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Original article

TERMITES, THEIR ROLE IN THE DAMAGED MUD BUILDINGS, AND PREVENTION METHODS: APPLICATION ON THE RUINS OF THE WHITE MONASTERY, SOHAG, EGYPT

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Abstract

Termites cause deterioration to archaeological buildings. They usually dig tunnels under foundations, causing soil loosening. They attack mud-brick and mortar to get hay pured that is found out, causing cracks in buildings. Because some Egyptian archaeological buildings were constructed from mud-bricks, termites cause them decay and deterioration. Therefore, the current study covers the ruins of the White monastery's mud buildings in Sohag. It makes use of XRD, XRF, EDX, SEM. Mineral Petrography study have also been the work of analysis chromatograph. It illustrates the mechanical deterioration by termites and the ways that provide an appropriate environment for the growth of some kinds of fungi and bacteria. In addition, methods of treating mud-brick and preventing termites, fungi and bacteria are proposed.

Keywords: *Mud-Bricks, Decay, Termites, Fungi, Bacteria, Preventing*.

1. Introduction

1.1. *The archaeological history of mud bricks and the white monastery*

Many studies were conducted on stone buildings but only few investigated mud-brick buildings that have spread all over Egypt for ages. Therefore, the current study investigates the role that termites play in the deterioration of mud brick buildings and the relation with other factors, e.g. the dete-rioration of microbi-ological and chemical composition of mud bricks. Mud bricks are one of the materials which used in buildings at different old civilization [1, 2]. The study of mud bricks is an important specially when are found in urban precisely [3, 4]. The White monastery, located 8 km to the west of Sohag, was constructed of white limestone. Its main buildings were built by St. Shenoda on the ruins of Pharaonic buildings [5], fig. (1).

Figure (1) Shows location of the white monastery, Sohag, after *Google 2016*

1.2. *Field observations and deterioration causes*

Termites play an important role in the deterioration of the white monastery's mud bricks. Capillarity water move through the walls and columns. After evaporation, salt crystals are noticed on the surface of the mud brick. Consequently, cracks and disintegration result (figure 1.g &h). This is attributed to low ventilation rate that cause low level of evaporation from the entrance of mud brick walls. When evaporation rate increase, salt crystals and many other factors of deterioration affect mud bricks [6-10]. When they contain water, pores play an important role in the decay of mud-brick [11]. Unfortunately, mud-bricks of the White Monastery were exposed to many deterioration factors, especially termites, fig. (2-a, b) [12]. Various samples were collected using non-destructive methods and were studied by Polarizing Microscopy (PLM), X-ray diffraction (XRD), scanning electron Microscope (SEM) and X-ray florescence (XRF). Hence, physical and chemical properties and microbiological growth were studied [13]. Mud bricks mainly contain clay, some organic materials and some fillers, fig. (2-c, d). This approves the properties of mud brick to decrease clay's viscosity and to make them stronger to resist weathering [14]. About 70-80 of termite species, from among more than 2600 species, are considered economically important pests [15]. The termites are mostly feed on anything containing cellulose component, and is one of the most important pests causing great losses to ancient buildings which bullied form adobe. The subterranean termite Psammotermes hybostoma is the most termite species foundations in Upper Egypt. Recently, it has caused serious damage to ancient buildings in archaeological areas in Sohag, Luxor and Aswan. Applications of synthetic pesticides are the commonly control methods for termites. However, there are increasing concerns over environmental pollution and effect on properties of buildings. Recently, plant essential oils have been considered as potential alternatives to synthetic pesticides, and they are containing many bioactive compounds having insecticidal. Furthermore, plant essential oils are extremely volatile; therefore, there is no problem of residue accumulation [16-18]. Some plant essential oils have been reported to exhibit insecticidal properties against termites [19, 20]. In this study, we investigated the repellent activity of essential oils from four medical plants and four their chemical compounds.

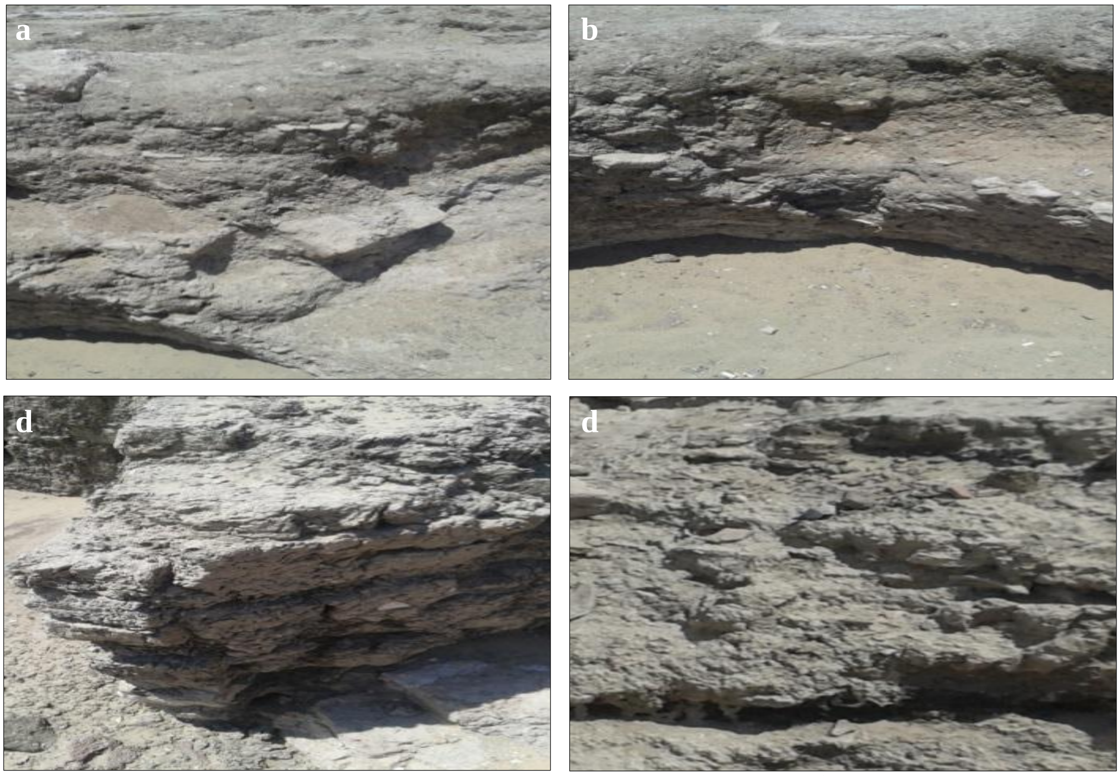

Figure (2) Shows mud bricks deterioration by termites and the weakness of their internal and external structure

2. Materials and Methods

2.1. *Petrographic examination*

The samples were examined using different microscopic types, such as: the polarizing microscope, (model Olympus BX51 TF Japan), with a digital camera. They were studied a magnification of 20X up to 40X.

2.2. *X-ray diffraction (XRD)*

The composition of the samples was analyzed using Philips X-ray diffraction (model PW/1710) at physics department, Assiut Faculty of Science, Egypt. The reflections of peaks were from 4 to 90°2è, with 0.06° /min speed, (d, Å) and (I/I°) were obtained [21].

2.3. *Chemical analysis by X -ray fluorescence (XRF)*

Elemental analysis was conducted using wavelength dispersive XRF spectrometry (Axios advanced, sequential wd_XRF Spectrometer, PANalytical 2005) at the analysis and consulting unit, National Research Center in Cairo

2.4. *Scanning electron microscope (SEM-EDX)*

The samples were analyzed using the scanning electron microscope (SEM, JSM 5500, JEOL Japan) of 70X up to 2500X range. In addition, small mud-bricks samples were covered with gold and analyzed by EDX.

2.5. *Termite collections*

The workers of *P. hybostoma*, termites were obtained from the infested area near from the white monastery, Sohag, Egypt using El-Sebay modified trap [22]. The species was reared in Petri-dishes provided with source of cellulose (corrugated cardboard moistened). The healthy workers with seven days age were used in the experiment.

2.5.1. Chemicals

The essential oils of camphor (*Cinnamomum camphora*) and orange peel (*Citrus Sinensis*) purchased from a commercial company (Obour City, Egypt), and (R)-(+)-Limonene, (S)-(-)-Limonene, (+)-Camphor and (-)-Camphor were purchased from Sigma-Aldrich (Egypt).

2.5.2. Experiment

The repellency test was conducted in arenas consisting of five cups of 12 cm diameter and 10 cm height, with a central cup (E) connected to the others four cups (A, B, C and D) by plastic cylinders (15 cm long and 1 cm in diameter). Cups A and B were arranged diagonally, and filled with piece of soil from ancient building butted with piece of corrugated cardboard treated with 100 μL (3% concentration) of each solution. Cups C and D (controls) were filled only with piece of soil from ancient building butted with piece of corrugated cardboard treated with 100 μL ethanol 99.5 % (Aldrich/Sigma, Egypt) only [23]. The treated cups were left out of direct sunlight for 20 min to evaporate the ethanol. After this period, twenty workers of *P. hybostoma* were released to the central cup. After 24h of the beginning of the experiment the total number of individuals per cups treated or not with essential oils was evaluated [24].

2.5.3. Soil analysis

The pH meter (Orion model 410A) was used for soil pH measured in 1:1 soil: water suspension (Jackson, 1973). Measuring the electrical conductivity of the soil past extract (ECe) was used to determine the total soluble salts by electrical conductivity meter (Orion model 150) [25]. Soluble calcium and magnesium were titrated by a standard versenate (EDTA) solution. A Flame-photometer was used to determined sodium and potassium. Calcium carbonate content was determined volumetrically using the calibrated collin's Calcimeter method. Soluble cations and anions were measured in the saturated soil paste extracted according to Jackson (1973) [25]. Soluble carbonate and bicarbonate were titrated by a standard solution of hydrochloric acid; chlorides were titrated by a standard solution of silver nitrate. Spectrophotmetr was used to determine the sulphates by the turbidimetric method. Organic matter (OM) content was evaluated by a modified Walkely-Blake method as described by Jackson, [25].

2.5.4. Statistical analysis

The experiment was conducted in a randomized design with 10 replications (arenas), each one with 20 workers of *P. hybostoma*, where the substrates are or are not treated. The results were compared by t-paired test at 5 % probability.

2.6. *Fungi and bacteria study*

Method which used of soil dilution plate to isolate Fungi from decayed mud bricks is according to Waksman (1922) [26]. The surface of mud bricks was scrapped with a sterile tool. Removed fragments were inoculated into nutrient agar medium in sterile Petri dishes (5 replicates were made for each sample) and incubated at 37 °C for 48 hours. Recovered colonies were purified and tested for Gram staining [27-30].

3. Results

3.1. *Petrographic investigation*

It is illustrated that the sample of ancient brick is dark gray with a bulk density of (1660 Kg/m^3), porosity (3.63 %), swelling (2 %), organic matter (12.6 %), and compression strength (79.86 kg/cm^2), tab. (1-a, b). The mineral composition of the sand fraction (250-125 microns) of ancient brick sample is as follows quartz (64 %), orthoclase (6 %), plagioclase (5 %) hypersthene (7 %), epidote (3 %), hornblende (2 %), biotite (5 %), muscovite (4 %) and opaque (4 %) .The mineral composition of the sand fraction is as follows: (125-63 microns) included quartz (58 %), orthoclase (3 %), plagioclase (2 %), hypersthene (8 %), epidote (5 %), hornblende (6 %), biotite (7 %), muscovite (4 %) and opaque (16 %), tab. (1-c) & fig (3-a, b, c, d).

Table (1-a) physical properties of investigated samples

Properties	Measurements
Colour	dark gray
Bulk density	1660 Kg/m^3
Swelling	2 %
Porosity	3.63 %
Organic matter	12.6 %
Compressive strength	79.86 kg/cm^2

Table (1-b) grain size analysis

Total Weight	Intervals	Wt. %.	Wt. % Cum.
20 gm.	>2.0 mm	1.7	1.7
	>1.0 mm	1.7	3.4
	>0.5 mm	2.7	6.1
	>0.25 mm	10.8	16.9
	>0.125 mm	21.4	38.3
	>0.063 mm	4.2	42.5
	<0.063 mm	57.5	100

Table (1-c) mineral composition of sand fraction

Mineral composition	250 -125 Micron %	125-63 Micron %
Opaques	4	16
Quartz	64	58
Orthoclase	6	3
Plagioclase	5	2
Hypersthene	7	8
Epidote	3	5
Hornblende	2	6
Biotite	5	7
Muscovite	4	4

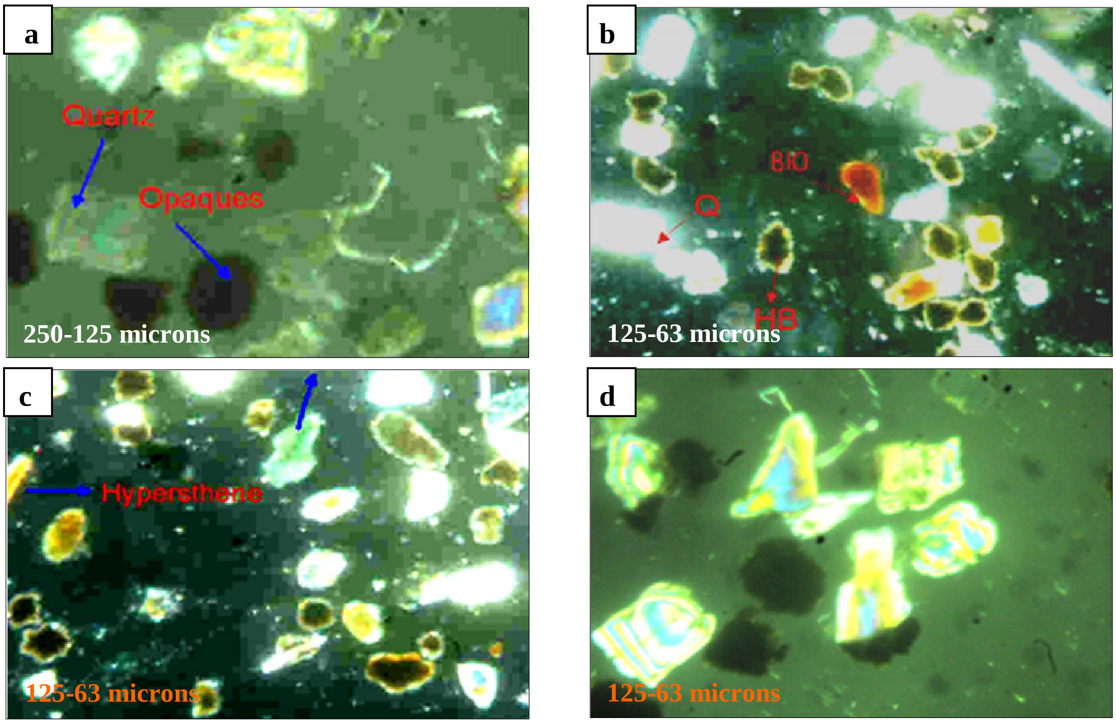

Figure (3-a, b, c, d) Shows sand fraction (250-125μm) showing quartz grains under cross Nicole

3.2. *Mineralogical analysis by XRD*

Mineral composition of the ancient brick's sample, is as follows: clays (smectite, illite and kaolinite) (68.1 %), calcite (19.1 %), plagioclase (9.9 %) and quartz (2.9 %), tab. (2-a) & fig, (4-a) Mineral composition of clay fraction of the ancient brick, is as follows: smectite (40 %), smectite / illite mixed layers (44.3 %), speolite (10.6 %) and kaolinite (5.1 %) with traceable amounts of non- clay minerals (quartz, feldspars and calcite), tab. (2-b) & fig, (4-b). The crystallinity of smectite (the main component of the clay fraction) was very poor (3 nanometer),fig. (4-c).

Table (2-a) mineral composition of the ancient brick sample

Whole Rock Mineral	Mineral %
Gypsum	0
Clay	68.1
Quartz	2.9
Plagioclase	9.9
K-feldspars	0
Calcite	19.1

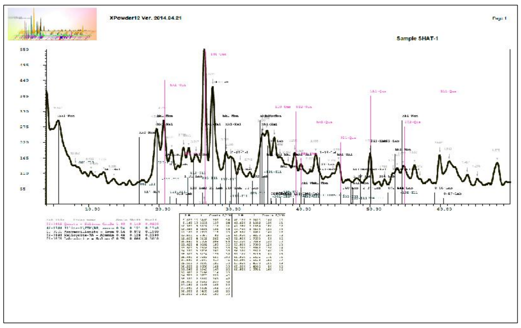

Figure (4-a) Shows XRD patterns of the samples of mud bricks

Table (2-b) mineral composition of the clay's fraction of the ancient brick

Clay Fraction	Clay Minerals %
Smectite	40.0
Smectite / illite Mixed layers	44.3
Speolite	10.6
Kaolinite	5.1

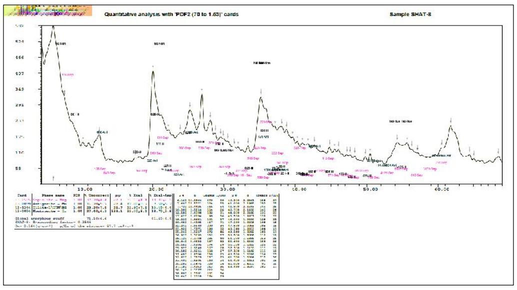

Figure (4-b) Shows XRD patterns of the samples

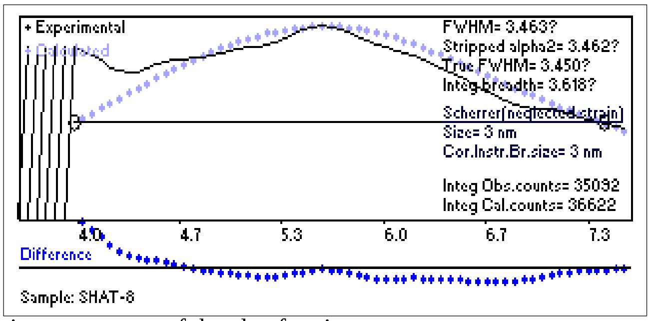

Figure (4-c) Shows the main components of the clay fraction

3.3. *XRF analysis*

The sample analyzed illustrated that the main components (Wt %) were SiO_2 (44.33 %), Al_2O_3 (14.69 %), Fe_2O_3 (10.85 %), Cao (4.13 %), SO_3 (0.55 %), Na_2O (1.70 %) and K_2O (1.79 %), tab. (3).

Table (3) main components (wt. %) of the samples using XRF analyses

Investigated Samples			
Main components	***Wt %***	***Main components***	***Wt %***
SiO_2	44.33	Co_3O_4	0.019
TiO_2	1.57	MnO	0.178
Al_2O_3	14.69	NiO	0.015
Fe_2O_3.	10.85	CuO	0.013
Mgo	2.77	ZnO	0.013
Ca O	4.13	Rb_2O	0.006
Na_2O	1.70	Ga_2O_3	0.002
K_2O	1.79	Y_2O_3	0.005
P_2O_5	0.48	ZrO_2	0.039
SO_3	0.55	SrO	0.039
CI	1.34	Nb_2O_5	0.004
LOI	15.41	CeO_2	0.037
Cr_2O_3	0.022		

3.4. *Bulk elemental analysis by EDX*

EDX micro analytical methods were conducted to identify the samples and evaluate their components, indicating that the elemental composition of the samples collected from different places could be put in a decreasing order according to their concentration as follow: Si (24.91-53.30%), Al (6.15-17.29 %), Fe (9.11-13.03 %), S (2.40- 5.99), Cl (1.45-0.00) and Ca (6.39-8.94 %), tab. (4) & fig. (5). This helped in understanding the weathering mechanisms affecting the mud bricks. Si was the main component. However, chlorine indicated that there was a crystallization of halite on mud bricks. It was also illustrated that the high concen-tration of calcium indicated the existence of gypsum and anhydrite. In addition, the moderate amount of Alum-inum could be attributed to feldspars. On the contrary, the relatively high amounts of iron were attributed to the origin of these samples and the atmospheric pollution. They played a significant role in deteri-oration.

Table (4) quantitative EDX microanalysis (compound %) of the value spot mud-bricks

Element	ms %	Oxide	ms %
Al	6.15	Al_2O_3	17.29
Si	24.91	SiO_2	53.30
S	2.40	SO_3	5.99
Cl	1.45	--	0.00
Ca	6.39	CaO	8.94
Fe	9.11	Fe_2O_3	13.03

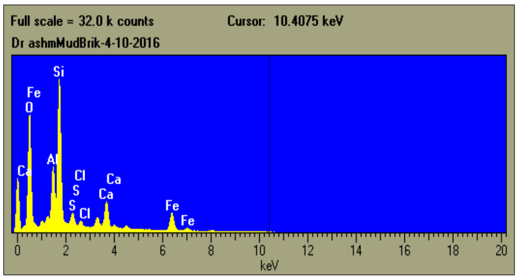

Figure (5) Shows mud-brick sample analyzed by EDX

3.5. *Scanning electron microscope (SEM)*

SEM investigation proved that the identified samples contain quartz crystals (SiO_2) as a main mineral, in addition to some and other salts mineral features such as such as halite (NaCl) and gypsum ($CaSO_4.2H_2O$). Within the same context, some deterioration features of quartz grains and decay of cement materials could be noted especially; breaking in the granules of plagioclase and calcite. Other samples show a differential of quartz grains, and a collapse of the internal structure of the mud-brick, all of these features are shown fig (6-a, b, c, d, e, f).

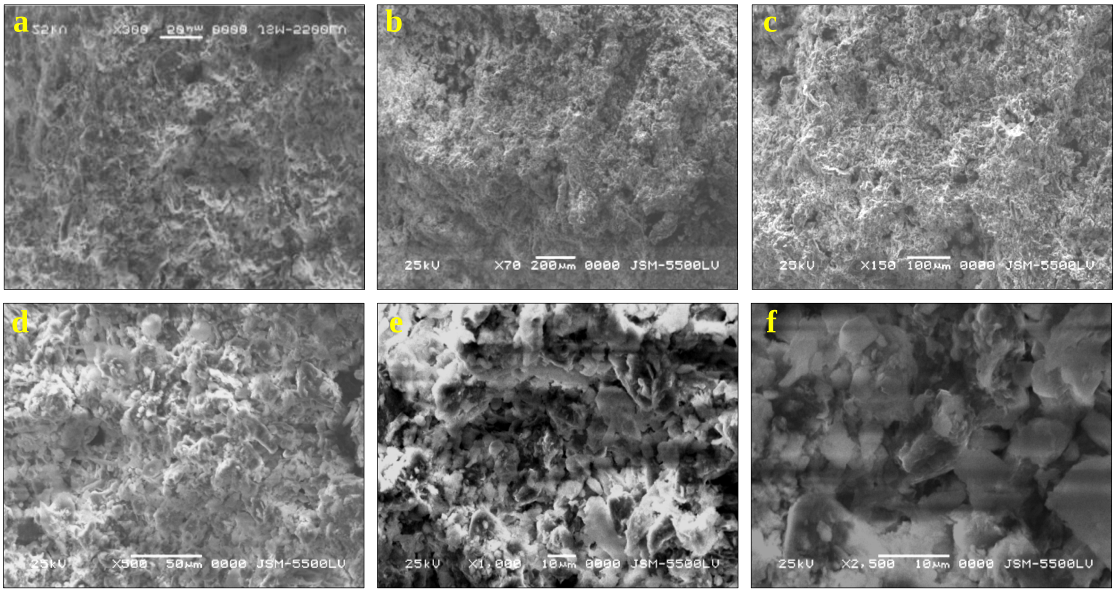

Figure (6) Shows SEM investigation of mud-brick deteriorated sample

3.6. *Termites growth*

3.6.1. Chemical characteristics of the soil

The chemical analysis of the soil, tab. (5). Data revealed that increase the values of Ca^{+2} + Mg^{+2}, Na^{+} and ECe. But a decreased was observed in N, P and K values.

Table (5) chemical contents of the soil

Investigated Samples					
Soil parameters	***Unit***	***Value***	***Soil parameters***	***Unit***	***Value***
pH	-	7.8	Cl	Meq/l	7
ECe	dS/m	3.4	SO_4	Meq/l	20
Ca	Meq/l	10	HCO_3	Meq/l	1
Mg	Meq/l	6	N	%	0.1
Na	Meq/l	11	P	%	0.01
K	Meq/l	2.4	K	%	0.94

3.6.2. Repellency bioassay

Results shows that all essential oils and constituents tested were activity against workers of *P. hybostoma*, although significant differences were found with respect to their efficiencies. The essential oil *C. Sinensis* and the constituents (R)-limonene and (S)-limonene exhibited a high significant degree repellent activity to workers of *P. hybostoma*, with an overall repellency rate of 68.5 %, 65 % and 81.5 %, respectively, fig. (7). However, *C. Sinensis*, (S) -limonene and (R) –limonene were more repellent to workers of *P. hybostoma* than camphor (*C. camphora*), (-) -camphor and (+) -camphor, at the tested concentration (3 %).

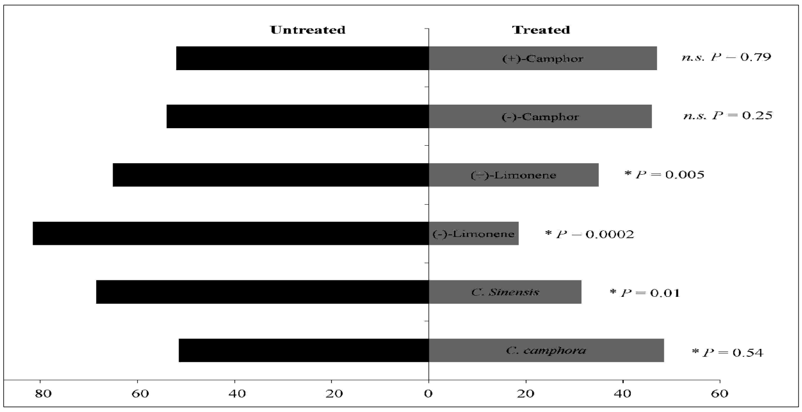

Figure (7) Shows preference (%) of workers of *P. hybostoma* for piece of corrugated cardboard treated or not with essential oils and constituents in free choice test. * Significant values; *n.s.* non-significant values at 5 % probability by t-paired test (p < 0.05).

3.7. *Fungi growth*

The biological deterioration of investigated mud bricks samples proved that there are three 3 fungal floras. They were identified as listed in tab. (6) & shown in fig. (8). Therefore, our study proved that moisture motivated biodete-rioration.

Table (6) identified fungal floras

Isolated Fungi in Investigated brick samples			
Variables	***(a)***	***(b)***	***(c)***
Kingdom	fungi	fungi	fungi
Division	Ascomycota	Ascomycota	Ascomycota
Class	Eurotimycetes	Eurotimycetes	Eurotimycetes
Order	Eurotiales	Eurotiales	Eurotiales
Family	Trichocomaceae	Trichocomaceae	Trichocomaceae
	Aspergillus niger	Aspergillus parasiticus	Aspergillus flavipus

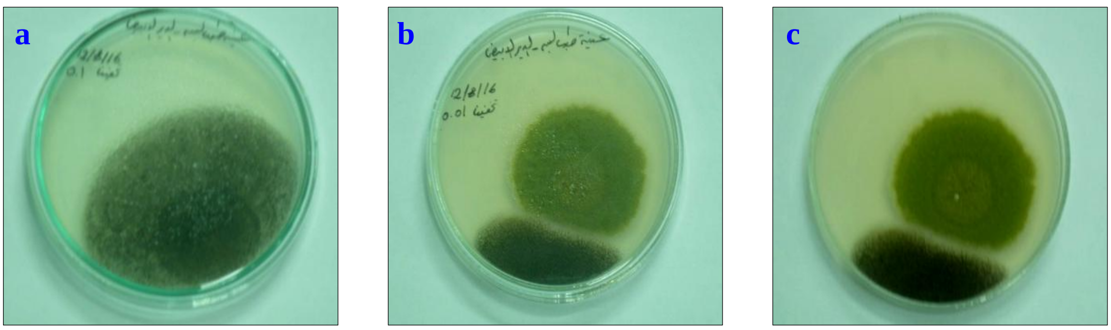

Figure (8) Shows fungi growth at Petri dishes

3.8. *Bacteria growth*

The bacterial effects in brick samples were laboratory investigated; the results proved that there are four species were identified. They were belonging to (*G +ve*) and (*G -ve*) bacteria as shown in fig. (9).

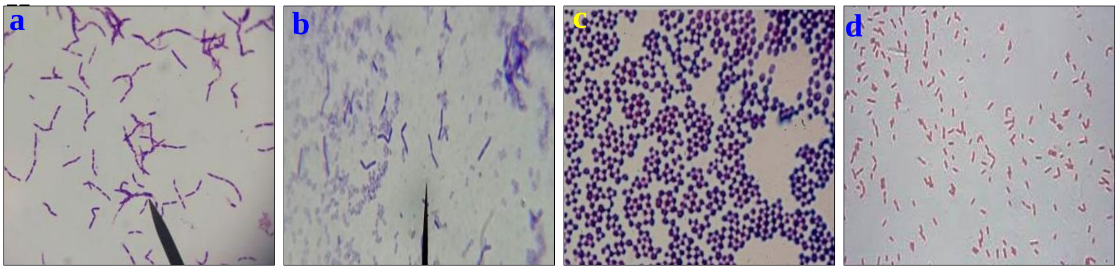

Figure (9) Shows isolated kinds of bacteria **a.** Bacillus cereus **b.** Bacillus subtilis, **c.** Micrococcusluteus Micrococcusruseus as (G +ve), **d.** Pseudomonas aeruginosa as (G -ve)

4. Discussion

The preliminary study reports the damage illustrated in the brick's appearance caused by the various factors, the most important of them are the presence of termites and the associated damage microorganisms. Results of the physical properties of the samples indicated a high degree influenced by the presence of termites. In addition to the effects of chemical and physical factors of deterioration, especially ground water, wind erosion and temperature variation in the study area. These properties that recorded bulk density (1660 kg/m^3), porosity (3.63 %), swelling index (2 %)**,** organic matter (12.6 %), and compression strength (79.86 kg/cm^2), tab. (1-a). Through tab. (1-b, c) & fig. (3), it could be noted that petrography investigations suggest that the grain size of the sample is classified as sandy mud (sand fractions). On one hand, the mineralogical composition of the fraction (250-125μ) is as follows: quartz (64 %), orthoclase (6 %), plagioclase (5 %), hypersthene (7 %), epidote (3 %), hornblende (2 %), biotite (5 %), muscovite (4 %) and opaques (4 %). On other hand, the mineralogical composition of the fraction, (125-63 μ) contains quartz (58 %), orthoclase (3 %), plagioclase (2 %) hypersthene (8 %), epidote (5 %), hornblende (6 %), biotite (7 %), muscovite (4 %) and opaques (16 %). Moreover, X-ray diffraction analysis, tab. (2-a) illustrates the mineral composition of the whole sample, as follows: (68.1 %) as clays (smectite, illite and kaolinite), (19.1 %), calcite, (9.9 %), plagioclase, and (2.9 %) quartz. In addition, the mineralogical composition of the ancient brick's clay fraction is as follows: smectite (40 %), smectite/illite mixed layers (44.3 %), speolite (10.6 %) and kaolinite (5.1 %) with traceable amounts of non- clay minerals (quartz, feldspars and calcite) as could be noted in tab. (2-b). With noting that the crystallinity of smectite is characterized by very poor index (3 nanometer). Within the same context, the presence of other minerals in the samples is attributed to some damage factors that have affected the brick milk, particularly termites and their chemical secretions. The chemical analysis by XRF, tab. (3) illustrates that SiO_2 (44.33 %) is the main component of the mud brick, in addition to some other oxides, such as CaO and SO_3, which are considered the main components of some salt as gypsum that causes mud brick decay. EDX analysis illustrates the elemental arrangement of the samples according to their concentrations, as follow: Si (24.91-53.30 %), Al (6.15-17.29 %), Fe (9.11-13.03 %), S (2.40- 5.99 %), Cl (0.00 - 1.45 %) and Ca (6.39-8.94 %) as noted in tab (4) & fig (5). From this point of view, it could be claimed that the presence of chlorine indicates the crystallization of halite on mud bricks. It also suggests that the high concentration of calcium indicates the existence of gypsum and anhydrite. Aluminum can be attributed to feldspars and the high amount of iron refers to the origin of the clay used in mud bricks. SEM investigation results indicate that the effect of decomposition and degradation in all mud brick samples is caused by termites' feeding on its organic compo-nents. Such damage is also caused by the presence of fungi, such as: *Aspergillus niger*, *Aspergillus parasiticus* and *Aspergillus flavipus*. In addition to the aggressive effects of bacteria, such as: **G+ve bacteria** *(Bacillus cereus, Bacillus subtilis, Micrococcus luteus and Micrococcus ruseus)*. **G-ve bacteria** (*Pseudomonas aeruginosa)*. The chemical damage caused by water agricultural drainage and sanitation has a significant role in increasing the rate of decomposition and crystallization of the various salts. Finally, SEM investigation and EDX analysis results, fig_s (6-b, c, d) support XRD results. They also illustrate that the samples contain (SiO_2), halite (NaCl) and gypsum ($CaSO_4.2H_2O$). In addition, they illustrate the weakness of the mud brick's internal structure as a result of deterioration to cement and other components. In the present study, the limonene constituents showed activity against workers of *P. hybostoma*. The results agree with results founded by Xie et al [31] who reported that the toxic activity of camphor was less strong than limonene. In the present study, the difference in the repellency of the oils from *C. Sinensis* and *C. camphora* may be attributed to the different chemical profiles of the respective oils as well as the genetic variability of pests submitted to different bioassays. The difference between the limonene enantiomers was found on the repellency test, with (S)-limonene proving to be more effective than (R)-limonene. Giatropoulos et al [32] report a similar finding for a different arthropod, *Aedes albopictus* Skuse (Diptera; Culicidae). There are few reports in the literature on the biological activity of chiral constituents found in essential oils against pests. However, several studies have been conducted on synthetic chiral insecticides and have showed greater bioactivity of one isomer over another [33]. The present repellency findings regarding the two limonene enantiomers against workers of *P. hybostoma* support notions put forth by Giatropoulos et al., and Pérez-Fernández et al [34] that optical antipodes can exhibit different biological properties.

5. Conclusion

According to this scientific study, mud buildings and their interaction with the surrounding environment were investigated. Therefore, recent techniques were obtained in the study and analysis of the mud-brick and outputs of the damage turned out to be mud-brick, indicating its cohesion as a result. Mud Bricks in the White Monastery in Sohag were exposed to many different causes of damage, the most important of which were termites, using organic material added to the mud-brick foodstuff which caused the deterioration of the internal construction of the brick milk. Many studies handled this issue, whether archaeological and historical or focusing on the causes of the damage of the brick in the study area. The petrographic study showed the properties of mud-brick, the composing granules and the extent of suffering from the various degrees of damage. They all confirmed the physical and mechanical properties. X-ray diffraction showed the mud-brick's compounds. The same was reported by the chemical analysis of X-ray fluorescence. Scanning electron microscope showed that the bricks were exposed to damage by termites. Output results were examined by the EDX analysis. In these studies, the soil resulting from the decomposition of mud-brick by termites was analyzed. In addition, fungi and bacteria resulting from damage to mud-brick termites were also investigated. The study also provided the most appropriate solutions to control the growth and spread of termites in the study area can also be useful in other areas especially archaeological Mud brick sites.Our results indicate the essential oil C. Sinensis and its component (S)-Limonene could be good candidates for the development of new and safe repellent compound against termites of P. hybostoma. Further studies are necessary to confirm the safety of this plant essential oil and its constituent in archeological areas and their modes of action.

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