Egyptian Journal of Archaeological and Restoration Studies
An international peer-reviewed journal published bi-annually
www.ejars.sohag-univ.edu.eg

Original article

# AN ANALYTICAL STUDY OF ONE OF THE ARCHAEOLOGICAL ARABIC PAPYRI IN THE MUSEUM OF ISLAMIC ART- EGYPT

Mahmoud, R.[1(*)], Hassan, R.[2], Mansour, M.[2] & Mohamed, H. [3]

[1] MA Student, Conservation dept., Faculty of Archeology - Cairo Univ., Egypt, [2] Conservation dept., Faculty of Archaeology, Cairo Univ., Giza, Egypt, [3] Director general of restoration, Museum of Islamic Art, Giza, Egypt
E-mail address: rushdyarabii@cu.edu.eg

**Article info.**

EJARS – Vol. 13 (2) – Dec. 2023: 223-232

**Article history:**
Received: 5-1-2023
Accepted: 10-6-2023
Doi: 10.21608/ejars.2023.330905

**Keywords:**
*Arabic gum*
*Carbon ink*
*Papyri*
*Damage*
*SEM-EDX*
*FTIR*

***Abstract**:*
*The study aims to analyze and examine a degraded archaeological papyrus in the Restoration Laboratory of the Museum of Islamic Art in Cairo to identify its state of degradation. The study employed the digital microscope, SEM with EDX, FTIR-ATR, and PH. The SEM micrographs showed the distinctive waveform in the papyrus, indicating that this papyrus was made in the manner of the slides. The EDX Unit confirmed that the ink used was carbon ink and showed high oxygen levels, indicating damage to cellulose fibers. Additionally, the result of the FTIR-ATR showed that gum Arabic was the material used as a binder for carbon ink. The difficulty in the current study lies in the small size of the samples and the severe damage the papyrus suffered from. This study is the first to be conducted on this papyrus, making it a promising study to reveal the nature of the technique used for it, the nature of the inks, and the mechanics of damage that occurred over thousands of years.*

## 1. Introduction

Manuscripts are considered one of the most important sources of access to heritage throughout history because of the texts and drawings that provide much information about the past. Unfortunately, most of these manuscripts have not been adequately preserved. Thus, they are exposed to many damage factors, including microbiology. For example, fungi degrade the cellulose and lignin of papyrus components, causing parchment to become brittle and peeling off writings and drawings. The length of the papyrus pages ranges from fifteen to thirty centimeters. The University of Leipzig has kept a strip of papyrus about 20 meters long, showing one hundred and ten columns of writing [1]. Papyrus is a giant root plant that may reach 9 meters high, but it is usually 4-5 meters. The rhizomes of sedge are epiphytic, and each apex initially adds to the length of the rhizome [2]. The papyrus plant, which was used to manufacture these manuscripts, consists of a stem with a triangular section and consists of only two parts: a thin hard shell and an inner cellular nucleus. This pulp is used in the manufacture of papyrus [3]. The papyrus plant was used not only in the manufacture of manuscripts but also in the manufacture of sandals, baskets, and boxes [4]. It consists of adjacent strips of papyrus fibers to give a net pattern [5]. Papyrus was produced from thin strips cut from papyrus. The pulp was laid out in two braided layers, pressed or beaten together, and dried [6,7]. Once the papyrus was made, it was bundled together to form lists [8]. The ink used in writing was one of the main components of the various records and documents [9]. Carbon ink was used in writing the pieces in question. It was used in ancient times as a writing material [10]. The inks consisted of a colored or inorganic substance and a binder, such as glue, and were diluted with water or other liquids, such as vinegar or wine, in manuscripts [11]. The inks were made by mixing ground pigments into a binder. The ink most commonly used was carbon black or carbon soot associated with gum Arabic [12,13]. The most popular medium of writing and coloring is mainly the use of gum Arabic when inking, especially carbon ink, to reduce the flow of liquid ink on a different writing surface, such as papyrus and paper. Carbon inks are based on the dispersion of carbon atoms using a water solvent [14]. Inactive carbon is chemically inert and lasts a long time on old papyrus, but it is affected and stained by wet weather or direct water due to the dissolution of the binder in the toner granules [15-17]. Carbon ink has the advantage that the particles do not fade over time even when exposed to light because carbon is chemically stable, but carbon ink tends to smudge in humid environments [18]. Knowing the composition of inks and materials helps museums for ancient preservation and storage purposes of papyrus [19]. The pigment was black. It is almost exclusively identified as carbon in the form of soot, charcoal, or bone black [20]. Temperature affects the decay of natural inks and pigments on the papyrus surface [21]. Papyrus is malleable, but relative humidity fluctuations affect it severely, with symptoms such as poor mechanical properties, breakdown from glucoside bonds in cellulose chains, and dissociation of fibrils [22]. Cellulose is a photopolymer consisting of several units of D-glucose lignin, and it is one of the main components of papyrus [23]. Two microcircular arrangement systems are present in cellulose: regions with limited crystalline patterns and regions in which the fibril bundles appear irregular, random, and pointed [24]. As the cellulosic archaeological materials are exposed to microbeological damage, they lose their endurance and physical and mechanical properties [25]. Therefore, papyrus is putrefied by various microorganisms, such as saprotrophic fungi. Furthermore, the spinning of actinomycetes has been observed on papyrus. Shitumene affects Papyrus frequently. These fungi dissolve vinegar or wine in manuscripts [26]. Fungi follow the Kingdom of Thalassa, which is completely devoid of chlorophyll and has a thick cell wall composed of simple sugars [27]. The fungus that grows on papyrus is white. It damages sedge by breaking down the cellulose due to the enzymes it secretes. The first process involves enzymes that break down cellulose into cellulose, while the second process involves the decomposition of cellulose into glucose, which is the cellular structure of cellulose molecules [28]. Some fungi feed on the sugars and starches stored in the cellular spaces of the papyrus and often have a color effect.

## 2. Materials and Methods

### 2.1. *Archaeological papyrus*

The archaeological papyrus understudy was located in the restoration laboratory of the Museum of Islamic Art No. 25093. It was a rectangular papyrus with separate areas and writings from Klein in Arabic, as the writings on the other side from the bottom begin with the Basmala. The papyrus was fragile because of the high humidity, lighting, and temperature. It was not preserved in drawers or folders designated for papyrus because it was not displayed. It was not preserved between glass panels where the high humidity caused biological damage to the papyrus, which was represented in the growth of some fungi on the top, as indicated by the isolations and examinations.

### 2.2. *Visual examination*

The papyrus pieces were visually examined by the naked eye. Then, they were examined by magnifying lenses. Before any restoration work, the papyrus pieces were documented by photography, which must be taken before and after the restoration work using a brand camera [*EF-SIII18-55mm, 55mm focal length, 18MP sensor, and 2.7 inch LCD screen*].

### 2.3. *Taking isolates*

Some isolates were taken from the anterior and posterior sides of the papyrus understudy.

### 2.4. *USB Digital microscope*

Using a digital microscope helped observe the aspects of damage that could not be seen with the naked eye because it has a high magnification power of 100 to 1000. This examination of papyrus pieces revealed color changes, small holes, and fine cracks. A digital microscope with the following specifications was used [*dynamic frames: 30 fps (under 600 lux brightness) – illumination range: 30000 lux (adjustable) – LED: 8 LED (adjustable) / material: plastic case / shell-color: black- under operating conditions of WIN XP/VISTA/WIN 7/8 32 bites & 64 bites*] at the X-ray diffraction laboratory, Cairo University.

### 2.5. *Scanning Electron Microscope (SEM)*

A scanning electron microscope was used [*Device brand: FEL company, model: Quanta 3D 200i operated under conditions of low vacuum for acceleration voltage 20.0 - 30.0 Kv using a large field detector with a working distance of 15-17 mm*] in the Grand Egyptian Museum for photographing the ink on the sample and identifying the changes of the sample as a result of the factors of damage over time and identifying the type of ink used in writing through racial analysis through the EDX unit.

### 2.6. *Infrared spectroscopy*

The infrared spectroscopy [*brand Braker Optics Company and model vertex 70 under a spectral range of 400-4000 cm$^{-1}$*] was used to identify the functional groups of the papyrus sample and the ink sample. It helped identify the extent of chemical changes in the papyrus used in writing over time and determine the type of medium used in the ink.

### 2.7. *pH measurement*

The pH was measured using paper indices in order to preserve the pieces of papyrus, the subject of research, as it is a safe way to identify the acidity rate in pieces of papyrus.

## 3. Results

### 3.1. *Visual examination*

The visual examination of papyrus pieces were, fig. (1-a), showing the presence of missing parts and peeling in the existing writings in addition to sharp edges and pieces and some color changes. This was documented using Photoshop, fig. (1-b).

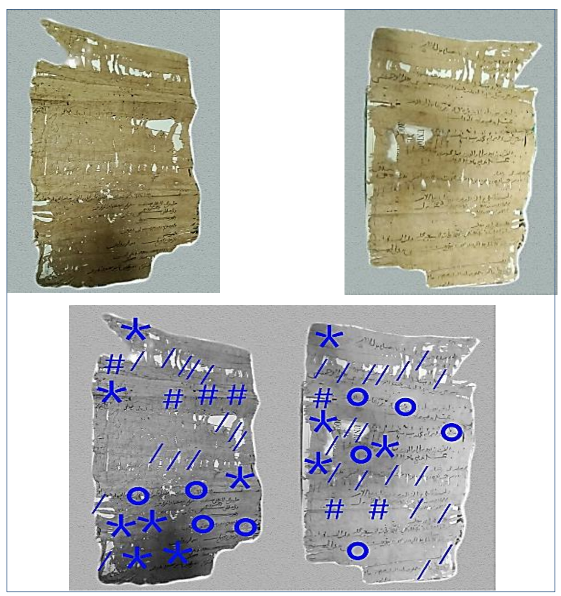


Figure (1) Shows the archaeological documentation of papyrus **a.** the obverse of the papyrus, **b.** the reverse of the papyrus, **c.** Photoshop archaeological papyrus ink fading and peeling (oo), Missing parts of the papyrus (//) color change in papyrus **(**)** and sharp cuts (**##**)

### 3.2. *USB digital microscope*

A digital microscope was used to examine the pieces of papyrus, which helped identify the damage that is hard to see by the naked eye. The papyrus needs appropriate preservation conditions of heat and humidity. Still, in the case of fluctuations in the humidity levels, this leads to a breakdown of the cellulose fibers and a breakdown in the mechanical properties [17]. The results of the digital microscope examination indicated the appearance of accumulated dust and dirt, in addition to some tears in sample 1. Additionally, they illustrated that a color change occurred in some areas with drying and shrinkage in the papyrus slices in sample 2, in addition to dispersion in the ink grains and peeling in some parts of the ink in sample 3. Sample 4 suffered from fading in the ink used for writing and the loss of some parts, $fig_s$. (3-a: h),

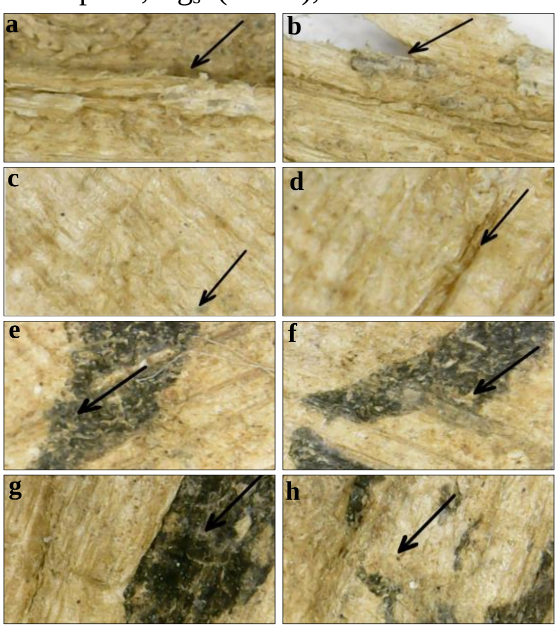



Figure (2) Shows digital microscope images of the archaeological papyrus (S 1) **a.** the dirt and dust on the surface of the papyrus, **b.** a tear in some parts of the papyrus, (S 2) **c.** a change in the color of the segments of the papyrus, **d.** drying and shrinkage of the slices of papyrus. (S 3) **e.** dispersion of ink granules, **f.** peeling in the ink, (S 4) **g.** fad-ing and discoloration in the ink, **g.** Loss of some parts of the ink used in writing.

### 3.3. *Taking isolates*

Isolates were grown in sterile Petri dishes containing a nutrition environment known as PDA, containing 200 grams of potatoes, 20 grams of agar, 20 grams of dextrose, and 1000 ml of distilled water. The dishes were incubated for 10 days in the incubator [29], where some fungal growths appeared. After doing the purification process, their laboratory examination by a light microscope, and preparing them on microscopic slides, it was found that there were three species, namely *Fusarium solani* (Mart), *Niger carbonaires*, and *Niger sydowii*, as shown in fig. (4-a, b & c).

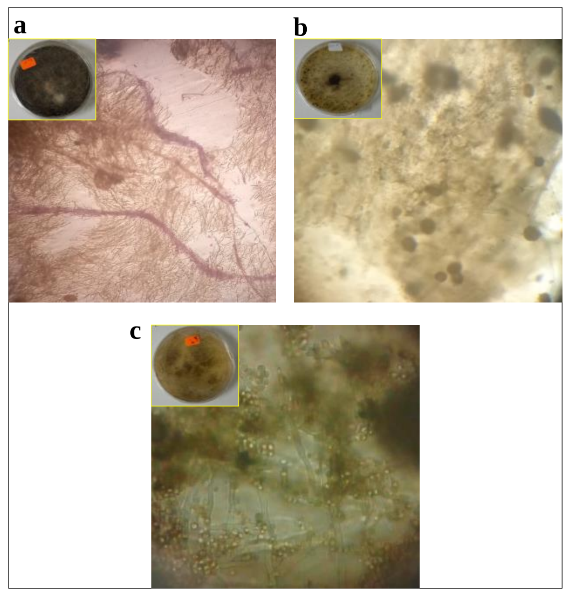



Figure (4) Shows pure plates and light microscopy pictures of the three aforementioned fungi; **a.** *Fusarium saloni*, **b.** *Niger carbonaires*, **c.** *Niger sydowii*.

### 3.4. *SEM examination*

Scanning electron microscope showed a beehive-like structure. It illustrated the appearance of the characteristic waveform of the papyrus. In the first stage, the stalk of the plant was sliced into pieces, and the pith was cut out and beaten with a hammer to produce wafers. These were arranged side by side and crosswise in two layers and were then beaten into sheets. Then, the individual pages were stuck together in the same way to form a standard roll of twenty pages, fig. (5-a). Moreover, the examination showed the presence of hyphae and fungal colonies on the papyrus surface [30], fig. (5-b). The fungi were voracious for any of [31] organic materials, such as papyrus, especially in the case of inappropriate preservation conditions. It analyzed the gum Arabic used as a color medium, which caused dispersion and decay of the ink granules, in addition to analyzing the cellulose fibers, which led to the fragility and decomposition of the papyrus.

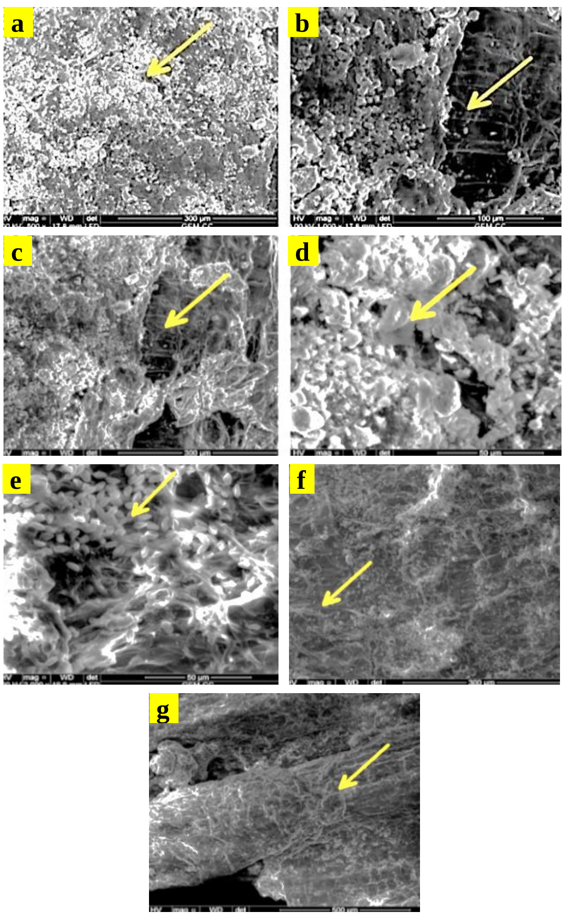



Figure (5) Shows SEM photomicrographs of (S 1) **a.** minute cracks in carbon ink layers, **b.** the waveform indicating the making of the papyrus by the slide method, **c.** the characteristic shape of the slides method, **d.** dispersion of carbon ink granules, (S 2). **e.** many fungal colonies scattered on the papyrus surface, **f.** presence of a network on the surface of the papyrus, **g.** Parenchyma cells that make up the papyrus tissue.

## 3.5. *EDX analysis*

EDX analysis proved the carbon ink in writing, as the carbon element appeared in very high proportions, as shown in the tables. It was abundant, especially in ancient times [32], and was mixed with gum Arabic as a binder [33]. The analysis showed the presence of a group of elements in different proportions, namely (C, O, Mg, Na, Al, Si, P, S, Cl, K, Ca, and Fe), tab. (1) & fig. (6).

Table (1) EDX analysis components of the ancient papyrus sample

| Elements | C | O | Na | Mg | Al | Si | P | S | Cl | K | Ca | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Intensity | 7.33 | 12.48 | 2.14 | 0.95 | 2.63 | 6.65 | 0.65 | 1.28 | 5.02 | 1.82 | 7.23 | 0.55 |
| Weight% | 22.31 | 50.69 | 3.04 | 0.97 | 2.13 | 5.00 | 0.47 | 0.87 | 4.05 | 1.69 | 7.44 | 1.35 |
| Net counts | 2255 | 3840 | 659 | 291 | 810 | 2045 | 201 | 394 | 1546 | 560 | 2224 | 196 |
| Atom % | 31.68 | 54.02 | 2.26 | 0.68 | 1.35 | 3.04 | 0.26 | 0.46 | 1.95 | 0.74 | 3.16 | 0.41 |

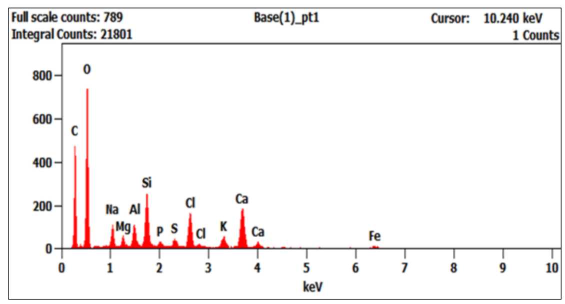



Figure (6) Shows EDX pattern of ancient papyrus sample

## 3.6. *pH measurement*

The degree of acidity of the papyrus was measured using colorimetric pH strips, as they do not harm the samples that represent the papyrus and do not need to be dissolved in water. It is a safe method [32]. The measurement was carried out by placing a drop of water on three samples. The color strips were placed and left for five minutes. Take the three readings and then take the average [16]. After measuring the pH of three samples, the average of the three measurements was taken, which was 6.3, fig. (7)

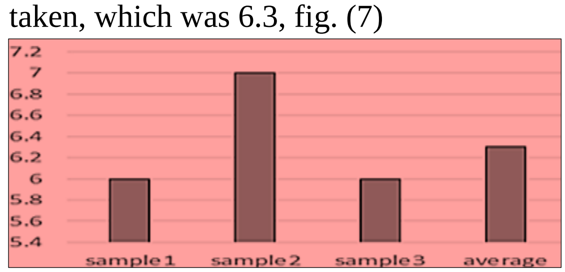


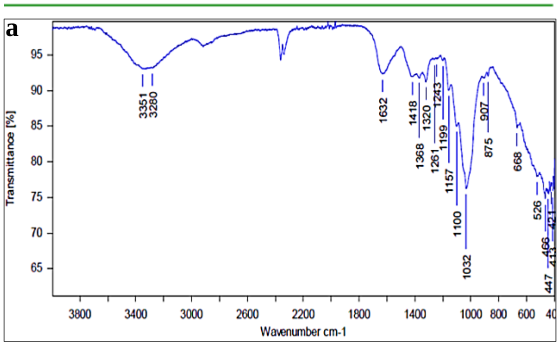

Figure (7) Shows pH measurement results for three samples of papyrus.

### 3.7. *Infrared spectroscopy*

When Coblents analyzed the absorption of hundreds of components and elements, he found many different chemical compounds, such as ethyl, hydroxyl, methyl, and methylene, where he used the absorption properties to know the frequencies or wavelengths. He was one of the researchers who studied the emission absorbed by organic and inorganic materials in the infrared region [35, 36]. The analysis using infrared rays was used in this research to identify the binder of the ink used in writing through its functional groups and determine the functional groups of papyrus [37]. Based on changes in the functional groups, chemical changes that occurred as a result of damage could be recognized [27,38]. Changes in the papyrus with writings had the greatest absorption of peaks near 3343 $cm^{-1}$, 3263 $cm^{-1}$, 2916 $cm^{-1}$-1614 $cm^{-1}$, 1363 $cm^{-1}$, and 1198 cm-1, where the O-H bond appeared at 3343, 3263 $cm^{-1}$, C-CH bond at 2916 $cm^{-1}$, C=C bond at 1614 $cm^{-1}$, C-$H_2$ bond at 1363 $cm^{-1}$, and C-O bond at 1198 $cm^{-1}$. They appeared in a sample devoid of any writings. The greatest amount of absorption of peaks appeared near 3351, 3280, 1632, 1418, 1368, 1320, 1243, 1199, 1157, and 1100. The O-H bond appeared at 3351 and 3280 A, and the C=C bond was shown at 1632. A C-$H_2$ bond was shown at 1418, 1368, and 1320, and a C-O bond at 1243, 1199, 1157, and 1100 [39-42]. All of these data are presented in tab. (2) & fig. (8).

Table (2) FTIR spectrum of the investigated samples

| Samples | Functional groups | | | | |
|---|---|---|---|---|---|
| | *O-H* | *C=C* | *C-CH* | *C-$H_2$* | *C-O* |
| Papyrus | 3351,3280 | 1632 | - | 1418,1368,1320 | 1243,1199,1157,1100 |
| Ink | 3343,3263 | 1614 | 2916 | 1363 | 1198 |
| Gum Arabic standard | 3320,3250 | 1599 | 2924 | 1413 | 1146 |



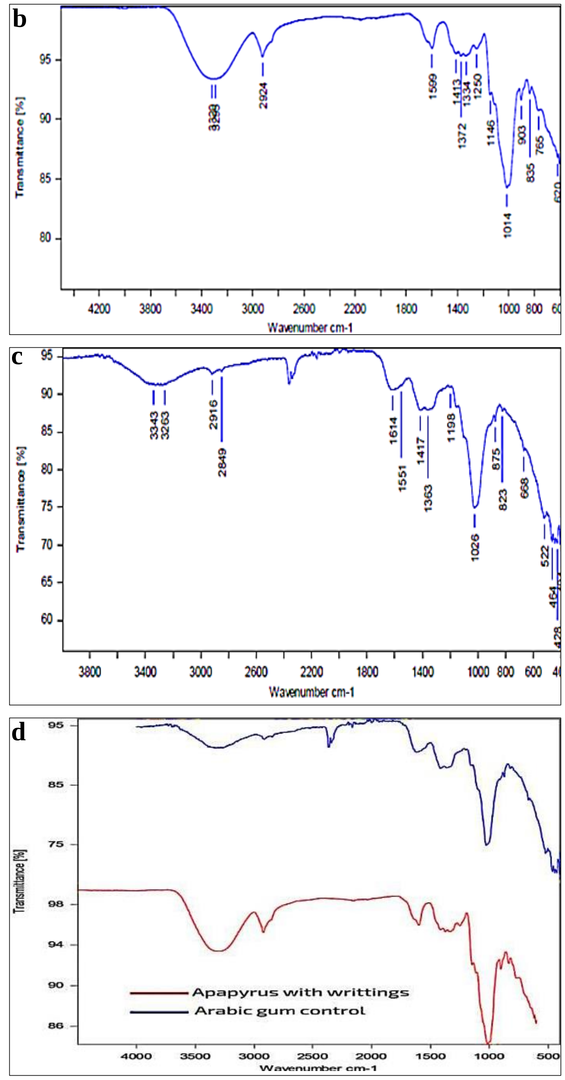




Figure (5) Shows FTIR spectra for **a.** papyrus free of writing, **b.** standard Arabic gum, **c.** papyrus with writings, **d.** arabic gum standered and papyrus sample with writings

## 4. Discussion

Archeological materials are exposed to many factors of damage, which affect them negatively. The greatest impact is on organic antiquities. Based on the visual examination and digital microscope imaging of that manuscript, we concluded that it was in completely inappropriate preservation conditions, especially in terms of the degree of humidity, which led to the presence of many missing parts, ink peeling, fading, and fragility of cellulose fibers that might be due to the effect of fungi on those pieces as a result of not keeping them in appropriate conditions. When they grow, they are among the strongest factors that decompose organic materials [43], including papyrus and graffiti, leading to dispersion and peeling of the inks [18]. The scanning electron microscope examination showed many fungal colonies and hyphae scattered on the surface of the papyrus, in addition to the appearance of the distinctive waveform, indicating that this papyrus was manufactured using the slide method [44]. These segments were obtained by cutting the inner core of the papyrus stem [45], as the inner core consists of cellulose, hemicellulose, and lignin [46]. In addition to some elements of silicon, aluminum, and calcium by compressing these strips [47], papyrus was made. Pressure occurred on each cell of the parenchyma as the slices were compressed together, which helped in obtaining good papyrus rolls [48,49]. After that, it was written on it using carbon ink mixed with gum Arabic, and this was proven by the elemental analysis of the manuscript, such as (C, O, Mg, Na, Al, Si, P, S, Cl, K, Ca, and Fe). The presence of potassium, calcium, and magnesium caused carbonic ink to mix with gum arabic [50-52]. The Egyptologist [19] noted that the ancient Egyptians used the same technology to produce ink throughout Egypt from about 200 B.C. to 100 A.D. Also, the appearance of the O-H hydroxyl group in the absorption region 3343,3263 $cm^{-1}$ in the blank papyrus sample indicated the occurrence of hydrolysis of the cellulose bond. By comparing the functional groups that appeared in certain absorption regions of the papyrus sample on the ones that were written with the gum Arabic standard, the conformity showed that the binder used in the ink was gum Arabic [36]. The papyrus had a pH of 6.3, which is considered harmless unless there is another source that can cause an increase in acidity.

## 5. Conclusion

*Papyrus, like any organic material, is affected by inappropriate preservation factors, especially high humidity. The results confirmed that the archaeological papyrus was made using the method of slices. It also proved that the writings on it were written using carbon ink. The analyses confirmed that the binder used was gum Arabic. Due to the inappropriate preservation conditions, the papyrus was subjected to microbiological damage. The examination showed the presence of many fungal colonies, which affected the papyrus, as they caused fading in the used ink and peeling through the analysis of the organic substance used as a binder in the ink.*

## References


**[1]** Saleh, R. (1901). *Alkitab bin alʾms wa lyawm (Making the book: Past and present)*, Arab Scientific Pub., Beirut

**[2]** Azza, N., Kansiime, F. Nalubega, M., et al. (2000). Differential permeability of papyrus and Miscanthidium root mats in Nakivubo swamp, Uganda, *Aquatic Botany*, Vol. 67 (3), pp. 169-178

**[3]** Lucas, A. (1945). *Ancient Egyptian materials and industries*, 2nd ed., Edward Arnold & Co, London.

**[4]** Parkinson, R. & Quirke, S. & Wartenberg, U. (1995). *Papyrus*, Univ of Texas Press, USA.

**[5]** Pliny the Elder. (1945). *Natural History*, Vol. 4 (B 12-16) Harvard Univ. Press, USA..

**[6]** Wallert, A. (1989). The reconstruction of papyrus manufactures: A preliminary investigation, *Studies in Conservation*, Vol. 34 (1) pp. 1-8.

**[7]** Leach, B. & Tait, J. (2000), Papyrus, in: Nicholson P. & Shaw I (eds.) *Ancient Egyptian Materials and Technology*, Cambridge Univ. Press, UK, pp. 227-253.

**[8]** Wiedemann, H. & Bayer, G. (1983). Papyrus: The paper of ancient Egypt, *Analytical Chemistry*, Vol. 55 (12), 1220-1230.

**[9]** Hamid, M. (2009). *Dirāsah taṭbīqīyah lt'thyrāt aḥbār al-kitābah al-mukhtalifah ʻalá al-makhṭūṭāt wa-al-wathā'iq* *al-waraqīyah wa-ahamm turuq al-mu'ālajah wa-al-ṣiyānah tṭbyqā 'alá mamādhij mukhtārah (An empirical and applied study of the effects of different writing inks on manuscripts and paper docum-ents and the most important methods of treatment and maintenance applied to selected models)*, MA., Restoration dept., Faculty of Archaeology, Cairo Univ. Cairo

**[10]** Lucas, A. (1922). The inks of ancient and modern Egypt, *Analyst*, Vol. 47, pp. 9-15.

**[11]** Shelby, E. (2013). *Taqyīm 'alamī w'mly lil-ṭuruq al-taqlīdīyah al-mustakhdamah 'ālmyan l'zālh ḥmwḍh al-waraq fī ba'ḍ al-kutub wa-al-dawrīyāt wa-al-maṭbū'āt al-mubakkirah (A scientific and practical assessment of the traditional methods used globally to remove the acidity of paper in some books, periodicals and early publications)*, MA., Conservation dept.,, Faculty of Archaeology, Cairo Univ., Egypt.

**[12]** Grohmann, A. (1952). *From the world of Arabic papyri*, Al Maeref Press, Cairo.

**[13]** Hassan, R., Mahmoud, S., Nessem, M., et al. (2021). Hydroxypropyl cellulose loaded with ZnO nanoparticles for enhancing the mechanical properties of papyrus (Cyperus papyrus L.) strips, *BioResources*, Vol. 16 (2), pp. 2607-2625.

**[14]** Lucas, A. (1991), Preservation and presentation of self in ancient Egyptian portraiture, *J. of the Museum of Fine Arts*, Vol. 3, pp. 4-14.

**[15]** Hassan, R., Ali, M., Fahmy, A., et al. (2020). Tawthīq wa-taqyīm makhṭūṭah waraqīyah qadīmah dhāt cover jldy bi-istikhdām al-ṭuruq alṭyfyh (Documentation and evaluation of an ancient paper manuscript with leather binding using spectrometric methods), *J. of Chemistry*, Vol. 2020, pp. 684-791.

**[16]** Abed-El Hamid, H. (1994). Al-*ṭarīqah al-'ilmīyah li-mu'ālajat wa-ṣiyānat al-makhṭūṭāt al-atharīyah wāl'khshāb wālmnswjāt (Scientific method for the treatment and maintenance of archaeological manuscripts, woods and textiles)*, Public Book Association, Cairo.

**[17]** Hamed, S. & Hassan, R. (2019). Microscopic characterization of acidic paper manuscripts, *Pigment & Resin Technology*, Vol. 48 No. 2, pp. 119-128.

**[18]** Christiansen, T., Cotte, M., Laredo-Portales, R., et al. (2017). The nature of ancient Egyptian copper containing carbon inks is revealed by synchrotron radiation-based X-ray microscopy, *Scientific Reports*, Vol. 7 (1), doi: 10.1038/s41598-017-15652-7

**[19]** Lee, L. & Quirke, S. (2000). Painting materials:, in Nicholson, P. & Shaw, I (eds.) *Ancient Egyptian materials and technology*, Cambridge Univ. Press, Cambridge, pp. 104-117.

**[20]** Martial, M. (2015), *Epigrams: With parallel Latin text*, 1st ed., Oxford Univ. Press, Oxford.

**[21]** Cockle, W. (1983). Restoring and conservation papyrus, *Bulletin of the Institute of Classical Studies of the Univ. of London*, pp. 147-165

**[22]** Fawzi, M. (2016). *Dirāsah muqāranah li-ta'thīr almnẓfāt 'alá al-tarkīb al-kīmiyā'ī wa-al-khawāṣṣ al-mīkānīkīyah ll'khshāb altālfh wa-ghayr altālfh ma'a taṭbīqāt 'amalīyat fī al-mu'ālajah wa-al-ṣiyānah 'alá aḥad al-namādhij al-atharīyah al-mukhtārah (A comparative study of the effect of detergents on the chemical composition and mechanical properties of damaged and undamaged wood with practical applications in treatment and maintenance on one of the selected archaeological models)*, Ph.D. Conservation dept., Faculty of Archaeology, Cairo Univ., Egypt

**[23]** Rabee, R. (2012). *Dirāsah tajrībīyah 'alá ba'ḍ al-mawādd wa-ṭuruq mu'ālajat al-aḍrār al-nājimah 'an al-ta'thīrāt al-mutabādalah bayna jallūd al-dibāghah wa-al-kutub al-waraqīyah tṭbyqā 'alī namādhij mukhtārah (An experimental *study on some materials and methods to deal with the damage caused by the mutual effects between the skins of tanning and paper books according to selected models)*, Ph.D. Conservation dept., Faculty of Archaeology, Cairo Univ.

**[24]** Gad EL Rab, H. (2007). *Dirāsah al-ʻawāmil al-ḍārrah lljlwd al-atharīyah wa-ṭuruq muʻālajatihā wa-ṣiyānatuhā tṭbyqā ʻalī namādhij Mukhtārah (A study of the damaging factors of archaeological skins and their methods of treatment and maintenance according to selected models)*, MA., Conservation dept., Faculty of Archaeology, Cairo Univ., Egypt.

**[25]** Zaki, A. (1987). *Muʻālajat wa-ṣiyānat al-bardīyāt al-atharīyah tṭbyqā ʻalá al-bardīyāt min hay'at al-āthār al-Miṣrīyah (Treatment and maintenance of archaeological papyri applied on papyri from the Egyptian Antiquities Authority)*, MA., Conservation dept., Faculty of Archaeology, Cairo Univ., Egypt.

**[26]** Abed-Maksoud, G. & El-Amin, A. (2013). The investigation and conservation of a gazelle mummy from the late period in ancient Egypt, *MAA*, Vol. 13, pp. 45-67

**[27]** Shahin, A., (1978). *Muʻālajat wa-ṣiyānat baʻḍ al-makhṭūṭāt wālbrdyāt min al-matḥaf al-Qibṭī (Treatment and maintenance of some parchment and papyrus from the Coptic museum)*, MA., Conservation dept., Faculty of Archaeology, Cairo Univ., Egypt.

**[28]** Ramadan, S. (2018). *Dirāsah tajrībīyah muqāranah fī taqwiyat al-nuqūsh al-ḥajarīyah aljyryh al-atharīyah al-mustakhrajah min turbah ʻāliyah alrṭwbh wa-ghunyat bālkā'nāt al-ḥayyah al-daqīqah bi-istikhdām al'krylyk wālmṣlbāt alnānwyh tṭbyqā ʻalá baʻḍ al-namādhij al-mustakhrajah min hfā'r madīnat Ūn bi-al-Maṭarīyah (A comparative experimental study in strengthening the archaeological limestone stone carvings extracted from soil of high humidity and rich in microorganisms, using acrylic and nano-hardeners, applying to some models extracted from the excavations of the city of Uon in el-Mataria)*, MA., Conservation dept., Faculty of Archeology, Cairo Univ., Egypt.

**[29]** Rabee, R. (2015). Analytical study of a manuscript, 'Tafsir Al khazin' - the seventeenth century AD], *Current Science Int.*, Vol. 4 (2), pp. 196-197

**[30]** Ayman, S., Mohamed, Z., Wael, A., et al. (2019). Assessment of the impact of different treatments on the technological and antifungal properties of papyrus (Cyperus Papyrus L. Sheets), *Materals,* Vol. 12 (4), doi: 10.3390/ma12040620

**[31]** Hassan, R. (2021), Recently discovered corn mummy in ibis - South of Abu Sir - North of Saqqara: A case study, *IJCS*, Vol. 12 (3), pp. 879-892

**[32]** Lucas, A. (1962). The inks of ancient and modern Egypt, *The Analyst*, Vol. 47 (550), pp. 9-15.

**[33]** Hassanein, R. (2019). *Derasa tagrebia fi estkhdam DNA fi tahlyl watarekh al - makhṭūṭāt ālbrdyā wa takum bad el toruk fi tak wayte albrdy wa el tatpek ala namozag mo khtar (An experimental study of the use of DNA in analyzing and dating papyrus manuscripts and evaluating some methods of strengthening papyrus by applying a selected model)*, MA., Conservation dept., Faculty of Archaeology, Cairo Univ., Egypt.

**[34]** Gore, R. (1943). *Infrared spectroscopy as an organic analytical tool, Am.* Chemical Society & Division of Chemical Education, Inc., USA.

**[35]** Cohen, Z., Kindzorra, E., Hahn, O., et al. (2015). Composition of the primary inks in medieval palimpsests effects of the removal, Opuscula Musealia, Vol. 23, pp. 75-82

**[36]** Bausch, F., Mario, J., Rencoret, J., et al. (2022). Papyrus production revisited:

differences between ancient and modern production modes, *Cellulose*, Vol. 29, pp. 4931-4932

**[37]** Noshy, W., Hassan, R., & Mohammed, N. (2022). Using biopolymers to strengthen the historical printed paper: mechanical and optical characters], *Pigment & Resin Technology*, Vol. 51 (2), pp. 212-226.

**[38]** Michele, R. (1999). *Infrared spectroscopy in conservation science: Scientific tools for conservation*, Paul Getty Pub., Los Angeles.

**[39]** Al Sharif, M., El-Sabbah, M., Salim, A., et al. (2020). A comparative study between spectroscopic and physical techniques for discrimination of the counterfeited computer-generated documents (A case study), *Egyptian J. of Chemistry*, Vol. 63 (10), pp. 3631-3639

**[40]** Baker, M., van der Reyden, D. & Ravenel, N. (1989). *FTIR analysis of coated paper*, The Book and Paper Group Annual, Vol. 8, AIC, NY.

**[41]** Hassan, R. (2015) A "Tafsir AL Khazen" manuscript ($17^{th}$ century AD). a technical study," *IJCS*, Vol. 6 (3), pp. 369-382

**[42]** Sterflinger, K. (2010) Fungi: Their role in deterioration of cultural heritage, *Fungal Biology Reviews*, Vol. 24 (1-2), pp. 47-55.

**[43]** Mark, J. (2016). Egyptian papyrus, *https:///www.worldhistory.org/Egyptian_Papyrus/* (10/2/2023).

**[44]** Portolés, J. (2017). East Asian materials and techniques in western conservation, Institute of Conservation (Icon), London, *https://culture360.asef.org/news-events/publication-east-asian-materials-and-techniques-in-western-conservation/* (8/11/2022)

**[45]** Chiappe, C., Silvio, C. & Sartini, S., (2019). Combined use of scanning electron microscopy-energy-dispersive x-ray spectroscopy and fourier transform infrared imaging coupled with principal component analysis in the study of ancient Egyptian papyri, *ACS Omega*, pp. 22041-22042.

**[46]** Owen, A. & Danzing, R. (1993). The history and treatment of the papyrus collection at the Brooklyn museum, in: AIC (ed.) *The Book and Paper Group*, AIC, Washington, pp.36-43.

**[47]** Ragab, H. (1980). *Contribution à l`étude du papyrus (cyperus papyrus L)*, Pub. by Ragab Papyrus Inst., Cairo.

**[48]** Hassan, R. (2021). Recently discovered corn mummy in Ibis - south of Abu Sir-north of Saqqara: A case study, *IJCS*, Vol. 12 (3), pp. 879-892

**[49]** Frozen, J. (2009). Conservation of ancient papyrus material, in: Bagnall, R. (ed.) *The Oxford Handbook of Papyrology*, Oxford Univ. Press, Oxford, pp. 79-100

**[50]** Rabin, I. Hahn, O. & Geissbühler, M. (2014). Combining codicology X-ray spectrometry to unveil the history of production of codex germanicus 6, (Staats und Universitätsbibliothek Hamburg), *Manuscript Cultures*, Vol. 7, pp. 126-131

**[51]** Affendi, A. (1999). *Dirāsah mkhtbryh wa-taṭbīqīyah li-ʻawāmil talaf al-makhṭūṭāt al-bardīyah wa-ṭuruq muʻālajatihā wa-ṣiyānatuhā wtrmymhā (Laboratory and applied study of the factors of damage to the papyrus manuscripts and methods of treatment, maintenance and restoration)*, MA., Conservation dept., Faculty of Archaeology, Cairo Univ., Egypt.