Study of Deterioration Factors and Aspects of the Linen Wraps of Tayuheret's Mummy in the Egyptian Museum

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Abstract:

The present paper aims to study cleaning the linen fabric wrappings used for mummies throughout ancient Egyptian history. It was applied to the linen fabric wrappings of Tayuheret's mummy (the Third Intermediate Period). The conservation and restoration of the mummy took the following stages; first the dating and technical/artistic analysis.

The assessment of the impact which used materials in the mummification on the linen wrappings of the mummy, then, examining the role of deterioration factors on the physical and chemical characteristics of the linen fabric wrappings. Followed by, studying the latest examination types and scientific analysis for the sample of Tayuheret's mummy (linen wrappings, mummification materials, and dyed linen fabric wraps). Finally, providing a restoration and conservation method of the linen fabric wrappings according to the scientific conditions of the conservation and restoration of archaeological linen fabric.

Keywords:

Linen wrappings, Mummification materials, Mummy, Examination and analysis, Biological degradation, Conservation and restoration.

الملخص البحث:

يهدف هذا البحث إلى دراسة تنظيف اللفائف الكتانية المستخدمة فى لف المومياوات فى العصور المصرية القديمة لذلك تطبيقا على اللفائف الكتانية لمومياء تايوحريت التى ترجع إلى عصر الأنتقال الثالث، ومريت عمليات العلاج والصيانة

بالعديد من المراحل بداية من معرفة تاريخ القطعة وتحليلها فنيا.وكذلك دراسة تقييم تأثير مواد المستخدمة فى عمليات التحنيط قديما على اللفائف الكتانية للمومياء، ايضا دراسة دور عوامل التلف المؤثرة على الخصائص الفيزيائية والكيميائية للفائف الكتانية.مع إجراء الفحوص والتحاليل العلمية للعينات التى تم أحذها من حالة الدراسة مومياء تايوحريت (لفائف كتانية- مواد تحنيط – لفائف كتانية مصبوغة)، مع تقديم طريقة للعلاج والصيانة للفائف الكتانية تتفق مع الاشتراطات العلمي المتبعة فى مجال العلاج والصيانة الكتان الأثري.

الكلمات المفتاحية:
اللفائف الكتانية ، مواد التحنيط ، المومياء، فحص وتحليل ، التلف البيولوجى

Introduction:

The ancient Egyptians used linen fabrics wrappings mummies because they sacred linen fabric, believing that Ozer was wrapped in it after death[1]. The importance of linen fabric was not limited to daily activities but included the Other World because the ancient Egyptian believed in and developed mummification through the different ancient Egyptian (Pharaonic) ages. Linen fabric was used as internal wrappings for mummies as if an outer coffin covered the mummy after mummification. Herodotus reported that Egyptian priests refused to allow the corpus not wrapped in linen fabric to the temple[2].

However, mummification in ancient Egypt needs further specialized exploration. More studies shall be conducted to examine the used materials, chemical composition, as well as the physical and chemical characteristics and their role and destructive impact on the mummies and linen fabric wrappings. Several deterioration manifestations have been noted on the mummies in the closed coffins in the burial rooms, such as the charring of Tutankhamun's mummy, its burned-like linen fabric wrappings, fading or changing color of some of them, and biological degradation.

Therefore, the present study aims to explore the deteriorating effects of some mummification materials on the deterioration of linen fibers used as wraps for the mummies and highlight the conservation and restoration methods of the wrappimgs. This topic is quite challenging because of several internal deterioration factors, including mummification materials and natural and human external factors. Thus, many relevant studies have been conducted. Furthermore, the applied part
poses challenges pertinent to the occupational safety and health of the conservator when handling mummies.

Historical and Architectural Background:

Archaeological Description of the Mummy:

Biographical data: "Tayuheret" was probably the wife of high priest" Masaharta".

Details: The mummy understudy (figure 1) is of Tayuheret CG 61032, the lector[3]. of Amun-Ra (a priest who recited spells and hymns during temple rituals and official ceremonies) of the Third Intermediate Period (the 21st dynasty) [4]. She was the wife of Masaaharta, the high priest of Amun in Thebes[5]. She and her husband's mummies were discovered in the Cache at Deir el-Bahari (Tomb DB 320, Room F) on the Western Bank in Luxor in 1881. It is thought that Tomb DB 320 was not the original burial site, but the mummy was transferred to it. Moreover, Tomb DB 320 includes over 50 mummies of kings, queens, princes, princesses, and others[6],

that were prone to robbery and looting by a lector of Amun called Htet (C.G.: 61032), and the gold-plated hands were lost[6]. However, (18) Shabtis, made of blue faience, 10 cm each, were found to help her in the Other World[7]. In the *Royal Mummies*, Smith examined and studied mummies at the Egyptian Museum that were thoroughly examined using C.T. Scanning to identify the mummification method[8]. The evidence from C.T. Scanning of Tayuheret's mummy demonstrates that she was old at death[9].

Fig. (1): The Mummy of Tayuheret

The Mummy of Tayuheret was mummified well but incompletely because the filling method in the early 21st dynasty was not set to high accuracy and quality. Moreover, the nose was filled to prevent deformation caused by wrapping, and the area between the lips was filled to occupy its space. The right eye was filled, but the left one was synthetic. The mummy might wear a wig because the natural hair might be completely white[10].

Technical Description:

Optical and Digital Microscopy:

Using the fabric's lens and the digital microscope to examine the wrap yarn of the mummy understudy showed that the fabric structure is warp 1/1 with 12/cm warp yarn and 14/cm weft yarn.

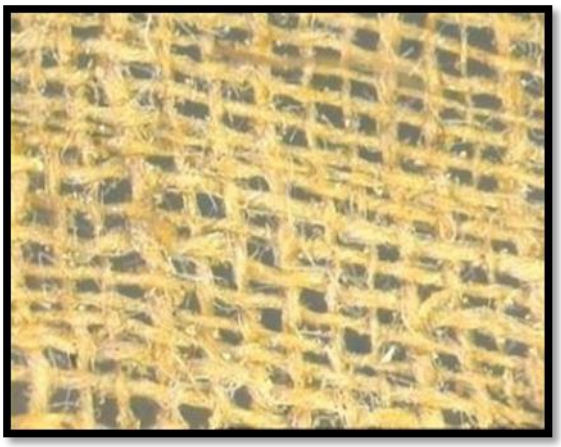


Fig. (2) shows the plain weave warp 1/1

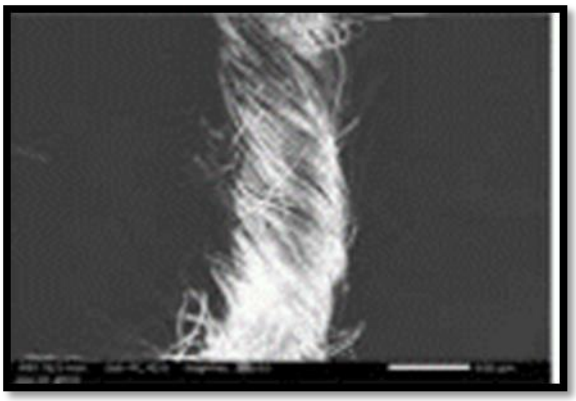


Fig. (3) shows the direction of the warps and wefts yarn

The microscopic examination illustrates that the threads yarns are linen fabric, the direction of the threads; both warps and wefts are to the left, taking the "S" letter form.

Physiochemical Deterioration:

1. Human deterioration
2. Dust and dirt
3. Discoloration and high acidity
4. Tears and cuts

Fig. (4) 1- Human deterioration, 2-dust and dirt, 3- discoloration and high acidity, and 4- tears and cuts

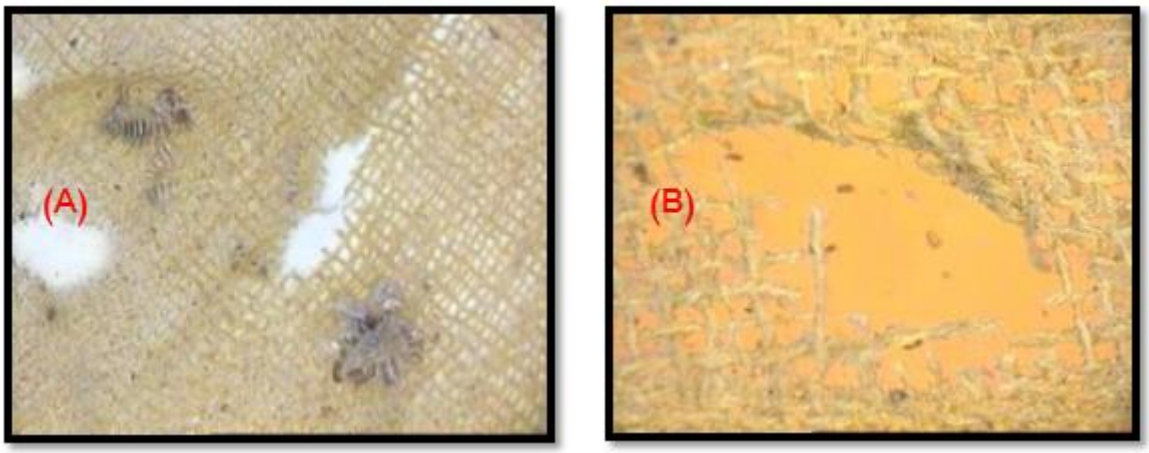


Fig. (5): Optical microscope images of deterioration phenomena; 1 cut of fibers, 2- insect infestation

Microbial Deterioration Manifestations:

Because of the appropriate environment for microorganism growth, including temperature and relative humidity, which encouraged the microbial deterioration of the linen fabric wraps of the mummy understudy, swabs were taken from different body parts from head to foot internally and externally through openings and cuts caused by thieves on the mummy's body.

1. Method of Swabs:

Swabs were taken using a sterilized medical swab on the infected surface. Then, they were put in a sterilized tube wrapped in aluminum foil to prevent pollution, then moved to the laboratory to be cultivated in a nourishing environment.

2. Cultivation of Swabs:

After taking the swabs, they were moved to the Regional Center for Mycology and Biotechnology, Al-Azhar University, for cultivation. The appropriate nourishing environments were cultivated, i.e., Dox's agar medium for fungi and Nutrient agar (Difco) for bacteria.

- Media structure

Table (1) illustrates the structure of Dox's agar medium

Sucrose	30.0gm
$NaNo_3$	2.0gm
K_2HPO_4	1.0gm
$MgSO_4.7H_2O$	0.5gm
KCL	0.5gm
$FeSO_4.7H_2O$	0.01gm
Agar	15.0gm
Distilled water	1000ml

Table (2) illustrates the structure of the Nutrient agar medium

Pepton	3gm
Beef extract	3gm
Sodium chloride	5gm
Agar	15gm
Distilled water	1000ml

The appropriate environment for fungi cultivation was prepared by dissolving the afore-mentioned salts in a little water and heating until boiling to cause complete dissolution. Then, the media of fungi

were sterilized at 121^{o}C and air pressure of 1.5. Under these sterilization conditions, the media were poured into Petri dishes and left until hardening. After that, the swabs were cultivated on the surface of the dishes directly, and the dishes were incubated at 28^{o}C for three days, keeping in mind that they should be observed daily. The bacteria media were incubated at 30^{o}C for 24-28 hours. This operation was repeated until the pure form of microorganisms was easily identified.

3. Isolation and purification of bacteria and fungi:

Isolation began after incubation to obtain pure bacteria and fungi in the cultivation media. It was carried out by isolating and cultivating every type of fungi and bacteria in the same previous media, incubating them in the same conditions. This operation was repeated until getting pure bacteria and fungi.

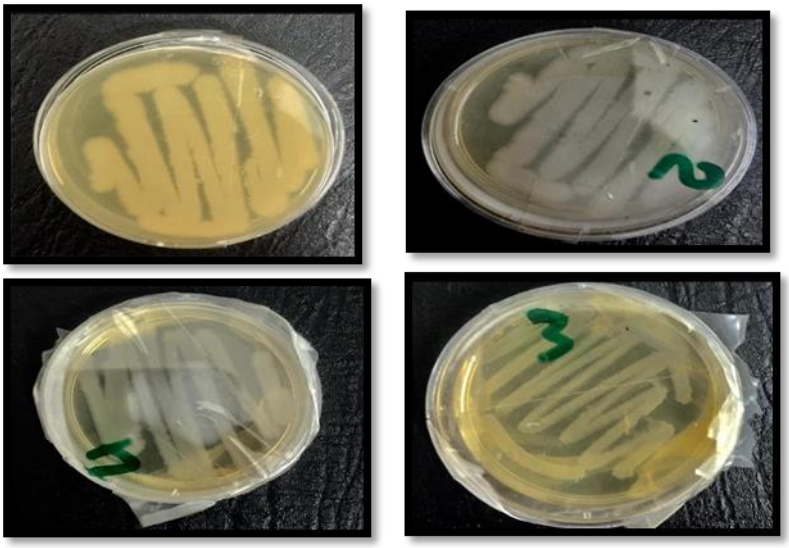


Fig. (6) illustrates microbial growths mixed with bacteria

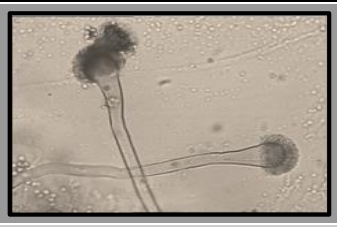
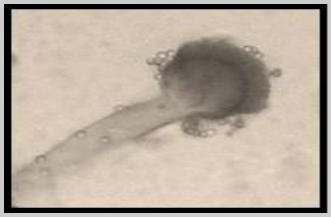
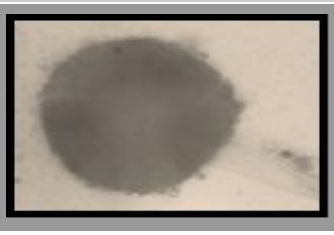
Fig. (7) illustrates microbial growths mixed with fungi

4. Identification:

Pure growths were taken and cultivated in the same media. Then, microbial slides were made under optimal sterilization conditions to prevent any microbial pollution. After that, the slides were examined using VITEK MS, which helped identify the types of fungi and bacteria.

Table (3): Results of Examining the Fungi Isolations

The following three microorganisms belonging to *Aspergillus* were isolated.

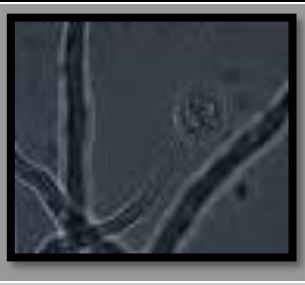
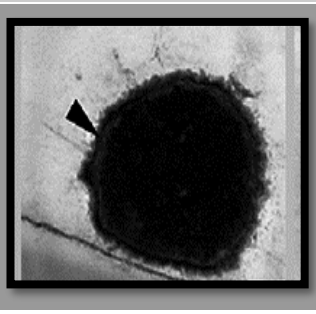
No.	Place of the sample	Name and classification of the fungus	SAM
1	Chest	***Aspergillus Fumigatus***	
2	Abdomen wraps	***Aspergillus fumigatus var. ellipticus***	
3	Right hand wraps	***Aspergillus foetidus var. pallidus***	

The following three microorganisms belonging to *Penicillium* were isolated.

No.	Place of the sample	Name and classification of the fungus	SAM
1	Neck	***Penicillium Citrinum***	
2	Left hand	***Penicillium glabrum***	

3	Left leg	***Penicillium Miczynskii***	

Table (4): Results of microbial e xamination of the bacterial isolates

No.	Place of the sample	Name and classification of the bacterium	SAM
1	Face	***Bacillus altitudinis***	
2	Feet wraps	***Bacillus cereus***	
3	Chest	***Acinetobacter radioresistans***	

Manifestations of Insect Deterioration:

The magnifying glass was used in the visual examination of the mummy's linen fabric wraps to identify insect infection and deterioration. It was found out that the mummy was infected by Black Carpet Beetle (figure 8) (Order: *Coleoptera*., Family: *Dermestidae*., Scientific name: *Attagenus sp*.) (one of the most dangerous pests that affect mummies and archaeological fabrics).

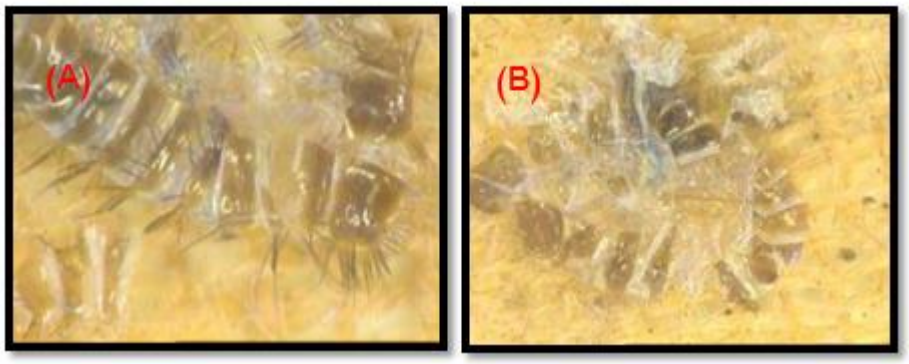


Fig. (8) illustrates the Black Carpet Beetle by optical microscope

Materials and Methods:

Samples:

The scientific examination was intended to elucidate the nature of the original and added materials as well as to establish the state of conservation of Wrappings, the loose Wrappings of the object detach and flake, from the fallen sample, a sample from the material was from the linen fabric for analysis.

Optical and Digital Microscopy(O.M):

Optical microscopy analysis were carried out using a Jenalumar Zeiss microscope equipped with a CCD camera for image capture and Delta Pix software. The optical microscope is also equipped with a set of polarizing filters and with a 200W mercury fluorescent lamp coupled with a suitable filter set (Zeiss filter set 02) that transmits only the wavelengths of the light emitted from the sample, blocking the light passed through the excitation.

The fibril samples were placed on glass slides, embedded in a small drop of mounting, containing and anti-bleaching agent (DABCO) and covered by a coverslip. Samples were then observed using different methods: Observation under bright field, phase contrast, differential interference contrast (DIC), epifluorescence and polarized light. All the microscopy observations were carried out by immersion lens at different magnifications[11].

Scanning Electron Microscope (SEM) Examination:

Several linen samples were examined using SEM (JEOL; Model: JSM-5200 SCANNING MICROSCOPE with 75 X, 500 X, 1000 X, 2000 X, and 3500 X magnification) to identify the type of fibers, direction of threads, and deterioration type [12]. Results Figure(9) illustrated the space between fibers and cuts in the linen wraps.

Fournier transforms Infrared spectroscopy (FTIR) analysis:

Binding medium has been studied by Fourier transform infrared spectroscopy (FTIR). The samples were analyzed as KBr pellets by JASCO FT\IRñ460 plus. Powdered samples pressed into potassium bromide (KBr) pellets and the powder mixture were then crushed in a mechanical die press to form a translucent pellet. KBr pellets of powdered samples were

examined between 4000 and 400 cm−1 at a resolution of 4 cm−1. Spectra were acquired between 1000-4000 cm^{-1}.

Sample One: Archaeological linen

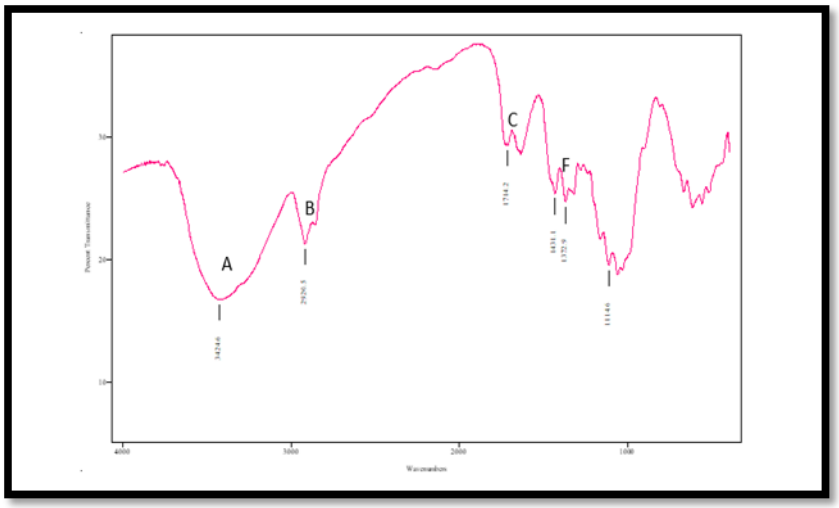


Fig. (9) illustrates FTIR analysis of archaeological linen

Sample Two: archaeological resin

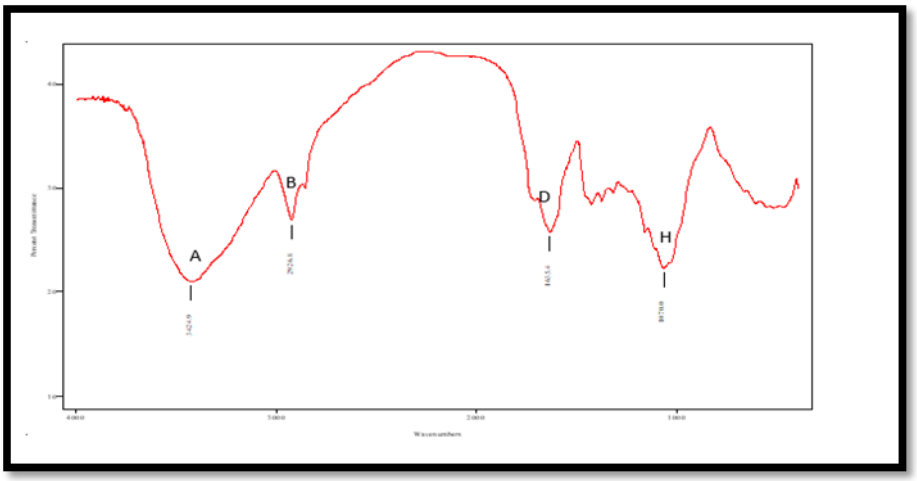


Fig. (10) illustrates FTIR analysis of archaeological resin

Sample Three: dyed linen

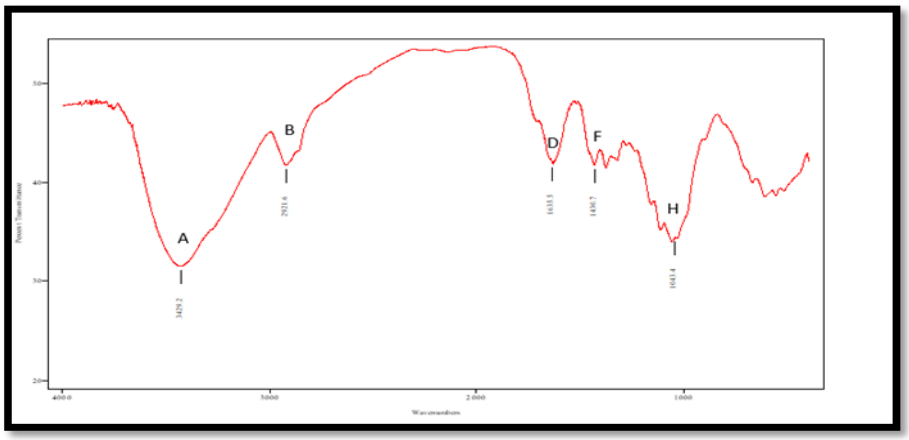


Fig. (11) illustrates FTIR analysis of dyed linen

Measuring the pH value:

pH was measured by extraction as follows:

1. The sample was cut into 0.2gm in 50 ml of water.
2. The sample was immersed in a solvent to extract the largest amount of organic acids in it.
3. The sample was heated at 50°C for 30 minutes.
4. The pH value was obtained using a pH meter.

Sample One: (Archaeological linen fabric): The pH value measured 5.19.

Sample Two: (Archaeological linen fabric with archaeological resin): The pH value measured 4.

Restoration and Conservation:

- **Sterilization**: First, linen fabric wraps were sterilized using para-dichlorobenzene dissolved in acetone (1% concentration) from four sides in Petri dishes to eliminate any fungi and bacteria. Then, the showcase was closed tightly and left for 15 days. After that, it was opened, and the swabs were taken from the wraps and cultivated in the laboratory. The swabs were found void of any harmful fungi or bacteria.

Mechanical cleaning: It is the first step of the actual leaning of the linen fabric wraps. It was carried out carefully from the head in order not to cause hair strands to fall because the space between the ventilator and the hair was not less than 3 cm. The linen fabric wraps in the back

- were handled carefully, as well. After that, the chest area was handled carefully because it was fragile. Then, dust and dirt in the abdomen and foot were sucked out.
  Soft brushes of soft natural hair were used to remove dust and dirt pending and unattached in the fabric of the wraps. In the case of stuck dirt, coarser brushes were used to clean without direct friction or injuring the wraps.
- **Softening and stretching operations**: Some wraps were very dry with folds. Therefore, they required softening and stretching that were carried out simply to maintain the wraps in the best condition possible without splitting. They were carried out using the vapor of distilled water with stretching carefully by putting the wrap on a special iron table with a piece of water-treated linen and a special iron for fragile archaeological fabric at low temperature. Water in the new linen evaporated, and water vapor penetrated the wraps, causing a good slow softening of the wraps. Using the iron, the wraps were stretched. Repeating this operation, the wraps were stretched and softened to complete the restoration and conservation of the wraps of Tayuheret's mummy understudy.
- **Rearranging the linen wraps**: Some linen fabric wraps were separated from the mummy's body. They were taken to carry out cleaning and stretching and used to wrap some lost parts, such as rewrapping the lost left hand and the feet and covering the head.
- **Reinforcement and fixation by needlework**: It was previously mentioned that the linen fabric wraps understudy had several holes, cuts, gaps, and missing parts that weakened the linen fibers, causing ruptures and cuts in other areas. Therefore, fixation by needlework was adopted to rewrap the linen fabric wraps on the mummy's body.
  Natural silk threads were used to fix the linen patches in color degrees similar to those of the linen fabric wraps using ultra-thin needles. It was considered that the stitches were narrow to fulfill the purpose and became hard to be observed.

Fig. (12) shows the chest before and after cleaning

Fig. (13) illustrates the hand and head before and after cleaning

Fig. (14) shows the foot before and after cleaning

Fig. (15) shows a total image of the mummy before and after cleaning

Results and Discussion:

− Mummification and deterioration causes of the mummy:

Linen fabric wraps were very dry because resin materials had some photochemical reactions, causing fragility, severe dryness, and splitting of the linen fabric wraps. Color change and fading also occurred due to the break of the long molecular chains into short ones non-retrospectively due to the natural light in the mummy's hall in the museum, which encouraged those photochemical reactions, as well. Moreover, relative humidity caused the decline of the physical and chemical characteristics because of the break of cellulose chains and being prone to bacteria and fungi infection. The wraps suffered severe friability and dehydration because the head partially broke the fibers as the cellulose molecules lost the chemically-bound water, and cellulose was exposed to dehydration, making the fibers harder [13]. The high acidity is motivated by several causes, such as very high air pollution gases, especially sulfur and nitrogen dioxide, in the museum because of its location and being locked in a showcase that is not tightly close. In the presence of oxygen, sulfur becomes sulfurous acid that oxides to sulfuric acid, decomposing the cellulose, hemicellulose, and lignin of linen fibers. Nitrogen dioxide deteriorates linen fibers. Furthermore, the wooden coffin and the identification card of the mummy might increase acidity. Some mummification materials composed of sulfur, such as beeswax, could form, in the presence of relative humidity, acids despite being weak acids by 6 or 6.5. The pH measurement of the archaeological samples showed that the environment of the monument was acidic, which caused insect, bacterial, and fungal growth on the mummy and the linen fabric wrap yarn. The lack of microbiological deterioration of the mummy's face (salt layer) occurred because it was an alkaline environment that hindered the appearance of fungi and bacteria. Moreover, the linen fabric wraps were weak with some cuts and holes. Therefore, reinforcement by needlework was adopted. It is a reverse method, meaning loosening the fixed piece without causing any damage. It is one of the best and most secure reinforcement methods that fit the warps fabric 1/1[14].

- **The cause of the damage to the mummy's left hand is due to several possibilities:**

A. The left hand of the mummy had some gold jewelry. It was destroyed and completely separated in ancient Egyptian times (most likely interpretation).
B. The mummy was stolen, and the hand was separated during excavation.
C. Due to the neglect and lack of good preservation, the left hand was broken and separated.

However, previous studies demonstrated that the mummy was stolen by a lector of Amun called Htet (C.G.: 61032), and the gold-plated hands were lost.

- **Covering the face of the mummy has many causes:**

A. At the time of excavation, these wraps were covering the face of the mummy. After mummification, the wrap yarn were unpacked, cut, and destroyed by the thieves of Deir el-Bahari tombs.
B. These wraps act as a barrier between the mummy and direct light that may cause photochemical reactions, causing a chemical change in the mummification materials.

Optical Microscopy (OM):

Optical microscope examination showed cuts and rupture of linen fibers and insect infestation that caused cuts and detachments.

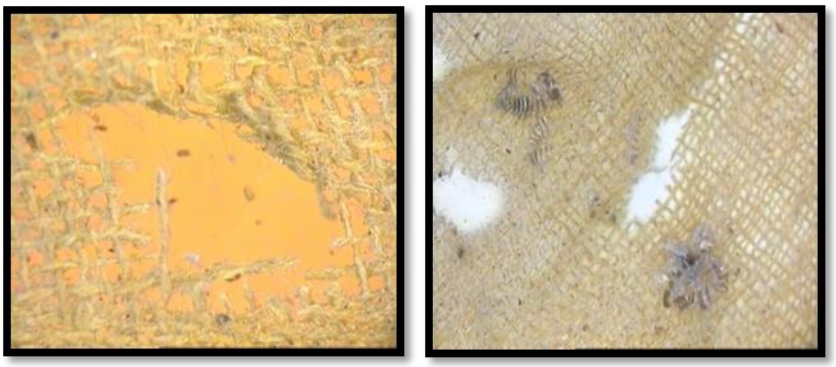


Fig. (16): Optical microscope images of deterioration phenomena; 1 cut of fibers, 2- insect infestation

SEM examination:

Analysis was undertaken in order to make preliminary observations of the decay and the fungal patterns of attack. Examination of the linen fabric surface by SEM (weakness in the bonding materials between the fibers), and fungi infection, Cellulose fibrils originating from mechanical disruption of the linen fabric cells surface by the fungal SEM examination helped also identify the deterioration, space, cuts, and cracks of the linen wraps because of the surrounding environmental conditions.

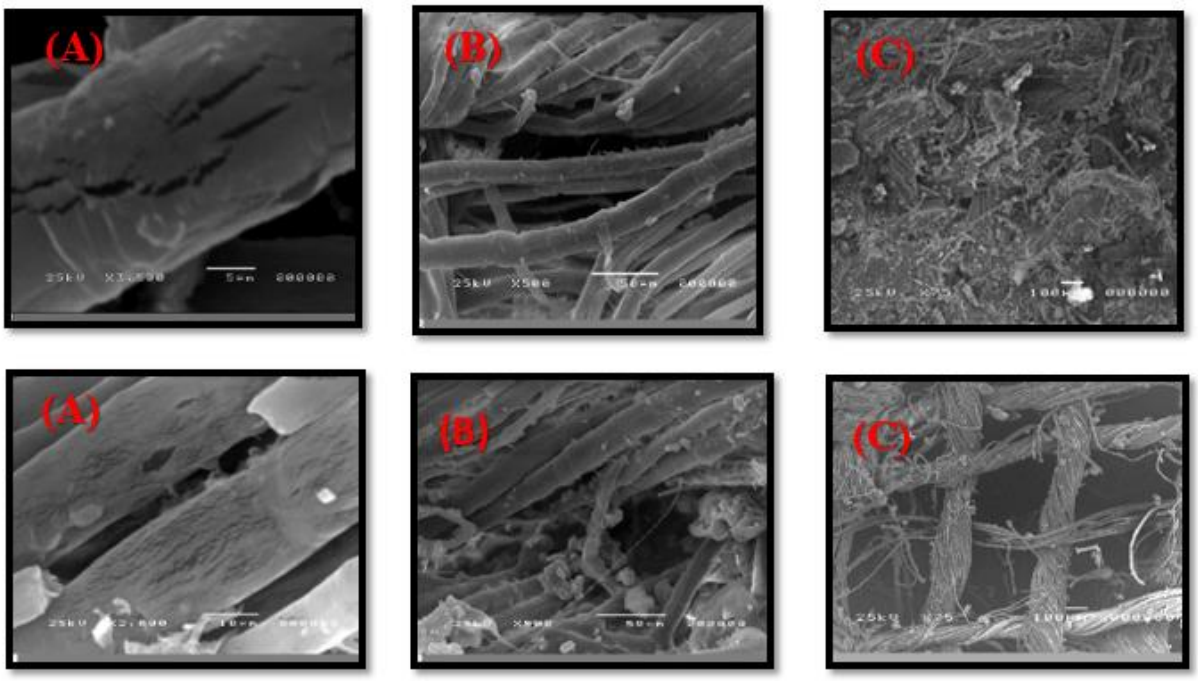


Fig. (17): SEM images of the deterioration of archaeological linen fabric samples: (1) Resin 50X, 75X, and 2500X; (2) Dyed linen 75X, 500X, and 3500X

Fournier transforms inferred spectroscopy (FTIR):

FTIR analysis of the archaeological samples figure (18) showed the lack of the functional groups, such as (C=O); the disappearance of hemicellulose because the disappearance of the peak indicates complete decomposition. Furthermore, the (OH) group expanded due to the low relative humidity, showing the low water content of cellulose, which caused the break of the long molecular chains and transformed them into short ones. The analysis demonstrated that hemicellulose is the weakest and most affected component by various aging processes. Fig. (18) illustrates the patterns of FTIR analysis: (1) Archaeological linen fabric sample in blue, (2) Archaeological linen fabric sample in black), (3) Linen fabric and resin sample in green.

Sample One: Archaeological linen with archaeological resin

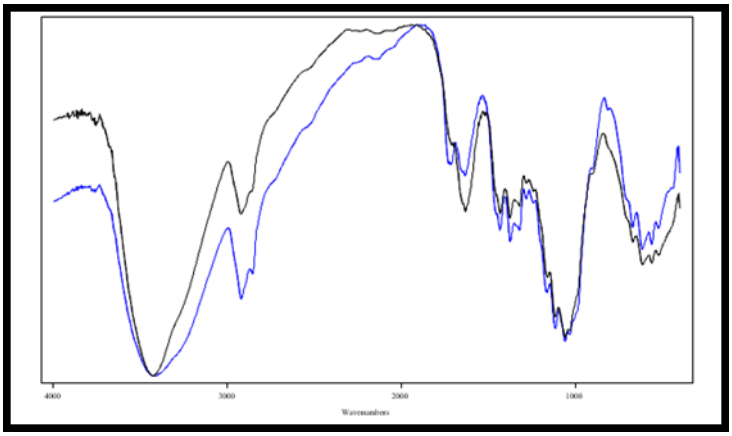


Fig. (18) illustrates FTIR analysis of archaeological linen fabric with archaeological resin

SampleTwo: Archaeological linen with dyed linen

Functional group	Sample: Archaeological linen	Sample: Archaeological linen with resin	Notes	Discussion
OH مد	3424.6	3424.9	A displacement of 3 cm^{-1}	(O.H.) slightly مد broadened in the absorption area due to the low relative humidity, indicating the low water content of cellulose, causing the break of long molecular chains and transforming them into short molecular chains.
CH مد	2920.5	2920.8	A displacement of 3 cm^{-1}	A slighter amplification of the relative intensity took place in the sample of linen with resin than in the archaeological linen sample.
C=O مد	1714	-----	The disappearance of the absorption line	Hemicellulose disappeared. Its peak disappeared, indicating its complete decomposition.
C=C مد	1431.1	1431.7	A displacement of 0.6 cm^{-1}	No clear decline was observed in the spectrum intensity of the absorption area of lignin.

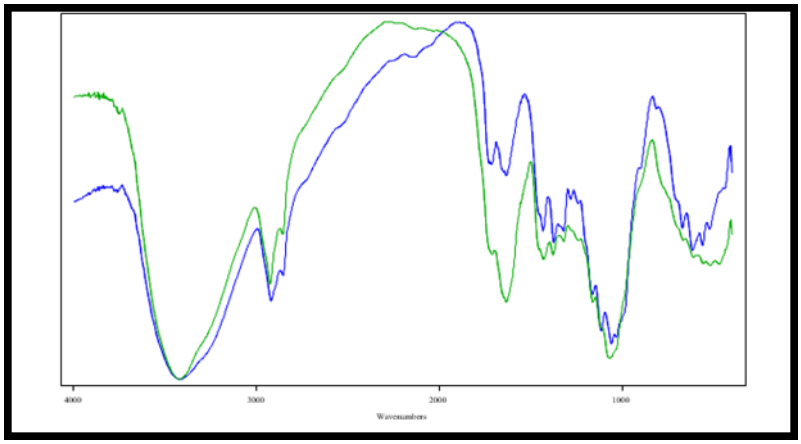


Fig. (19) illustrates FTIR analysis of archaeological linen fabric with dyed linen

Functional group	Sample: Archaeological linen	Sample: Archaeological linen with resin	Notes	Discussion
مد OH	3424.6	3429.2	A displacement of 4.6 cm^{-1}	(O.H.) slightly broadened in the absorption area due to the low relative humidity, indicating the low water content of cellulose, causing the break of long molecular chains and transforming them into short molecular chains.
مد CH	2920.5	2920.6	A displacement of 1.1 cm^{-1}	A slighter amplification of the relative intensity took place in the sample of linen with resin than in the archaeological linen sample.
مد C=O	1714	------	The disappearance of the absorption line	Hemicellulose disappeared. Its peak disappeared, indicating its complete decomposition.
مد C=C	1431.1	1430.7	A displacement of 0.1 cm^{-1}	A slight decline was observed in the spectrum intensity of the absorption area of lignin.
مد C-O	1114.6	1043.4	High displacement	The relative intensity decline might be because of the loss of hemicellulose and lignin; non-crystallized components.

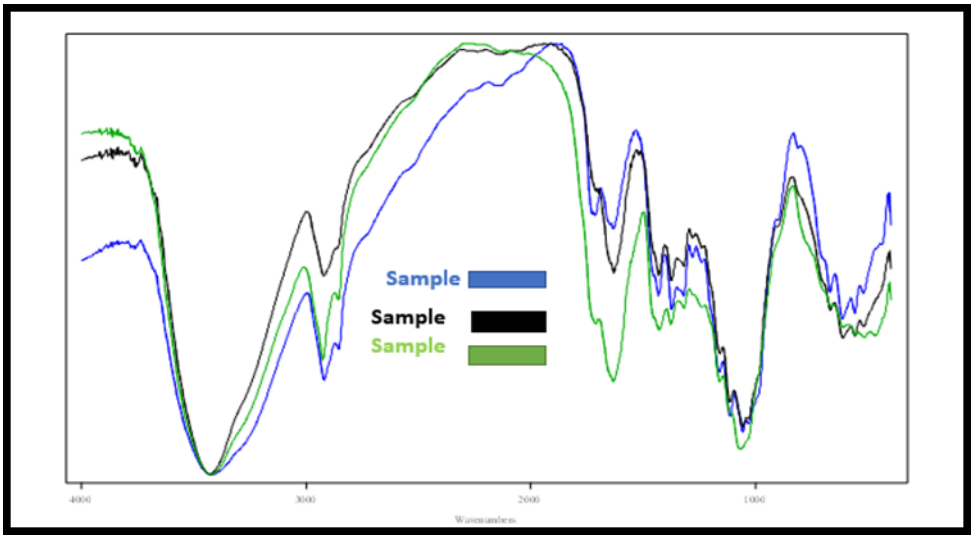


Fig. (20) illustrates the patterns of FTIR analysis: (1) Archaeological linen sample in blue, (2) Archaeological linen fabric sample in black), (3) Linen fabric and resin sample in green

- Regarding the adhesive, FTIR analysis illustrated that the sample might contain animal glue and juniper seed that was used because of its volatile oils that could resist biological and microbiological growth. Thus, the embalmer was keen to use these seeds on linen wraps. Sometimes, juniper was added in a natural form.

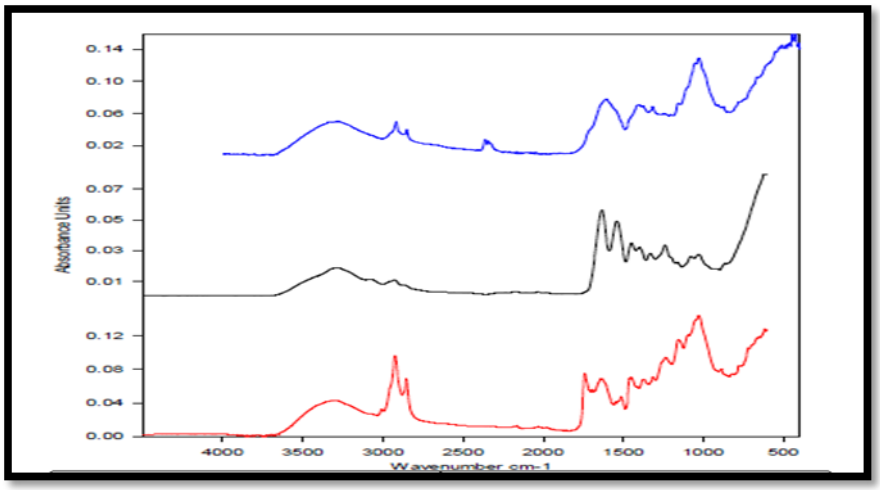


Fig. (21) shows FTIR analysis of animal glue and juniper

- Analysis of the pH value illustrated acidity, which caused microbiological deterioration of the mummy.

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