SCIENTIFIC CULTURE
www.sci-cult.com

SCIENTIFIC CULTURE, Vol. 11, No. 1, (2025), pp. xx-xx
Open Access. Online & Print

DOI: 10.5281/zenodo.14807067

PLANT GROWTH AFFECTING MASONRY STONE BUILDING IN RAMESSES II TEMPLE, KARNAK, EGYPT

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Received: 13/12/2024
Accepted: 07/02/2025

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ABSTRACT

Historic buildings are threatened by deterioration because of environmental factors, including chemical, physical, and biological effects. The present paper aims to evaluate the effect of higher plants growing as major biodeterioration factors on the Ramses II Temple in Karnak-Luxor by studying their chemical and physio-mechanical effects. Different techniques, e.g., an optical microscope (OM), scanning electron microscope equipped with energy dispersive X-ray (SEM-EDX), X-ray diffraction (XRD), and microbiological examination, were used to investigate and analyze some sandstone to define the bio-deterioration effects of higher plants on this valuable site. The results demonstrated that three essential types of higher plants affected the temple, i.e., *Alhagi graecorum Boiss*, *ExSteud*, and *Imperata cylindrica (L.) P. Beauv*. Therefore, it could be affirmed that the deterioration features affecting the temple walls, as demonstrated by chemical and mechanical mechanisms, are breakdowns, erosion of the granules, penetration of salts in the surface, surface granules, and small gaps.

KEYWORDS: Plant growth, Masonry, Higher plants, Sandstone, Biodeterioration

1. INTRODUCTION

Both historic and modern buildings are subject to environmental deteriorative action, especially bio-deterioration processes (Gaylarde, 2020). These processes include the aggressive effects of animals (Keopannha, 2008), insects (Hedges et al., 1996), microorganisms (Moncmanová, 2007), and higher plants (Elgohary et al., 2022). It was recognized that the higher plants, particularly in tropical countries (De Mello, 2021), play an important role among the various agencies responsible for the deterioration of stone monuments (Viles, 2012). Vegetation, which grows on historic buildings and ruins, is one of the main reasons for the deterioration of both the roots and the aerial part of the plants, damaging the structure of the walls (Matthiesen, et al. 2020). Moreover, branches and leaves hide the building, thereby hindering its appreciation and causing static damage due to their weight (Mishra and Saini, 2016), which may cause stones or large portions of the wall to fall. Plant growth may obstruct the regular maintenance of structures (Lisci and Pacini, 2003). It may influence other decay factors by causing changes in the microclimate, which may encourage the growth of other forms of biodeteriogens, such as insects and microorganisms (Fisher, 1972). Plants rarely differ from their substrates: They cause damage sooner or later, whether because of the acid metabolites they create or because their roots penetrate the building material or grow in spaces between rocks (Lisci and Pacini, 2003; El-Gohary and Al-Naddaf, 2009). Higher plants take root in pre-existing cracks in outdoor stone and masonry and cause biophysical and chemical damage. Their biophysical damage happens because the radial thickening during growth causes higher pressure on the structural parts of the building (Lisci and Pacini, 2003; Caneva, et al., 2008), which leads to breakage and crumbling around the roots (Kumar and Kumar, 1999). Furthermore, higher plants can increase the risk of fire in dry conditions, as the materials' chemical and mechanical can be altered, which ultimately causes structural stability problems of historical and/or modern construction (Pozo-Antonio, et al., 2020). This circumstance can often lead the spectator to be obstructed by covering essential surface information (Jain et al., 1993). According to (Caneva and Roccardi, 1991), plant growth that affects the archaeological sites includes about 25 vascular plant species, such as trees, bushes, and climbing phaner-ophytes. In this context, *Capparisspinosa*, *Ficuscarica*, *Hedera helix*, and *Ailanthus altissima* are extremely common and potentially damaging plants (Ortega et al., 1988). They pose a threat because of their ability to penetrate the walls, forming an intensive cap that causes surface loss and fragments (Bartoli et al., 2017; Celesti-Grapow and Ricotta, 2021) and decompose the mortar (Honeyborne, 1998). In this paper, the authors study the aggressive effects of three types of higher plants on the Rameses II Temple in Luxor. This work aims at check the aggressive effects resulted from plant growth that affects one of the marvel masonries building in Egypt (*Ramesses II Temple, Karnak)*. Furthermore, studying the different deterioration forms attributed to the three types of plants spread in the most archaeological sites in Egypt. Additionally, it aimed at using some investigation and analytical techniques for defining the components of deterioration products., furthermore, the novelty of this research owed essentially to the new findings that explain and establish the most important destructive effects attributed to the harmful effects of some species of plants spreading in the most Egyptian temples, whether chemical or biological.

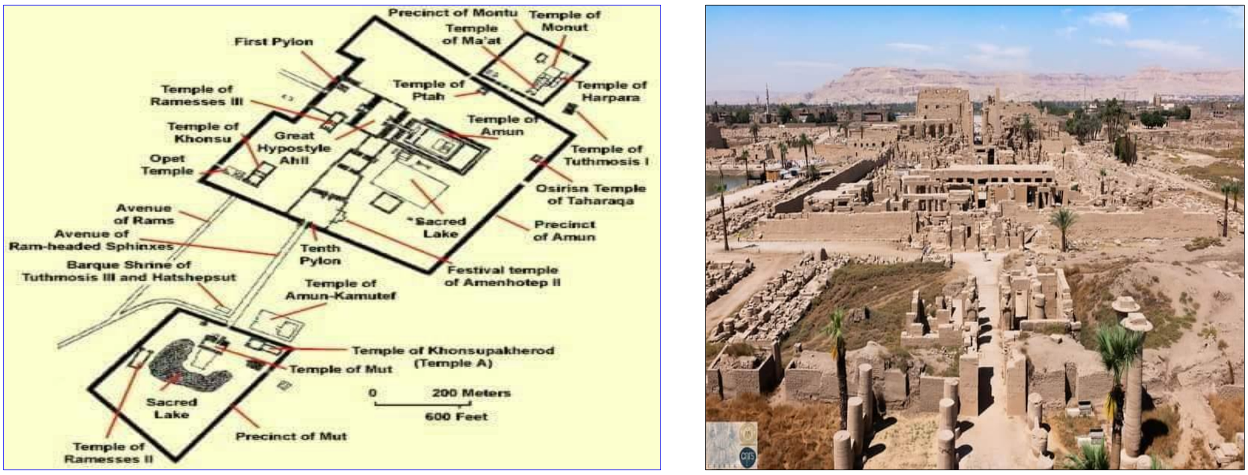

Figure 1. Shows a. a location map (After: centre Franco-Egyptien), b. a top view of temple Ramesses II (After: Cnrs-Emilie)

2. HARMFUL EFFECTS OF HIGHER PLANTS ON RAMESES II TEMPLE IN LUXOR

2.1. *Study site (Rameses II Temple)*

Rameses II Temple, Luxor, on the far eastern side of Amun Temple, was built around the unique obelisk. The temple, figure (1) consists of a gateway and pillared hall with a central false door (Sullivan, 2008). The stone used in the temple is sandstone, which consists mainly of quartz grains of different sizes ranging from $^{1}/_{16}$: 2 mm. Lithologically, it varies in color, shape, and grain size (El-Gohary, 2000; El-Gohary, 2013).

2.2. *Types of higher plants growing in the (affected) Rameses II temple*

After a microscopic examination in the Botany dept., Faculty of Science, Sohag Univ., three plant species, i.e., Alhagi graecorum Boiss, and Imperata cylindrica (L.) P. Beauv, were found. They are the most common and widespread species in the archaeological sites in Egypt (Mahgoub, 2016). Alhagi graecorum Boiss is a perennial dendritic plant with up to 80 cm wooden length at the base, especially in the old species. Smooth or low-bristled, the leg is vertical or climbing and branched heavily; it has a simple leaf and grows in a moist environment (Hosseini et al., 2021). In addition, Alhagi has long, creeping stolons that penetrate into the soil (Boulos, et al., 1984). Moreover, the height of the shrub may be 1 m., and its root depth is about 15 m. underground (Fakhri and Adelzadeh, 2013) as most plant species grown in harsh environments and saline soil (Abou Gabal, et al., 2013). Although the aggressive deterioration affects the archaeological sites, many chemical compounds are extracted from Alhagi, such as carbohydrates, tannins, and unsaturated sterols (Awaad et al., 2006; Samejo et al., 2012). Imperata cylindrical (L.) P. Beauv is a perennial rhizomatous plant with horizontal underground stems and narrow linear leaves with sharp edges. It has a fibrous root system from which the rhizomes emanate, and the presence of rhizomes of the Imperata plant makes it difficult to control as the single rhizome produces about 350 parts in 6 weeks, which covers an area of 4 m. in 11 weeks. Rhizomes can also survive in winter at 14 ° C but cannot survive in icy areas (Clifford, 1997). Imperata plant grows in soil with a pH = 4.7 (Rodríguez et al., 2005), at sites with disturbed soils and roadsides (King and Grace, 2000). Also, Imperata grows in soil with a high pH of more than 7 (pH> 7), as in the case of the Egyptian land. The plant reproduces by seeds and rhizomes. The rhizomes are responsible for the survival of plants for a long time as the soil penetrates to a depth of 1.25 m (Sellers, et al., 2012).

2.3. *Deterioration mechanisms of the monument understudy*

According to (Guillitte, 1995; Mishra, et al., 1995; Hueck, 2001; Jain, et al., 2009; Miller, et al., 2012; D'Orazio, et al., 2014) and by assessing the condition state of Ramses II Temple, it could be asserted that the temple was exposed to synergetic damaging mechanisms (physical, chemical and biological) due to plant growth in different places.

2.4. *Biophysical mechanisms*

Higher plants can break down building materials physically as their permanent roots grow. So, as they penetrate cracks, they are increasingly putting pressure on the surface of the stone (Caneva, et al., 1988). The growth of plants in the temple causes some damage, such as hiding the building features, increasing the risk of fire, particularly in dry conditions, and damaging the monument's beauty, making it hideous. This circumstance can often lead the spectator to be obstructed by covering essential surface information. In addition, other forms are caused by the mechanical force of roots penetrating deeply into the structure, such as opening cracks, crumbling, loosening stones and large fragments of walls, widening gaps between the adjoining blocks, and increasing the dimensions of the cracks already present.

2.3.1 Biochemical mechanisms

Water, nutrients, CO_2, and the place of root growth are the main things plants need to thrive on bedrock (Dempsie, 2014). In addition, some general nutrients, such as P, K, N, Mg, and Ca (Roccuzzo, 2012) will be taken up by the plants as ions after dissolving in water. For example, Alhagi graecorum Boiss affects the wall chemically, causing the leaching of the surface beside the falling down of some parts of old mortar and creating a void, change of stone color, high moisture content, and salt crystallization.

2.3.2 Biogenic mechanisms

Microorganisms found in air, water, and soil can grow and live on inorganic and organic materials. Enzymes secreted by these species can be catalysts that attack building materials by chemical reactions (Betina, 1993). Relative humidity and temperature levels decide whether or not these species survive (Elgohary et al. 2022). From a specialized view, it could be claimed that some harmful effects are caused by some fungi and bacteria due to Phragmites and Imperata on the temple Ramses II stone. Some features are shown in Fig.2.

Figure 2. Shows growing higher plants in different area of the temple causes some deterioration features

3. MATERIALS AND METHODS

Different effects of Alhagi graecorum Boiss on the decaying of Ramesses II Temple sandstone were investigated by collecting some samples from different locations. Some techniques were used to investigate and identify the characteristics of plant samples and their negative roles. For instance, a digital microscope was used to study the optical appearances of stone samples affected by plant actions (Adams, 2017). A Scanning Electron Microscope (SEM) Quanta 250FEG (Field Emission Gun) attached with an EDX Unit (Energy Dispersive X-ray Analyses), with an accelerating voltage of 30 K.V., magnification14x up to 1000000 and resolution for Gun.1n) was used to examine the morphological features of the deteriorated stone samples. Furthermore, the chemical composition of investigated samples, especially the elements of weathering products, must be identified. XRD Model D8 ADVANCE from Bruker X-ray diffraction (XRD) was used to identify the mineralogy of the affected samples due to plant influences. According to (El-Gohary and Redwan, 2018), "Perkin Elmer AAS Analyst 400 - Unico-1200", an atomic absorption spectrophotometer and chemical titration method were adapted for analyzing water samples collected from the Holly Lake beside Karnak Temple to evaluate TDS and dominated salts in water. In addition, hydrochemical examinations (dominated saturated salts and their concentrations) were identified using a hypothetical combination of water methods. According to (Bhatnagar et al., 2010; El-Gohary & Redwan, 2018), microbiological investigations were achieved to identify some species of fungi and bacteria that affected the temple stone.

4. RESULTS

4.1. *Optical investigation*

The Optika microscope was used to determine the change in sandstone samples, as shown in Fig. (3). The photos of different samples showed silica grains, dirt, dust, decomposition of quartz grains, changing the surface color of sandstone, and corrosive of cement materials due to deterioration processes. They also showed the reddish-brown color as an indication of iron oxide (hematite) and the weakness of the binding material.

Figure 3. Sandstone samples under stereo microscope

4.2. *SEM-EDS investigation and elemental analysis*

SEM-EDX investigation results of the first sandstone samples, table (1) & figure (4-a) illustrated that the granules were in a relatively homogeneous form with quartz crystals and granules of different homogeneity of aluminum silicate, which suggests the presence of clay clusters, including Si, Al, and Fe in varying proportions. The second sample, table (1) & figure (4-b) illustrated enlarged granules in a heterogeneous form, gaps, and erosion of the surface of silica granules with the presence of decaying plants where the proportion of carbon was high (62.12) with the presence of some clay components, such as Fe, Si, Mg, Al, and K. The third sample, table (1) & figure (4-c) illustrated erosion, especially in the area of connection between the granules, causing the separation of the granules from each other and the beginning of various gaps with erosion on the surface of the granules. Moreover, Si, Al, and Fe appeared as the main elements.

Table 1. Results of Elemental Ratios of Sandston by EDX

Elements	Cat 1			Cat 2			Cat 3		
	Wt %	*At %*	*K-Ratio*	*Wt %*	*At %*	*K-Ratio*	*Wt %*	*At %*	*K-Ratio*
O k	42.41	58.09	0.1154	40.67	62.79	0.0582	-	-	-
Na K	-	-	-	-	-	-	40.64	51.24	0.1895
Mg k	-	-	-	0.96	0.97	0.0028	-	-	-
Al k	7.37	5.94	0.0390	5.33	4.88	0.0213	-	-	-
Si k	4.96	31.96	0.2385	12.11	10.65	0.0601	2.20	2.27	0.0111
Cl k	-	-	-	-	-	-	54.58	44.62	0.4298
K k	2.07	1.16	0.0150	0.47	0.30	0.0042			
Ca k	-	-	-	0.66	0.41	0.0065	2.58	1.87	0.0173
Ti k	-	-	-	32.62	16.82	0.2931	-	-	-
Fe k	7.25	2.81	0.0641	7.19	3.18	0.0614	-	-	-
Total	100.00	100.00	-	100.00	100.00	-	100.00	100.00	-

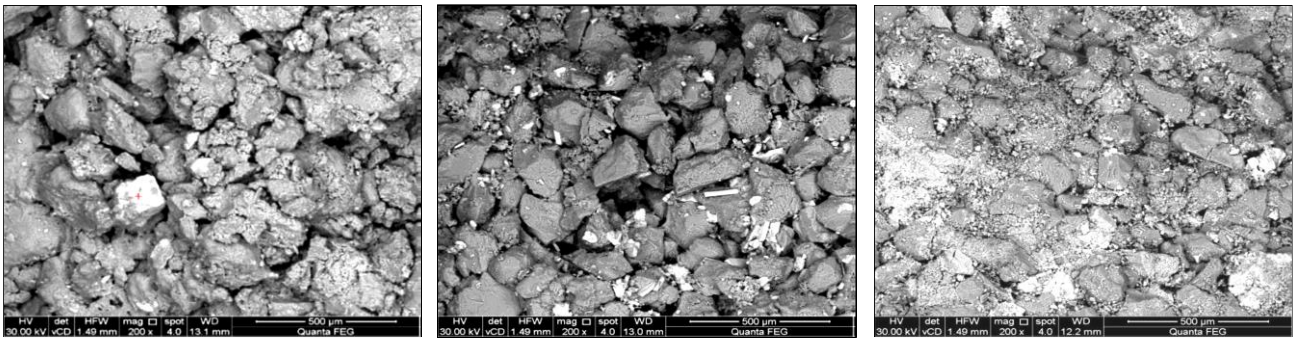

Figure 4. SEM micrograph of sandstone the a. 1st sample, b. 2nd sample, c. 3rd sample

4.3. *Mineralogical examination*

The XRD of the first sample illustrated that it contained quartz (SiO2), fersilicite (FeSi), and xifengite (Fe5Si3), as shown in figure (5-a). The XRD of the second sample illustrated that it contained fersilicite (FeSi) and xifengite (Fe5Si3). The XRD of the third sample illustrated that the sample contained quartz (Si O2), sylvite (KCl), halite (NaCl), sodium sulfate (Na2SO4), and potassium nitrate (KNO3) (as shown in figures (5-b & c).

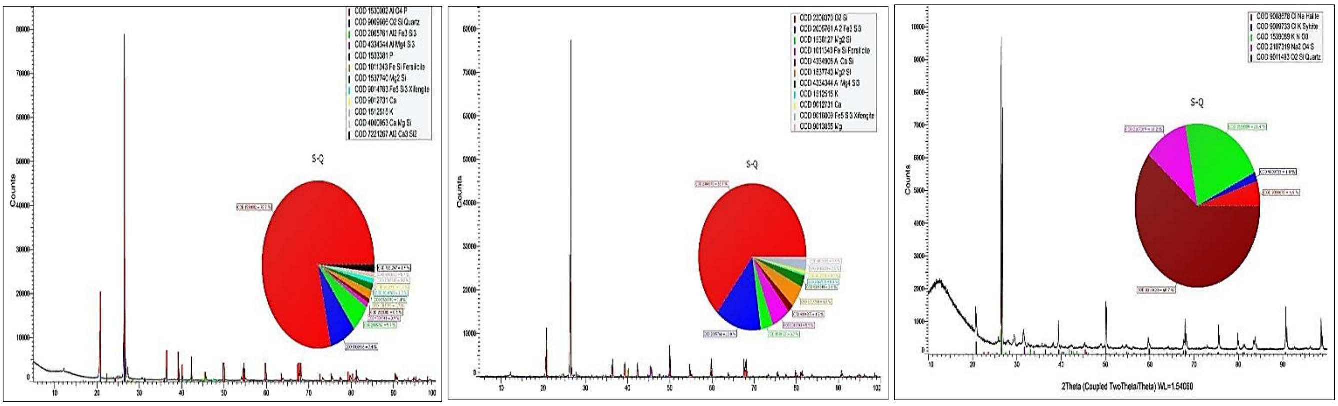

Figure 5. XRD patterns of sandstone the a. 1st sample, b. 2nd sample, c. 3rd sample

4.4. *Hydrochemical examination*

The hydrochemical analytical results of the water sample proved that the sample contained a high level of different major cations and anions, in addition to the main dominated salts coming from domestic water. All of these data are listed in table (2).

Tab. 2. *Chemical analytical results of domestic waste water in the study area*

	Parameter	Value	Unit	Salts	Percentage %
Cations	Ca^{++}	114.6	ppm	Na_2SO_4	10.9
	Mg^{++}	14.69		NaCl	17.1
	Na^{+}	52.5		KCl	0.6
	K+	1.08		NO_3	0.7
Anions	HCO^{3-}	36.6		Other Characteristics	
	SO^{4-}	286.6		pH	8.64
	Cl^{-}	70.2		TDS	522.5 ppm
	NO^{3-}	2.64		EC	803.84 µS/cm

4.5. *Microbiological investigation*

Through microbiological examination, some species of fungi and bacteria were found, i.e., three fungal species (Aspergillus niger, Aspergillus flavus, and Emercielle nidulans) in addition to two bacterial specie (Vibrio and Pseudomonas aeruginosa), as shown in table (3).

Table 3. Some microorganism species dominated in the temple

Type of Microorganism	
Species	**Name**
Fungi	Aspergillus niger
	Aspergillus flavus
	Emercielle nidulans
Bacteria	Vibrio
	Pseudomonas aeruginosa

5. DISCUSSION

The deterioration of many archaeological buildings results from various biological and population mechanisms, in addition to the pedogenetic action of plants, as clearly demonstrated by Caneva and Altieri (1988). Higher plants in Egyptian archaeological sites are one of the most severe bio-deterioration factors to monumental structures in Egypt due to many negative roles (El-Gohary, 1996; Radi, et al., 2017). In this regard, three main types of damages were studied, i.e., biophysical, biochemical, and biodeterioration.

5.1. *Biophysical damage*

The mechanical degradation of the stone surface happens through root penetration, causing pressure by growth, which increases pore structure (Ferrari, 2015). This action is sufficient to supply the essential nutrients that a plant needs (Mishra and Saini, 2016; Cochran and Berner, 1996). In our case, pore structure played a key factor in enabling plants to extract water from pores, obtaining the essential dissolved macronutrients and micronutrients in water or that are present in the rock composition itself, as discussed by many authors (Sharma, 2006; Dempsie, 2014; Jones, 2014; De Mello, 2021). This mechanism ultimately causes complete mechanical destruction of some parts in the building (Hossam, 2021). Another mechanism that affected most stone temple blocks was the water trapped in the pores or within the stone that created a space where plants could expand their roots (especially large sizes) depending on the quantity of CO2 and its growing place (Kimball et al., 1993; El-Gohary, 1996). They cause significant mechanical breakdown of the temple structure by creating deep fissures and wide cracks within the stone blocks (El-Gohary, 2000).

5.2. *Biochemical damage*

Biochemical damage resulting from higher plants can break down building materials by accelerating the chemical weathering mechanism, which varies from the direct action of metabolism to exuding several substances through their roots, such as special enzymes, amino or organic acids that seriously affect the stone body through mineral transformations (Banfield et al., 1999). These processes occur in rhizosphere zoon because of the interactions between mineral and plant nutrition (Jungk, 1996). Moreover, aerobic organisms produce carbon dioxide respiratory, a carbonic acid that decays and dissolves stones and forms soluble salts (Cutler and Viles, 2010). In the present study, these effects accelerate or even initiate the chemical weathering of minerals through the combination between the roots with the H+ of the rhizosphere causing a large number of chemical reactions due to their strong negative charge as discussed by Cochran and Berner (1996) and Winkler (2013). Moreover, they create several deterioration symptoms, especially with the high chelating ability of organic acids (Booth et al., 2003; Chen et al., 2021; Celesti-Grapow and Ricotta, 2021). Once roots have entered the rock via cracks and fissures (Pawlik et al., 2016), they enhance chemical weathering, especially with the presence of enough moisture content and LMW organic acids (Landeweert et al., 2001), which produce acid and root sap. These materials ultimately cause the chemical decomposition of rock minerals (El-Gohary, 2011).

5.3. *Biodeterioration damage*

This damage is more dangerous than the previous two. It is attributed essentially to the effects of algae, fungi, bacteria, and lichens (Caneva and Roccardi, 1991). Microbial populations can solubilize the cations and cause diagenesis of minerals through secondary metabolite excretion, leading to stone biodeterioration (Ehrlich, 1990). In the current study, only the effects of fungi and bacteria are addressed as they grow in the study area. Fungi are the common members of microbial communities that grow on stone monuments (Strzelczyk, 1981; Gorlenko 1983). They are the most active microorganisms in rock weathering (Rossi, 1978) and can cause severe harmful effects because of their high ability to grow with minimum values of organic matter and low humidity index (El-Gohary, 1996). Their effects are mostly realized through the acidolysis mechanism by organic acid excretion (De la Torre et al. 1991; 1993). In addition, they manifest other severe deterioration symptoms, such as surface pitting, etching of stone components, and complete dissolution of grains (Burford et al., 2003a).

5.4. *Evaluation of analytical investigation results*

5.4.1. Stereo microscope

Stereo microscope results, figure (3) illustrated that the *dirt and dust deposition* as an important alteration form (Anaf et al., 2015) affected the temple stone surfaces, causing a visual nuisance, especially in decorated areas (Grau-Bové and Strlič, 2013). *The decomposition of quartz grains*, figure (3-a), resulted from alteration processes owing to the synergetic environmental factors characterizing the study area, especially "plant enzymes, groundwater, sunlight, and wind" (El-Gohary, 2017; Hosam, 2021). *Changing the stone rock fabric or color superficial weathering*, figure (3-b) was attributed to the effects of some chemical reaction between sap roots of plant species and stone components that was enhanced with the high ratio of sunlight that led to oxidation of iron-bearing, as attested by Begonha (1994) and El-Gohary (2015) in similar cases. *Corrosive cement materials and loss of material below the stone surface*, figure. (3-c) resulted from the development of cracks and the ongoing loss of cohesion between grains, attributed to the etchable of cement material, particularly with a salt mechanism within the pores and under the surfaces (Ahmad, 2012; Kottke, 2009; Ouacha et al., 2013; El-Gohary, 2015)

5.4.2. SEM attached to EDS

According to SEM, figure (4-a), it could be claimed that homogeneous deposition of quartz crystals mixed with aluminum silicate as a dust deposition occurred on the stone surfaces. This deposition is extremely coarse angular and sub-angular particles. It is a negative effective factor for the artistic significance of our site, as mentioned by Tétreault (2003), El-Gohary (2008), and Brimblecombe et al. (2009) in similar cases. Moreover, the enlargement of the heterogeneous granules (deepening and widening), figure (4-b) is attributed to the effects of the biochemical process resulting from plant sap roots and salt species (Pawlik et al., 2016) dominated in the area. Surface gaps and erosion of silica granules result from the effects of biomechanical due to plant growth, as discussed by Zwieniecki and Newton (1995) and Embleton-Hamann (2004). In the same context, erosion symptom, figure (4-c) as an indirect effect of chemical weathering results through the effect of saline groundwater extricated by Alhagi and Imperata, which are two main species of six communities recognized in halophytic vegetation (saline) system (Zahran and Willis, 2009). EDX analyses revealed that the analyzed samples are divided into 3 categories, figure (6): **1st cat**. is a slightly affected sample, as stone core (Si+Fe) equals 48.21%, and dust components equal (Al+K) 9.39%., with no salty crust. **The 2nd cat**. is a moderately affected sample, as stone core (Si+Fe) equals 19.30% and dust components equals (Mg+Al+K+Ca) 7.42%., and other contaminated particles (Ti) equal 32.62%, with no salty crust. **The 3rd cat**. is a heavily affected sample, as stone core (Si) equals 2.20%, dust components equal (Ca) 2.58 %., and salty crust (Na+Cl) equals 95.22%. Regarding the high ratio of (Ti) in 2nd cat., it could be asserted it occurs as discrete crystals or aggregates made of several crystals that are embedded in interstitial clay minerals, quartz, and calcite (Morad, 1986) or through the replacement of feldspars, which is also common in sandstones extensively cemented by calcite. Through SEM examination, figure. (4-a), it could be claimed that two principal modes could do this process: **1)** co-precipitation of titanium oxides with other clay minerals and calcite, and **2)** solitary precipitation in dissolution voids of feldspars, as asserted by Morad & Aldahan (1987).

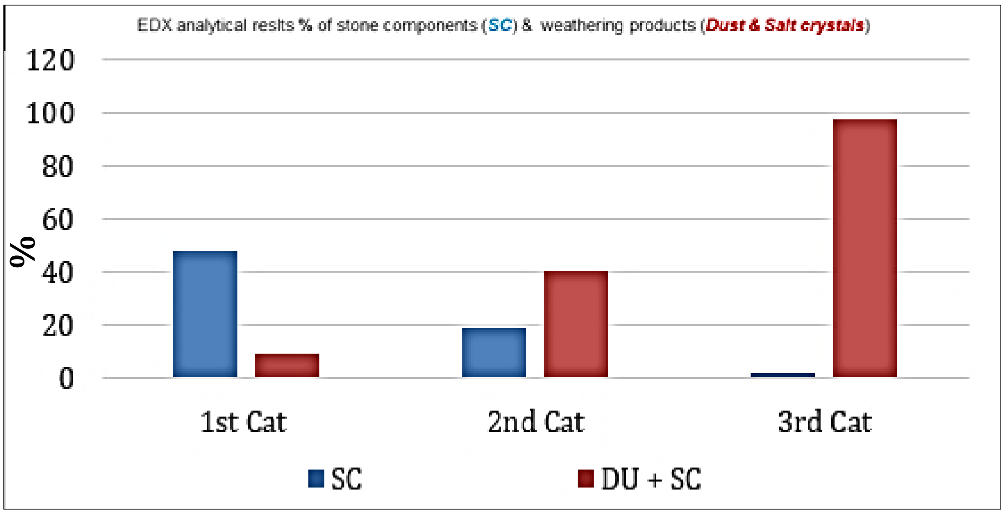

Figure 6. The relation between stone components and weathering products

5.4.3. X-ray diffraction

XRD assured the EDX results. Quartz (SiO_2), fersilicite (FeSi), and xifengite (Fe_5Si_3) are the major components of the **1st** and **2nd cats.**, as shown in figure (5-a). Quartz grains (SiO_2) represent the main component in all investigated samples (75%, with a porosity index of 38.15%) in the **1st cat**. and (65% with a porosity index of 40.30%) in the **2nd cat.**, figure (7). They are commonly clear, rarely cloudy and moderately to very well-sorted (Aggour, et al., 2012). It is characterized by bimodal, very well-sorted particle size and ferruginous cement (El-Gohary, 2013; El-Gohary, 2015), with the presence of interconnected pores and a relatively high permeability index (Zaid, et al., 2018). The **3rd cat**. is a heavily affected sample, and quartz represents (~ 20%), with a porosity index of 54.21%) and is characterized by degradation features due to the aggressive effects of dominated salts present with large proportions in the study area. These salts (Halite, Sylvite, and Thenardite) were spread and transmitted from the soil to the stone through capillary rising (Hosam, 2021). Sylvite (KCl) is a potassium salt that occurs due to deliquescence-recrystallization/ rehydration of salt crystals under oscillating humidity due to its hygroscopic properties (Godts et al., 2017). Halite (NaCl) and Potassium Nitrate (KNO_3) are soluble components of type I pore solutions. They are often found as a salt efflorescence in the damaged zone of areas affected by rising damp, as agreed with data presented by Steiger, et al. (2011). Furthermore, the presence of (Na_2SO_4) known as Thenardite, causes some cracks and micro-fissures that play an important role in the stone bleeding phenomenon (El-Gohary et al., 2022) that ultimately destroys stone, especially with high crystallization pressure (Yuan, 2019; Wasserman, 2021).

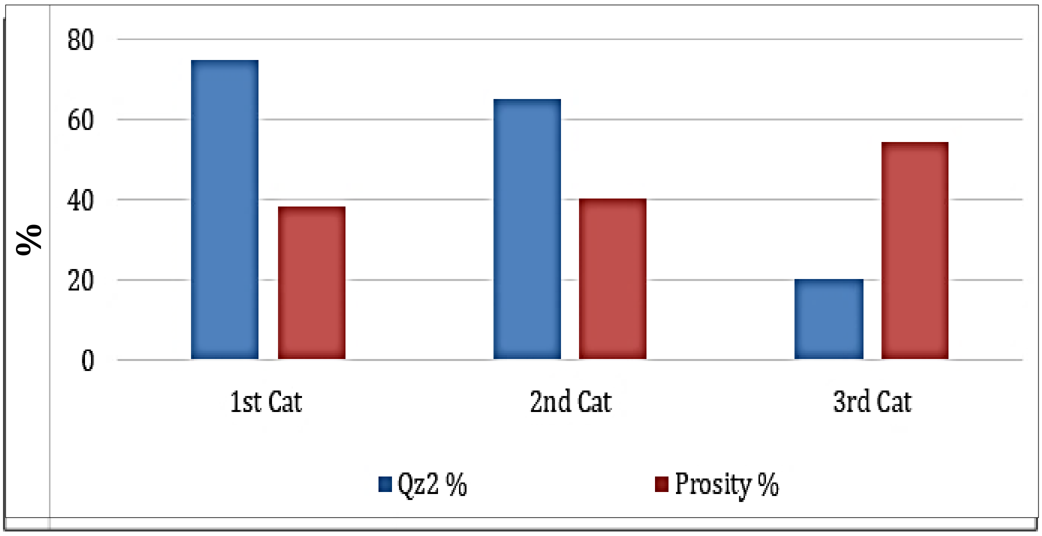

Figure 7. Porosity index of the investigated samples in the 1st cat., 2nd cat. & 3rd cat.

5.4.4. Atomic absorption spectroscopy (AAS)

Elemental analysis by AAS and titration results, table (2) proved that Ca, Mg, and Na as cations, in addition to HCO3, SO4, Cl, and NO3, as anions, were detected as the most common elements. These results responded well to the XRD analysis and EDX results. According to Collin (1923) and El-Gohary and Redwan (2018), the hypothetical combinations of the dominant salt within the stone pores are based on the reaction between the ions of the strong acids (Cl−, SO42− and NO3−), form chemical combination with alkalis (Ca++, Na+, and K+). In the same context, these combinations led to different kinds of salts that were in relation to the salts that affected the temple building materials, especially the mortar layer, causing high salt decay of the temple construction materials, tab. (3). Regarding the hydrochemical examination, the analyzed sample was alkaline, with pH (8.64) TDS (522.5 ppm), and loadings of EC (803.84 µS/cm) as an important characteristic factor of the sample result from the synergetic combination between anthropogenic and natural activities but not from river waters65 (El-Gohary & Abdel Moneim, 2021; Rahman, et al.,2021)

5.4.5. Microbiological investigation

It was proven that they contain two types of microorganisms: fungi and bacteria. On the one hand, fungi include 3 species (*Aspergillus niger*, *Aspergillus flavus*, and *Emercielle nidulans*). On the other hand, bacteria include 2 species (*Vibrio* and *Pseudomonas aeruginosa*). Aspergillus niger belonging to fungi imperfecti (Warscheid and Leisen, 2009) grows profusely on the stone body of the temple in dark/black coloration, especially beside thick vegetation layers (Salvadori, 2000). This color is owing to the interaction with sand powder (the main mineral of sandstone), especially in consolidated areas (Paraloid B-72 used consolidants) as surface treatment, which is in fully agreed with the result extracted by (Hirsch, et al., 1995; Salvadori and Municchia, 2016). Their importance in the decay of rocks is attributed to the releasing of some elements, such as K, Mg, Fe, and Al, from stone components through acid attack causing severe damage, as shown in figure (3-a) (Eckhardt, 1980). On the other hand, the penetration of their hyphae into the substrate depends on their structure, chemical composition, and state of stone conservation, as attested by Gadd (2007). Moreover, the resulting fungal **EPS** (*Exopolysaccharide*) facilitates biofilm formation attached to the rock, increasing the mechanical pressure through shrinking and swelling alternative cycles, as discussed by Burford, et al. (2003b). *Aspergillus flavus* is the most fungi spp. That caused the most deterioration forms to the object isolated from weathered materials in Egypt (Abd El-Tawab et al., 2012; Abdelhafez et al., 2012; Mansour and Ahmed, 2012). Furthermore, it impacts mineral dissolution, precipitation reactions on quartz, and microbial decomposition of rocks due to acidity crucial effects and enzymatic activity, especially near plant roots affected zones, as discussed by Barker, et al. (1998), Sterflinger (2010), and Banfield, et al. (1999) or when the soil dries out and penetrating of oxygen within the cracks within the stone surfaces (Petersen, et al., 1988; Daly, 2011). Emercielle nidulans, known as *phyllospheric fungi* isolates or *aspergillus nidulans* was obtained from some plant species (Esh and Taghian, 2021). In our case, it produced acetic acid (CH_3COOH) that decreased sandstone mechanical properties due to the etching process affected the stone body, figure (2-b), as demonstrated previously by Li and Shi (2020) Furthermore, surface erosion and cracks that affected some areas in the temple could be due to the effects of acid secretions from the chemical reaction of this spp. with the stone substrate (Mishra, et al., 1995). *Vibrio* is the most common cellulolytic aerobic among bacteria spp. (Canev, et al., 1991), according to Sampaio, et al. (2022). Vibrio, particularly *V. vulnificus* spp., is an aquatic heterotroph living between sediments and saline water, and it plays an important role in material mineralization due to its enzyme effects (Thompson and Polz, 2006). In our case, it is responsible for some pigmented bio-film on the stone surfaces, yellow color, especially in the zones characterized by a high concentration of NaCl, figure. (5-c) as explained previously by Hu et al. (2022). *Pseudomonas aeruginosa* is one fluorescent group of pseudomonas. It is a gram-negative bacillus found widely in nature, soil, and water (Planet, 2023). In our case, the negative role of this spp. attributed to the production of some pigments through their metabolic activity on the stone surfaces (aesthetic damages) that finally led to complete destruction mechanisms (Cicinelli, et al., 2018; Zhanga, et al., 2019). These mechanisms include acid production of organic and oxidation as the major biochemical reactions (Liu et al., 2018). On the other hand, it could be claimed that this spp. play as a notable stimulus for a specific type of deterioration forms (pettings) on archaeological materials such as metals, stones, and paintings, as discussed by Ghiara et al. (2019) in a similar case.

6. CONCLUSION

Biodegradation in Ramesses II Temple, Karnak, is a complex phenomenon through different mechanisms. Our observations suggested that plant origins that affected the building are *Alhagigraecorum Boiss*, *Imperatacylindrica* L. and *P. Beauv*. These effects were realized through physical, chemical, and biological mechanisms. After defining different deterioration mechanisms that caused many deterioration forms by scientific techniques, it could be asserted that the building materials understudy were highly affected, especially by the continuous supply of water from the Holly Lake. Our results attested that many deterioration symptoms were defined, such as surface accumulations, surface color fading due to oxidation, corrosive of cement materials, weak binding material due to salt crystallization, enlargement of the granules in a heterogeneous form, gaps and erosion of silica surface, especially in the area of connection between the granules, separation of the granules, detachment of old mortar, and etching of stone surface due to slight root action.

Author contributions: Ahmed Hosam conducted the experimental and methodological works, including data collection and analysis; Ahmed Salam made the formal analysis interpretation of the results and the drafting of the manuscript; Mohamed El-Gohary: supervise, revised and validate the results and discussion section. All authors read and approved the final manuscript.

Acknowledgements: the author would like to pay my respects to Dr. Moaz Hamed to his effort in the interpretation the plant species in the laboratory of Microbiology department National Institute of oceanography and fisheries, Red Sea branch.

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