring and measuring the concentration of dust and solid air pollutants

The concentration of suspended particulate matter within the Cairo Hall (Letters and Industries) at the museum was observed and quantified using meticulously weighed filter paper and an electrically operated air sampling pump with a predetermined flow rate. The apparatus utilized for sample collection is depicted in Figure (2). Analysis of the samples was performed employing Atomic Absorption Spectroscopy at the National Research Center. Sampling activities spanned two consecutive months, commencing from January 11, 2023, to February 14, 2023, with a sampling frequency of two samples per week, each subjected to 12-hour exposure duration.

INTERNATIONAL JOURNAL OF ADVANCED SCIENTIFIC RESEARCH AND INNOVATION

Online ISSN: 2785-9541

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Fig .2 The figure illustrates the air suction pump utilized for the collection of dust samples at the study site.

The concentration was determined by the disparity in weight of the filtration paper before and after sample collection, employing the subsequent equation:

$$\text{TSP } \mu/m^3 = \frac{(\text{Wf} - \text{Wi})x10^6}{V}$$

Considering the following:
TSP µg/m^3 = denotes the concentration of Total Suspended Particles.
WF = represents the weight of the filtration paper post-sampling (in grams).
WI = signifies the weight of the filtration paper pre-sampling (in grams).
10^6= is employed for converting grams to micrograms.
V= denotes the volume of air samples (in cubic meters).

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Online ISSN: 2785-9541

Volume 7, Issue 1, 2024, 17 – 46

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Fig .3. depicts the configuration of the filtration paper employed for sample collection.

Fig .4. depicts the morphology of the filter paper following sample collection.

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Assessment of indoor air fungal contamination

Fungal pollution was evaluated through the exposure of five Petri dishes containing Agar Media, specifically Yeast Malt Extract Agar (MEA), utilized for fungal isolation. This nutritional medium consists of the following components:
(4g Dextrose, 4g Yeast, 10g Malt, 20g Agar) The medium is dissolved in 1 liter of distilled water and subsequently heated to the boiling point. It is then sterilized in an Autoclave at a temperature of 121°C and atmospheric pressure (15 PSI) for a duration of 15 minutes. Following sterilization, these nutrient substrates are poured into Petri dishes under sterile conditions and allowed to solidify. Thereafter, they are positioned at a height of 1.5 meters above ground level, as depicted in Figure (5a-c), and exposed to museum air for a period of four hours. Upon adequate sealing, they are expeditiously transported to the microbiology laboratory. Subsequently, they are placed within an incubator set at a temperature range of 28°C to 30°C for a duration spanning 5 to 7 days, following which purification and identification procedures ensue.

Fig .5a-c. Depicts the positions where Petri dishes containing agar media were situated during sample collection.

Microbiological Examination of Ancient Leather Sandals

Microbiological examination was conducted by sampling biological swabs from various areas of the leather surface, utilizing sterilized cotton swabs, to procure specimens cultivated in suitable petri dishes containing appropriate nutrient medium. The isolation process commenced immediately after the collection of biological swabs within the microbiology laboratory, under optimal sterilization conditions, employing the Pouring Agar Plates method with Tryptic Glucose Yeast Agar (TGY agar) from R.I. Biolife Italiana S.r.l. as the nutrient medium.
(5.0g Tryptone, 2.5g Yeast Extract, 1.0g Glucose, 15.0g Agar Bios LL) Dissolved in 1 liter of distilled water, with a pH = 7, and prepared under the same previously mentioned conditions.

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Fig .6. Depicts the microbial isolates obtained during the incubation period.

Following the conclusion of the incubation period, the process of isolation and purification is carried out by collecting individual colonies that appear on the agar plates. Each colony is then cultured on new petri dishes containing Potato Dextrose Agar (PDA), comprised of 5g Potato Extract, 20g Glucose, and 17g Agar dissolved in 1 liter of distilled water. These cultures are incubated under the same aforementioned conditions. This procedure is repeated until obtaining pure fungal isolates, which are subsequently transferred to slant tubes for preservation, in preparation for identification steps.

Results and discussion

Regulation of temperature and relative humidity

The investigation has elucidated that within the initial phase of observation, the diurnal oscillations between temperature and relative humidity manifested a state of relative moderation throughout each diurnal cycle. Nonetheless, over the span of four weeks, a conspicuous and pronounced divergence in relative humidity levels became apparent, spanning a range from 51.9% to 68.7%. The differential rate of alteration between these two proportions amounted to 16.8%. Particularly noteworthy was the discernible surge in relative humidity recorded during the third week of observation, peaking at 68.7%, juxtaposed against a comparatively stable temperature regime fluctuating between 21.8°C and 24.8°C across diurnal periods, denoting a marginal temperature variance of 3°C between the measured extents. Conversely, a substantial reduction in relative humidity levels was also noted during the initial day of the fourth week, registering 51.9% during the nocturnal epoch and escalating to 62.2% during diurnal intervals, thus denoting a discrepancy of 10.3%. This transition coincided with a perceptible elevation in temperature, which soared to 27.9°C

Online ISSN: 2785-9541 **Volume 7, Issue 1, 2024, 17 – 46** Print ISSN: 2785-9533

during daylight hours, while exhibiting a nocturnal decrease to 22.6°C, illustrating a temperature gradient of 5.3°C between the recorded epochs.

In the second phase of the study, a notable discrepancy in relative humidity was observed, both within daily cycles and over the span of four weeks, with readings ranging from 49.6% to 73.5%. The difference between these two percentages was quantified at 24.9%. Conversely, temperature profiles exhibited a high degree of consistency, both daily and across the four-week timeframe, registering values between 28.8°C and 30.8°C, with a minimal 2°C variance between the two measurements.

The study elucidates a conspicuous and pronounced oscillation in relative humidity percentages across distinct periods, notably accentuated during the second phase. Relative humidity levels exceeded 73% during the initial week, while reaching a nadir of 49.6% in the fourth week of the same phase, attesting to a substantial variability within this interval. This fluctuation is further underscored by Tables (1) and (2), which delineate temperature readings, relative humidity values, and the associated rates of change throughout the study's phases

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Table (1) elucidates the relative humidity values and their corresponding rates of change over the course of the study period.

Season	Duration	highest value	Lowest value	Rate of change (%)
Winter 2022	First week	60.7	55.3	5.4
	Second week	62.1	55.4	6.7
	Third week	68.7	59.4	9.3
	Fourth week	63.6	51.9	11.7
Summer 2023	First week	73.5	63.2	10.3
	Second week	68.7	55.2	13.5
	Third week	67.1	60.5	7.6
	Fourth week	69.9	49.6	20.3

INTERNATIONAL JOURNAL OF ADVANCED SCIENTIFIC RESEARCH AND INNOVATION

Online ISSN: 2785-9541

Volume 7, Issue 1, 2024, 17 – 46

Print ISSN: 2785-9533

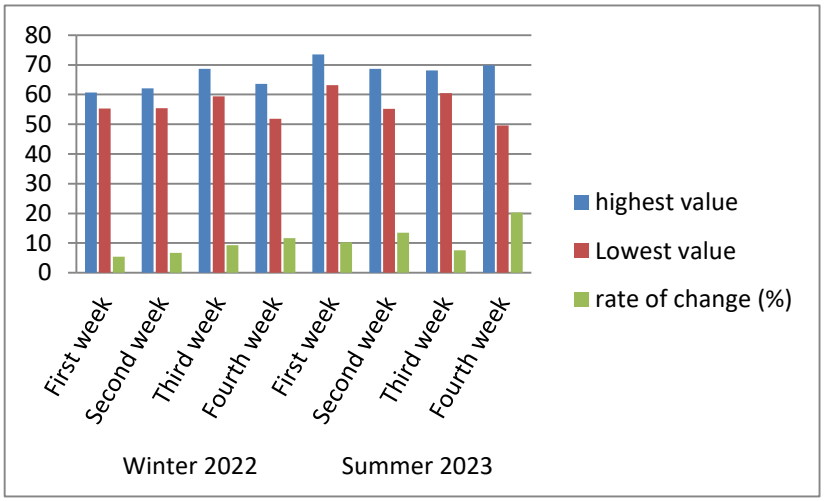

Fig. 7. Illustrates the outcomes of the relative humidity percentage (%) during the study period.

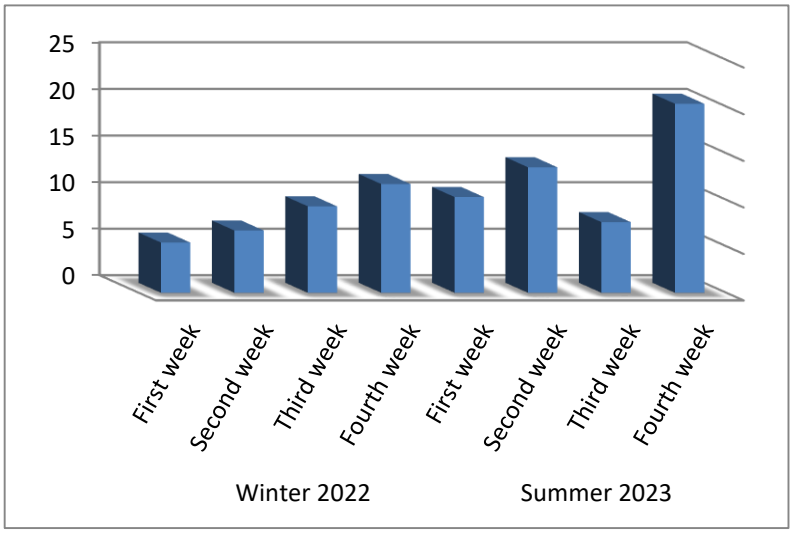

Fig .8. Illustrates the weekly rate of change for relative humidity (%) during the study period.

It has further emerged that the degree of temperature fluctuation remained low throughout each phase of the study. The highest temperature recorded during the initial phase was 24.8°C, while the lowest was 21.8°C. In contrast, temperatures exhibited a notable increase during the second phase, peaking at 30.8°C and reaching a nadir of 28.8°C. These temperature ranges are deemed unsuitable for the preservation of organic materials in general, and particularly so for ancient leather artifacts. They exceed the recommended

Online ISSN: 2785-9541 **Volume 7, Issue 1, 2024, 17 – 46** Print ISSN: 2785-9533

values for maintaining and safeguarding organic substances, specifically archaeological leather, which typically fall within a relative humidity range of 45-50% and a temperature range of 18-20°C [9].

It is widely recognized that elevated levels of relative humidity contribute to accelerated deterioration rates for various archaeological materials, particularly leather. This is attributed to the potential conversion of pollutant gases into acids, catalyzing chemical degradation processes within the leather structure [7]. Consequently, such chemical transformations may lead to the disruption of chemical bonds within the leather matrix [12].

The impact of relative humidity fluctuations on leather preservation varies according to the specific environmental conditions of the storage locale, whether it be a repository, library, museum, etc. The overall climatic conditions, both external and internal, alongside the design and ventilation systems of exhibition spaces, exert significant influence on the relative humidity levels surrounding archaeological artifacts [3].

Moreover, fluctuations in temperature can also precipitate chemical degradation processes by prompting chemical reactions [11]. Abrupt oscillations between relative humidity and temperature can induce expansion and contraction phenomena in leather, resulting in irreparable damage. Given the intimate correlation between relative humidity and temperature, their mutual influence forms a pivotal component of environmental regulation within museum settings [24, 3]. Consequently, meticulous control of both relative humidity and temperature parameters is essential when managing the environmental conditions surrounding archaeological artifacts [4].

Table (2) illustrates the temperature percentages and the rate of change during the study. period.

Season	Duration	highest value	Lowest value	rate of change (°C)
Winter 2022	First week	24.8	23.8	1
	Second week	23.9	23	0.9
	Third week	23.2	22.7	0.5
	Fourth week	27.9	21.8	6.1
Summer 2023	First week	29.9	28.8	1.1
	Second week	31.6	30.5	1.1
	Third week	31	30.3	0.7
	Fourth week	30.7	30.1	0.6

INTERNATIONAL JOURNAL OF ADVANCED SCIENTIFIC RESEARCH AND INNOVATION

Online ISSN: 2785-9541

Volume 7, Issue 1, 2024, 17 – 46

Print ISSN: 2785-9533

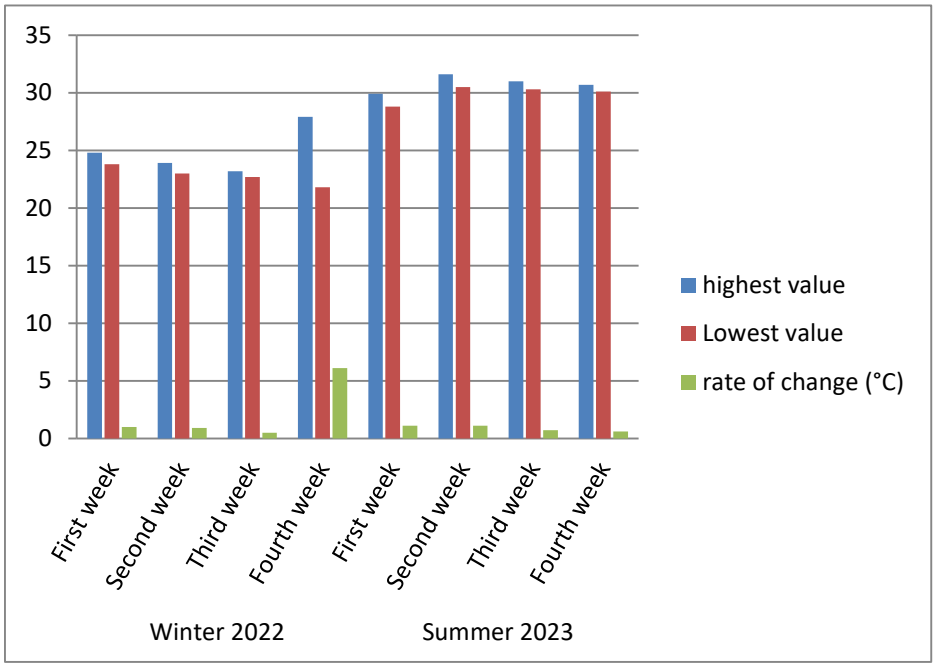

Fig .9. Presents the results of temperature measurements (°C) during the study period.

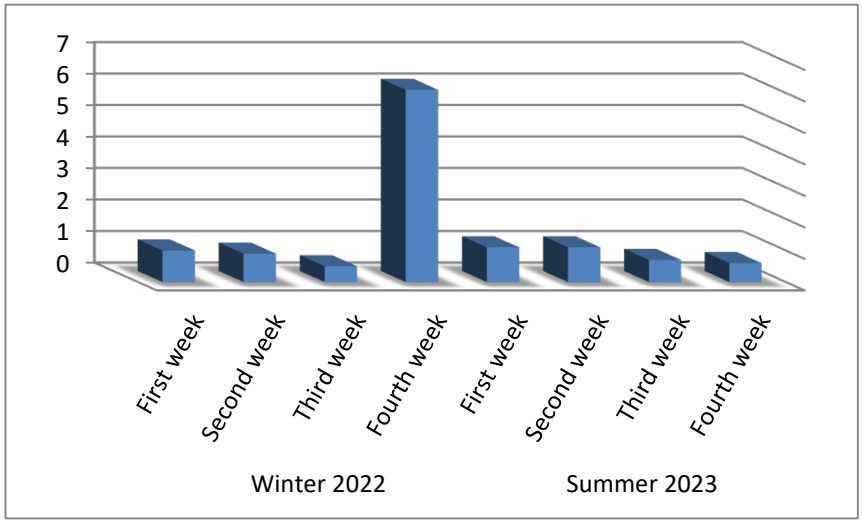

Fig .10. Depicts the weekly average rate of temperature change (°C) over the course of the study period.

Online ISSN: 2785-9541 **Volume 7, Issue 1, 2024, 17 – 46** Print ISSN: 2785-9533

The concentration of sulfur dioxide gas (SO_2)

It is discerned from Table (3) that the highest recorded concentration of sulfur dioxide gas (SO_2) amounted to 82µg/m^3, while the lowest concentration stood at 71µg/m^3. The study further elucidates that the average concentration of sulfur dioxide gas at the study location reached 76.5µg/m^3. These concentrations surpass the recommended threshold outlined in the "Pollution Control for Historic Buildings" guide issued by The Museum Libraries and Archives Council (MLA) [6], which advises that sulfur dioxide concentrations within historic buildings equipped with chemical filters should not exceed 2.6µg/m^3. For buildings lacking chemical filters, the concentration should not surpass 39µg/m^3.

The occurrence of sulfur dioxide gas influences relative humidity alongside facilitating agents such as iron and copper on leather and manuscripts, prompting the oxidation of sulfur dioxide gas and its conversion into sulfuric acid. This process, in turn, instigates the manifestation of acidic degradation, commonly referred to as Red Rot. Consequently, this phenomenon engenders the disintegration of the bonding substance among leather fibers, ensuing in the decomposition of the fibers themselves, gradually transmuting the leather into a powdery residue over the course of time [4, 3].

The concentration of nitrogen dioxide gas, NO_2

It is further elucidated by Table (3) that the highest recorded concentration of nitrogen dioxide gas (NO_2) stood at 75µg/m^3, while the lowest concentration measured 60µg/m^3. The study unveiled an average NO_2 concentration of 67.5µg/m^3 at the study site, surpassing the recommended threshold outlined in the MLA guidelines: 1.9µg/m^3 within archaeological edifices equipped with chemical filtration systems, and 38µg/m^3 within structures lacking such filtration systems.

The concentration of ammonia gas, NH_3

It is evident from Table (3) that the highest concentration of ammonia gas (NH_3) recorded was 70 µg/m^3, while the lowest concentration observed was 60 µg/m^3. The study elucidated that the average concentration of ammonia gas at the research site reached 6µg/m3. The presence of ammonia gas leads to alkaline degradation of leather, and in conjunction with sulfur dioxide gas, it results in the formation of saline deposits of ammonium sulfates on manuscripts and leather, thus distorting them [3].

The concentration of formaldehyde, HCHO

The maximum concentration of formaldehyde (HCHO) recorded was 165 µg/m^3, with the lowest concentration noted at 120 µg/m^3. The study identified an average formaldehyde gas concentration of 142.5µg/m^3 at the research site, exceeding the recommended reference values outlined in the MLA guideline, which stand at 36µg/m^3. It is evident from the findings that formaldehyde ranks highest among the pollutants at the study location, followed by sulfur dioxide gas, nitrogen dioxide gas, and ammonia, respectively. The heightened levels of formaldehyde pollutants may be attributed to internal factors and sources within the museum [3], including the use of wood in display and storage furnishings, adhesive floor tiles utilized in museum flooring, and other materials employed in exhibition and storage settings.

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Online ISSN: 2785-9541 **Volume 7, Issue 1, 2024, 17 – 46** Print ISSN: 2785-9533

The concentration of volatile organic compounds (VOCs)

Table (3) demonstrates that the peak concentration of volatile organic compounds (VOCs) reaches 140µg/m^3, with the lowest concentration recorded at 120µg/m^3. The study reveals an average VOC concentration of 130µg/m^3. According to the Indoor Air Quality Guide for Cyprus, the permissible concentration of VOCs in indoor work environments should not exceed 0.1 milligrams per cubic meter [32].

The aggregate concentration of particulate matter suspended and respired

The highest recorded concentration of total suspended dust particles was 185µg/m^3, contrasting with the lowest concentration of 170µg/m^3. Through the investigation, an average total suspended dust concentration of 177.5µg/m^3 was elucidated. These concentrations surpass the permissible reference values within museum settings, prescribed at 20-100 µg/m^3 for entrances, corridors, and congested halls, and do not exceed 10 µg/m^3 in storage facilities and archives, as delineated by the MLA guidelines. Additionally, the study revealed that the maximum concentration of inhaled suspended dust particles reached 77µg/m^3, while the minimum concentration was observed at 71µg/m^3. The average concentration of inhaled suspended dust particles was determined to be 74µg/m^3.

Table (3) delineates the concentrations of pollutant gases and suspended particulate matter measured within the museum environment (µg/m^3).

Gas	**(Concentration** µg/m^3)		
Sulfur dioxide (SO_2)	**Lowest**	**highest**	Average
	71	82	76.5
Nitrogen dioxide (NO_2)	60	75	67.5
Ammonia (NH_3)	60	70	65
Formaldehyde (HCHO)	120	165	142.5
Airborne organic compounds	120	140	130
Total inhalable dust	71	77	74
Total suspended dust	170	185	177.5

Online ISSN: 2785-9541 **Volume 7, Issue 1, 2024, 17 – 46** Print ISSN: 2785-9533

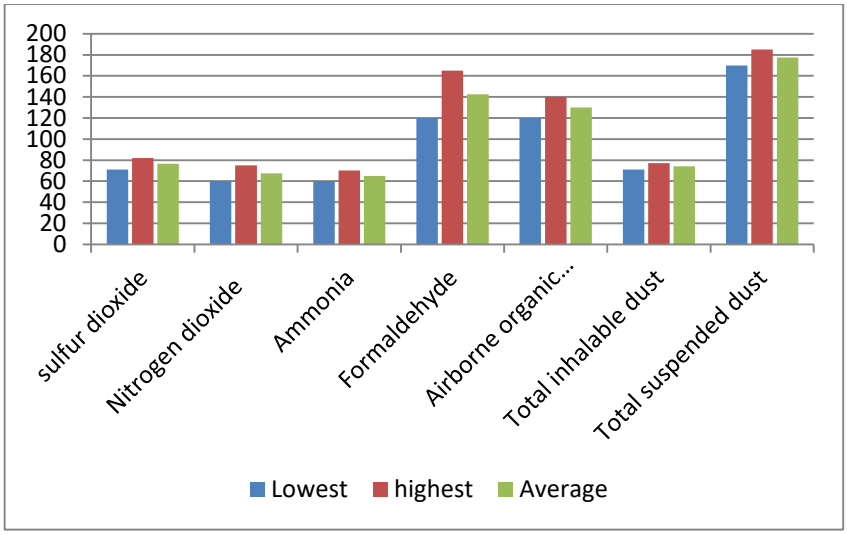

Fig .11. Illustrates the results of pollutant concentrations (µg/m^3) at the study site.

The concentration of inorganic particulate matter

The measurement results indicate that the highest concentration was observed for iron, with a recorded rate of 19.7µg/m^3, representing a notably elevated level. Following iron, lead exhibited its highest concentration at 5.27µg/m^3, succeeded by copper with its peak concentration reaching 0.41µg/m^3. Subsequently, cadmium maintained a consistent concentration throughout the study period, measuring at 0.0069µg/m^3. These particulates are implicated in dermal abrasion [22], and serve as catalysts for chemical reactions, particularly the metallic elements iron (Fe) and copper (Cu) [21, 3].

Table (4) depicts the concentration of suspended particulate matter measured within the museum environment, expressed in µg/m^3.

Month	Sample number	Date	Operating Hours	Fe (µg/m^3)	Cu (µg/m^3)	Pb (µg/m^3)	Cd (µg/m^3)
January	1	11/01/2023	12	16.3	0.13	0.27	0.0069
	2	14/01/2023	12	3.9	0.20	0.20	0.0069
	3	16/01/2023	12	32.8	0	0.41	0.0069
	4	21/01/2023	12	7.9	0.13	5.27	0.0069
	5	24/01/2023	12	6.1	0.06	0.006	0.0069
	6	28/01/2023	12	6.1	1.11	0.13	0.0069
February	7	01/02/2023	12	2.2	0.27	0.006	0.0069
	8	04/02/2023	12	19.7	0.41	0.69	0.0069
	9	07/02/2023	12	13.1	0.06	0.13	0.0069
	10	11/02/2023	12	11.8	0.06	0.006	0.0069
	11	14/02/2023	12	5.2	0.27	0.006	0.0069

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Table (5) illustrates the mean concentration of solid particles measured within the museum environment, expressed in µg/m^3.

Element	highest	Lowest	Average
Cd (µg/m^3)	0.0069	0.0069	0.0069
Pb (µg/m^3)	5.27	0.006	0.64
Cu (µg/m^3)	1.11	0.06	0.27
Fe (µg/m^3)	32.8	2.2	11.37

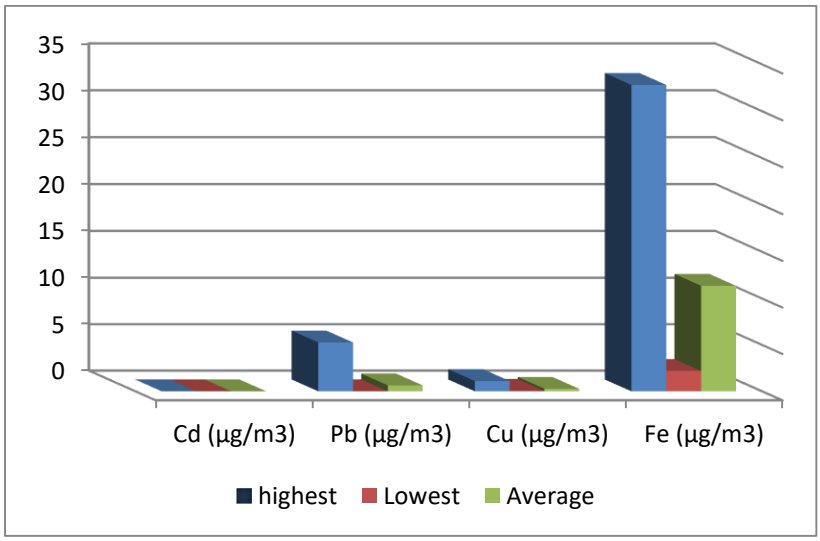

Fig .12. Illustrates the concentration of particulate matter suspended in the museum environment, (µg/m^3).

Evaluation of fungal contamination in indoor air and historical sandals

Fungi were characterized based on their physiological and morphological traits. This involved culturing pure isolates and mounting them onto microscopic slides for examination. A meticulous analysis of these slides was conducted using the compound microscope's ocular lens to determine the morphological attributes of the microorganisms. This facilitated comparison with standard morphological features outlined in specialized scientific references and literature dedicated to microorganism identification [30]. Identification was performed using a magnification of (10x) for the ocular lens and (40x) for the objective lens, as illustrated in Figures (13-35). The identification results revealed the presence of fungi in the museum environment, including:

- **The fungi identified within the preserved ancient sandal (the subject of study):**

  (Cladosporium, Aspergillus niger).
- **The fungi identified within the museum atmosphere:**

(Curvularia, Alternaria, Yeast, Nigrospora, Botrytis, Stachybotrys, Penicillium, Cladosporium, Aspergillus versicolor, Aspergillus cleistothecia, Aspergillus flavus, Aspergillus Fumigatus, Aspergillus niger).

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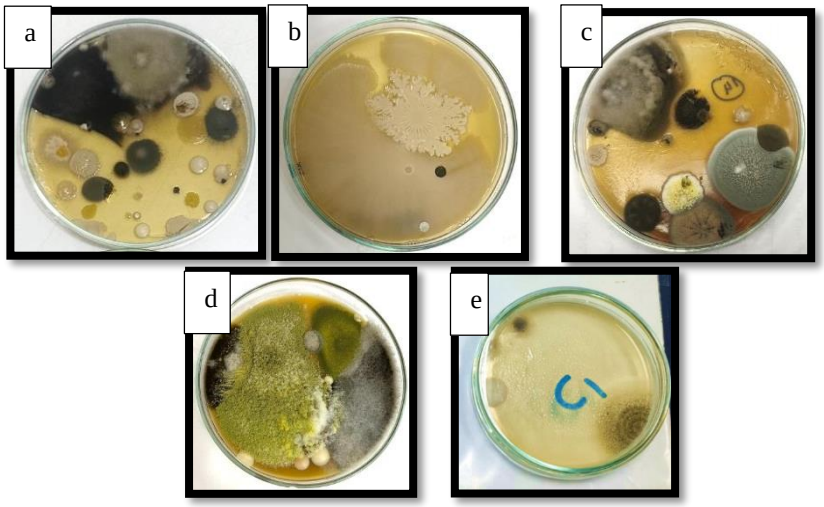

Fig. 13a-e. Depicts the colonies within Petri dishes following the incubation period.

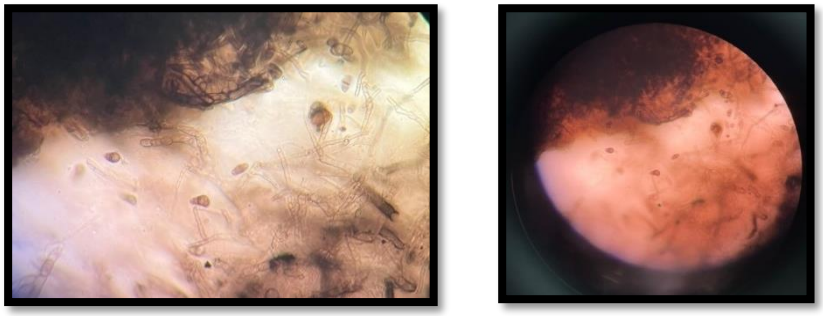

Fig. 14. Demonstrates the fungal species *Curvularia* under microscopic examination.

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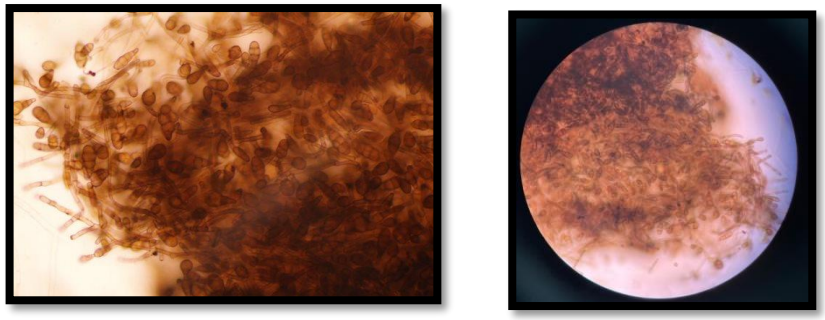

Fig .15. Demonstrates the fungal species *Alternaria* under microscopic examination.

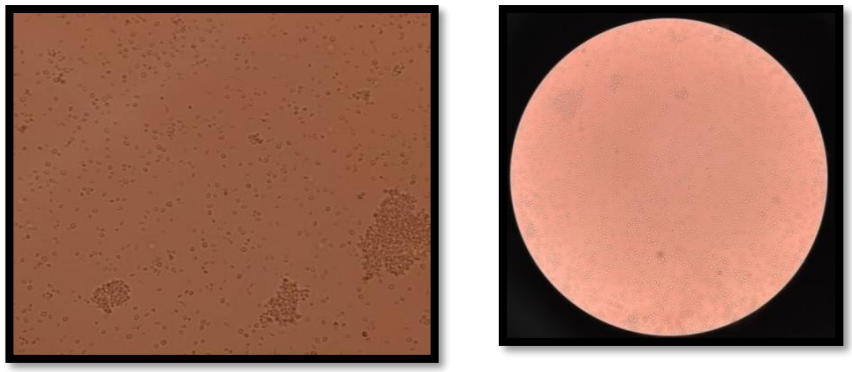

Fig .16. Demonstrates the fungal species *Yeast* under microscopic examination.

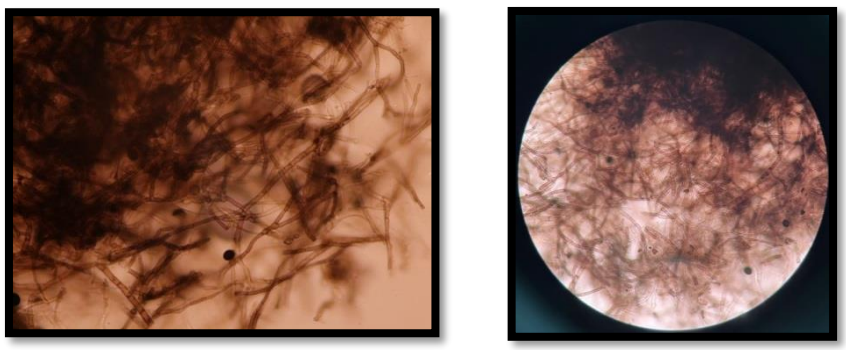

Fig .17. Demonstrates the fungal species *Nigrospora* under microscopic examination.

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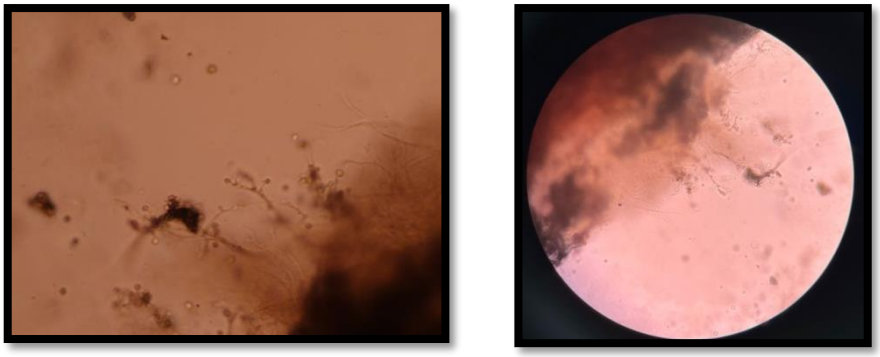

Fig .18. Demonstrates the fungal species *Botrytis* under microscopic examination.

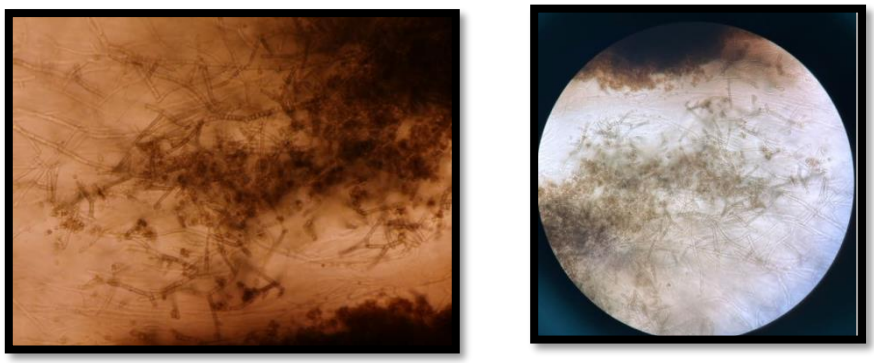

Fig .19. Demonstrates the fungal species *Cladosporium* under microscopic examination.

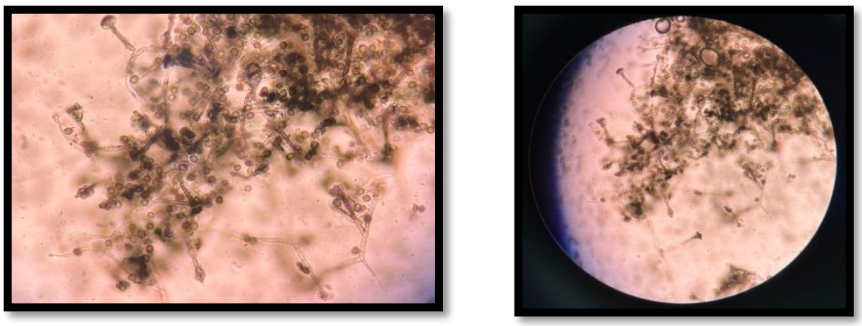

Fig .20. Demonstrates the fungal species *Stachybotrys* under microscopic examination.

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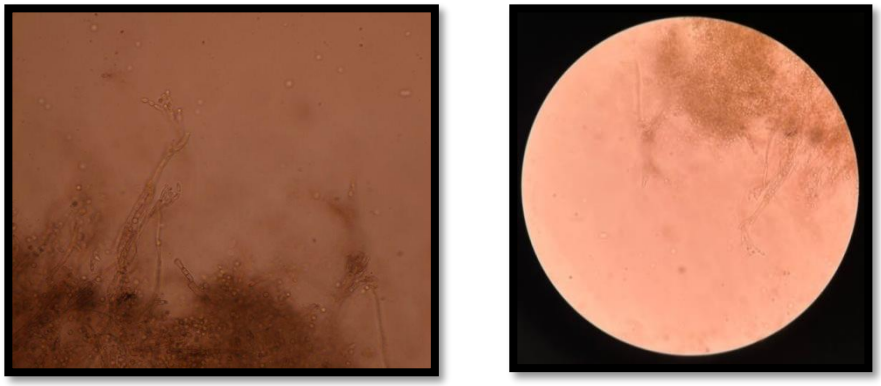

Fig. 21. Demonstrates the fungal species *Penicillium* under microscopic examination.

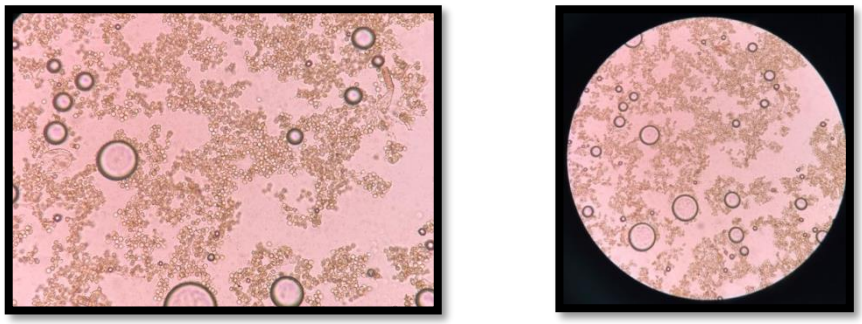

Fig .22. Demonstrates the fungal species *Aspergillus versicolor* under microscopic examination.

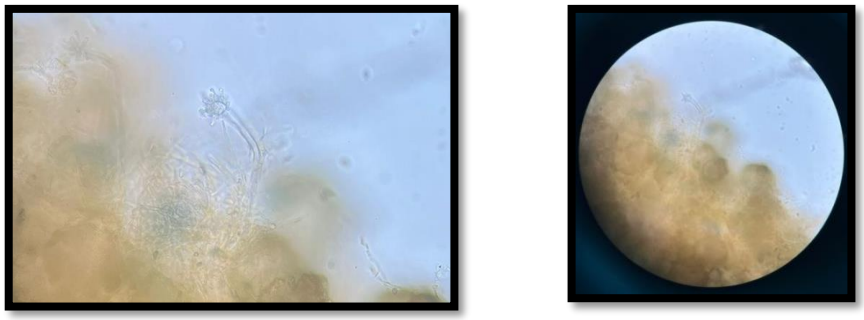

Fig .23. Demonstrates the fungal species *Aspergillus cleistothecia* under microscopic examination.

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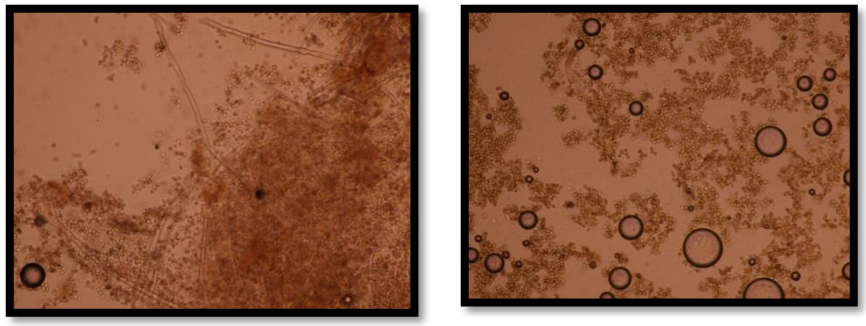

Fig .24. Demonstrates the fungal species *Aspergillus flavus* under microscopic examination

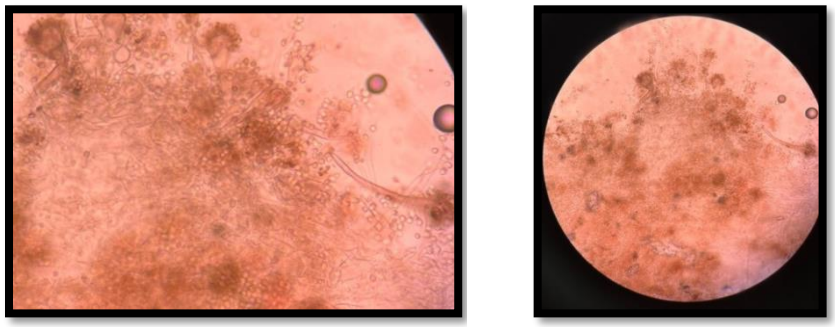

Fig .25. Demonstrates the fungal species *Aspergillus Fumigatus* under microscopic examination.

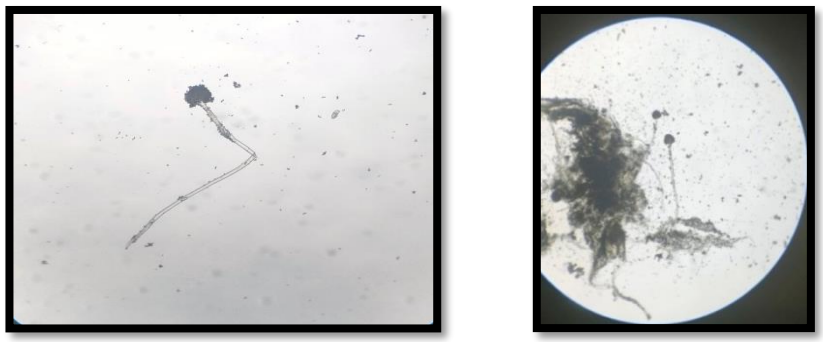

Fig .26. Demonstrates the fungal species *Aspergillus niger* under microscopic examination.

- **The fungi identified in the leather sandal:**

(Aspergillus niger, Alternaria alternate, Aspergillus terreus, Aspergillus nidulans).

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Fig .28. Illustrates the fungus *Alternaria alternate* in a pure culture within a Petri dish after the isolation and purification process.

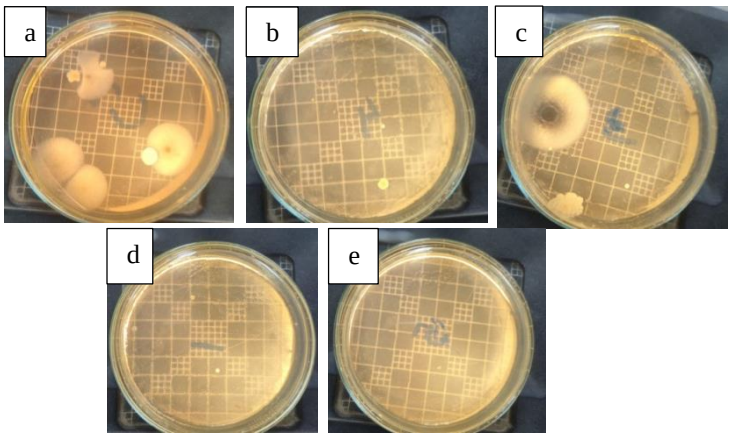

Fig .27a-e. Demonstrates the colonies within Petri dishes after the incubation period under the Colony Counter apparatus.

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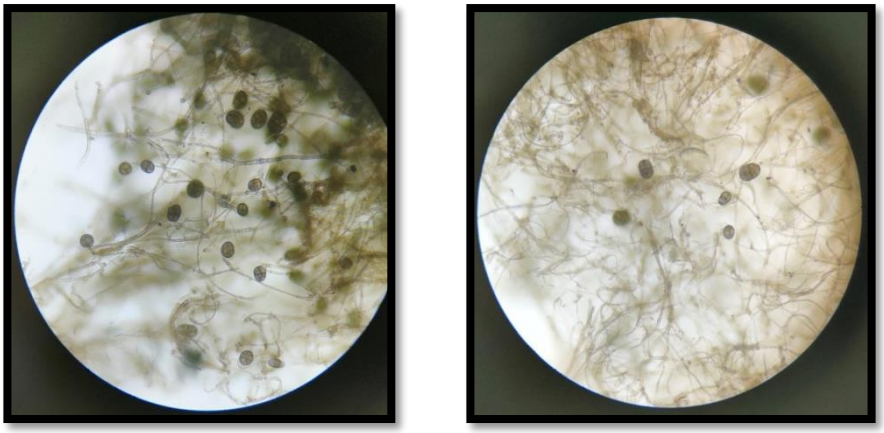

Fig .29. Demonstrates the fungal species *Alternaria alternate* under microscopic examination.

Fig .30. Illustrates the fungus *Aspergillus* ***terreus*** in a pure culture within a Petri dish after the isolation and purification process.

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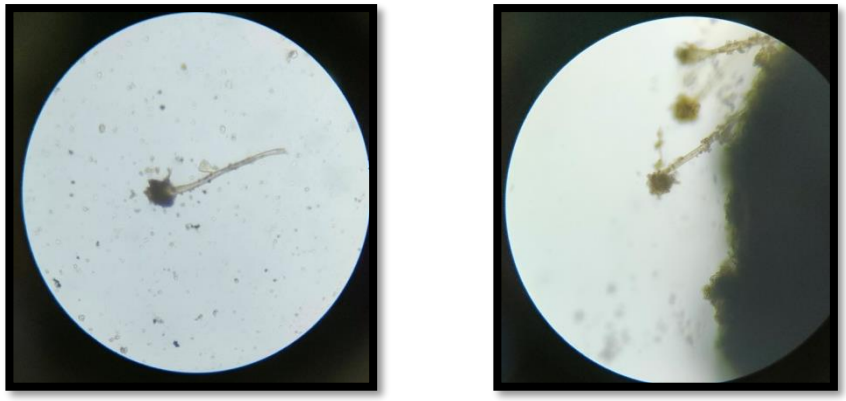

Fig .31. Demonstrates the fungal species *Aspergillus terreus* under microscopic examination.

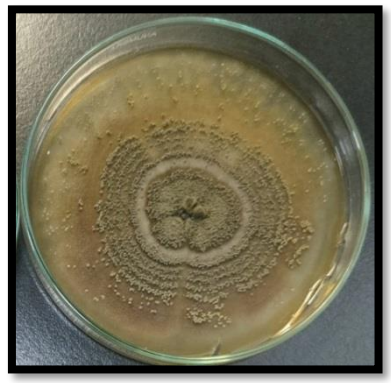

Fig .32. Illustrates the fungus *Aspergillus nidulans* in a pure culture within a Petri dish after the isolation and purification process.

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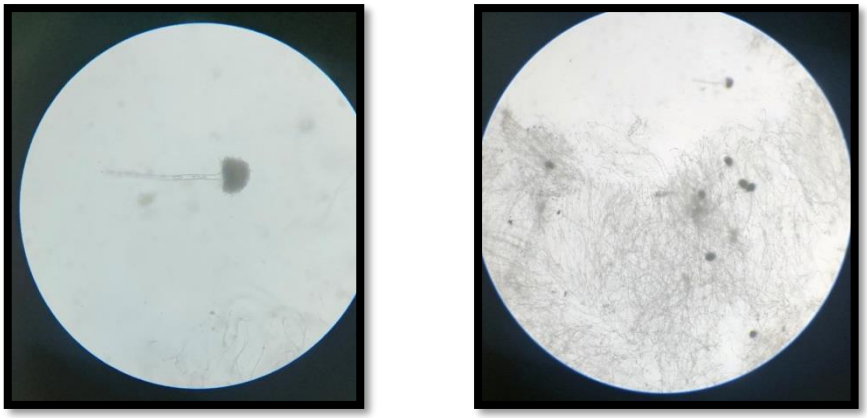

Fig .33. Demonstrates the fungal species *Aspergillus nidulans* under microscopic examination.

Fig .34. Illustrates the fungus *Aspergillus niger* in a pure culture within a Petri dish after the isolation and purification process.

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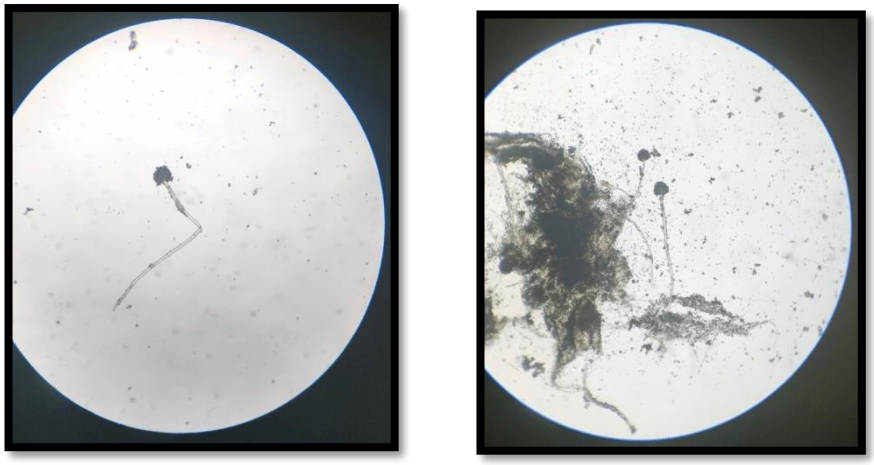

Fig .35. Demonstrates the fungal species *Aspergillus niger* under microscopic examination.

Through the results, it was found that the dominant fungus in the museum is *Aspergillus Niger*, as it was found inside and outside the window, as well as on the leather sandals.

Organic matter, relative humidity, temperature, and dust are fundamental prerequisites for the growth and vitality of these fungi within museum environments. The type and extent of fungal colonization present in indoor air are contingent upon various factors, including the occupancy rate, ventilation system design, geographical location, and structural conditions, all of which exhibit considerable variability across regions and architectural contexts**.**

Fungal decay results in the degradation of proteins and lipids inherent in leather, catalyzed by enzymes produced by fungi such as *Penicillium, Aspergillus flavus, Curvularia*, and *Alternaria* [5, 25], consequently leading to partial or complete loss of the leather substrate [1]. Initially, these fungi initiate the breakdown of fats and simple proteins within the leather, followed by collagen degradation [27]. The deleterious effects resulting from mold infestation can be catastrophic [13].

Fabbri Bruno (2017) noted that the principal factors facilitating fungal proliferation are relative humidity levels surpassing 65% and temperatures ranging from 25 to 30 degrees Celsius, conditions consistent with those found in the museum environment (study site) [16].

Certain fungi have the potential to pose health risks to museum personnel, inducing leather sensitivities and potentially impacting the human respiratory system, notably species such as *Aspergillus flavus* and *Aspergillus fumigatus*. Ideally, their concentration should be maintained at zero [5, 25]. conducted a survey to investigate the health symptoms experienced by employees while working in two distinct libraries—one established in 1956, designated as the old library, and the other established in 2009, referred to as the modern library. The survey findings encompassed a range of general symptoms, including respiratory difficulties, coughing, eye dryness and watering, eye irritation, sneezing, nasal congestion, cold symptoms, throat irritation, headache, fatigue, dizziness, nausea, and leather inflammation.

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However, employees in the modern library reported fewer health complaints for most symptoms compared to their counterparts in the old library [25].

Conclusions

The indoor environment of the Cairo Museum situated within the Egyptian Geographical Society's premises, is deemed unsuitable and hazardous for the conservation or storage of archaeological artifacts. Findings from the study reveal significant and conspicuous fluctuations in both relative humidity and temperature levels throughout various phases of investigation. Furthermore, there is a notable escalation in air pollutant concentrations within the museum's milieu, precipitating the deterioration and decay of archaeological holdings, while also fostering a Conducive habitat for microbial organisms and insects.

Consequently, these artifacts are exposed to considerable risks of degradation and eventual loss. It is imperative for the museum to exercise stringent control over these variables and, at minimum, provide the essential prerequisites for artifact preservation and enduring safeguarding. A comprehensive investigation is warranted, accompanied by the formulation of a comprehensive strategy aimed at ameliorating preservation and storage conditions within the Egyptian Geographical Society Museum.

Acknowledgments

Much gratitude and appreciation to Professor Dr. Mahmoud Sayed Morsi, professor of textiles at the National Institute of Standards, Giza. Also to Professor Dr. Abdel Hameed A.Awad, and Dr. Yuosra Saeed, Air Pollution Research Department, National Research Centre, Dokki, Giza, Egypt. and Dr. Ahmed Mohamed El Sayed, the researcher at the Research and Development Center, Egypt University of Science and Technology, For their participation and contribution to this study.

Gratitude is also extended to the team of the Egyptian Geographical Society, for their cooperation, guidance, and facilitation of the workflow during the study period.

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