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Evaluating the Combined Efficacy of Polymers with Fungicides for Protection of Museum Textiles against Fungal Deterioration in Egypt

OMAR ABDEL-KAREEM*

Conservation Department, Faculty of Archaeology, Cairo University, Egypt

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Abstract

Fungal deterioration is one of the highest risk factors for damage of historical textile objects in Egypt. This paper represents both a study case about the fungal microflora deteriorating historical textiles in the Egyptian Museum and the Coptic museum in Cairo, and evaluation of the efficacy of several combinations of polymers with fungicides for the reinforcement of textiles and their prevention against fungal deterioration. Both cotton swab technique and biodeteriorated textile part technique were used for isolation of fungi from historical textile objects. The plate method with the manual key was used for identification of fungi. The results show that the most dominant fungi isolated from the tested textile samples belong to *Alternaria, Aspergillus, Chaetomium, Penicillium and Trichoderma* species. Microbiological testing was used for evaluating the usefulness of the suggested conservation materials (polymers combined with fungicides) in prevention of the fungal deterioration of ancient Egyptian textiles. Textile samples were treated with 4 selected polymers combined with two selected fungicides. Untreated and treated textile samples were deteriorated by 3 selected active fungal strains isolated from ancient Egyptian textiles. This study reports that most of the tested polymers combined with the tested fungicides prevented the fungal deterioration of textiles. Treatment of ancient textiles by suggested polymers combined with the suggested fungicides not only reinforces these textiles, but also prevents fungal deterioration and increases the durability of these textiles. The tested polymers without fungicides reduce the fungal deterioration of textiles but do not prevent it completely.

Key words: Egyptian and Coptic Museums in Cairo, fungal deterioration, fungicides with polymers, historical textiles

Introduction

Fungal deterioration seems to be a predominant feature in museums and other culture objects of organic materials such as paper, textiles, wood, *etc.* (Abdel-Kareem *et al.*, 1997; Agrawal, 2001; Bhatnagar and Mani, 2001). The ability of textiles to absorb and retain moisture from the surrounding environment in the museums, coupled with their organic components makes them highly susceptible to fungal deterioration. There are many factors which cause that historical textiles are more liable to fungal deterioration. Textile materials are good nutrient materials for fungi. Progressive changes of the properties of textile materials most commonly happen during natural aging. These changes in the characterization of textile materials cause that historical objects become more susceptible to fungal deterioration (Szostak-Kotowa, 2004).

Fungal deterioration of historical textiles is a serious problem in Egypt (Abdel-Kareem *et al.*, 1997). This is due to the fact that improper environmental conditions in Egypt promote the fungal growth and the nature of the textiles too. Historical textiles in Egypt are more acidic according to the surrounding environments (Abdel-Kareem, 2002), which is considered to create favorable conditions for fungal growth. High humidity accompanied by lack of ventilation in storage rooms in Egyptian museums enhances the fungal growth on textile objects. In some cases contaminated conservation materials such as improper polymers can cause fungal infestation of conserved textile objects (Florian, 1997).

Fungal deterioration causes changes in the properties of textiles such as losses in the strength, their general durability, discoloration, and appearance. In addition, many fungi contain coloured substances that can cause stains and spots on textile objects. Fungal deterioration causes various coloured stains on the surface of a textile object (Mukerji *et al.*, 1995; Abdel-Kareem, 2007). These stains contain chemical substances which can still deteriorate a textile object if the fungus dies or is killed (Montegut *et al.*, 1991; Florian, 2004).

* Corresponding author: O. Abdel-Kareem, Conservation Department, Faculty of Archaeology, Cairo University, Egypt; **e-mail: Omaa67@yahoo.com**

It is important to think of a way to remove these fungal stains from textile objects. However, it is reported that fungal stains are extremely difficult to remove from historical textile objects as the methods that are known for removing fungal stains are very harmful to textiles (Agrawal, 2001). The chemical changes occurring with the fungal growth result in decreased fabric strength and lead to partial or total destruction of the material (Szostak-Kotowa, 2004). Molds can be dangerous to people working in museums and in some cases can pose a major health hazard (Merritt, 1993). A large number of fungal species are reported to cause deterioration of textiles and culture heritage. There are different methods for prevention of fungal deterioration of textiles with the use of chemicals and nonchemical methods. Chemical treatments include using fungicides and fumigants. Nonchemical methods comprise the use of UV and gamma rays, heat, electron beams and microwaves (Bhatnagar and Mani, 2001). Unfortunately these methods are not evaluated well from conservation perspective. Most of the methods mentioned above may cause damage to ancient textiles such as fading of dyes, dryness of fibers, and breakdown in the strength of the textile fibers and so on.

It is emphasized that the best method to prevent fungal growth on museum textiles, is to protect textile surfaces from contamination, control moisture in materials and relative humidity to be low and avoid the treatments which may activate conidia to start germination (Florian, 1997). In some cases this method could not be applied in all museums (Abdel-Kareem, 2000a). In such a situation some other solutions have to be thought off, such as fumigants and fungicides for preservation of textiles. There are a large number of studies that have been carried out on fungicides used for protection of museum textiles (Agrawal, 1995; Abdel-Kareem, 2000a). Numerous studies for industrial purposes have also been carried out on the microbial deterioration and degradation of polymers and on their protection with biocides (Whitney, 1996; Srivastava, 2001; Lucas *et al.*, 2008). Other papers have also focused on textile conservation methods (Abdel-Kareem, 2000b; 2005). In this study a new approach to prevent fungal growth on consolidated historical linen textiles was evaluated.

Experimental

Material and Methods

Isolation and identification of fungi from historical biodeteriorated textile samples

Biodeteriorated samples. Both cotton swab technique and biodeteriorated textile part technique were used for collecting samples for isolation of fungi from historical textile objects. Although it was confirmed in previous studies that using of parts of the investigated objects is the best method which can be used in identifying fungi from biodeteriorated historical textiles (Abdel-Kareem *et al.*, 1997), in some cases this method is considered destructive. Thus it could not be used with all investigated textile objects in this study. Instead, the cotton swab technique was applied with all investigated textile objects. This method scores highly in most of the criteria required for isolating fungi from ancient objects (Chaisrisook *et al.*, 1995).

Isolation and identification of fungi. Very small biodeteriorated textile parts separated from the original ancient object were washed with sterilized distilled water and were transferred by using sterilized tweezers and were put on 2 modified media in Petri dishes (Abdel-Kareem *et al.*, 1997). The used media are 1 – Medium of Greathous, Klemme and Barker with disk of pure 100% linen fabric with linen textile samples or with disk of pure 100% wool fabric with wool textile samples. 2 – Czapek-Dox agar modified without sugar.

In the case of using the cotton swab technique the fungal species were isolated by using sterile moist cotton buds swabbed onto the surface of textile objects where fungal growth or fungal structures were observed. Cotton swabs were then used to distribute the fungi on media in Petri dishes. The Petri dishes were then incubated for three to four weeks at 28°C (until growth of colonies was observed). For purification and identification, the developed fungi were isolated in pure culture on slants of the appropriate media (Czapek dox agar and malt extract agar) (Booth, 1971). Identification of fungal species was performed according to standardized methods by consulting the appropriate manuals (Domsch *et al.*, 1980; Gilman, 1975; Raper, and Fennell, 1965; Raper and Thom, 1949).

Evaluating the suggested treatment for controlling fungal growth using consolidated polymers

It was confirmed in previous studies that some polymers used in the conservation of historical textiles can accelerate fungal growth on historical textiles (Keyserlingk, 1990); some of them may inhibit fungal growth and others can accelerate it (Abdel-Kareem, 2000b; 2005). However, there is no doubt that all the polymers used in textile conservation cannot prevent the fungal deterioration of textiles. This study introduces a new suggestion by adding some selected fungicides that are commonly used in textile conservation to some selected polymers which are often used in textile conservation. For evaluating the new composed chemical the following processes were carried out.

Polymers. Four selected polymers were used in this study (see Table I). The polymers were selected

Table I
List of polymers used in this study.

	Trade name	Chemical name	Producer
1	Klucel G (SD)	Hydroxypropylcellulose	Lascaux Restauro
2	Lascaux 498 HV (E)	Butyl acrylate / methyl methylacrylate	Lascaux Restauro
3	Mowilith DM5 (E)	Vinyl acetate/acrylic ester copolymer	Hoechst
4	Mowilith DMC2 (E)	Vinyl acetate/dibutyle maleate copolymer	Hoechst
5	Tylose MH300 (SD)	Methyl hydroxy ethyl cellulose	Hoechst

Table II
List of fungicides used in this study.

	Trade name	Chemical name	Producer
1	Preventol O-Na	Sodium o-phenyl-phenol (NaOPP)/2-hydroxybiphenyl sodium salt tetra hydrate	Bayer
2	Neo-Desogen	a water solution of ammonium basic with a strong biocide action	ARTE

according to the relevant references that confirmed that these polymers are suitable, effective and commonly used in the reinforcement of textile artefacts (Abdel-Kareem, 2005; Abdel-Kareem *et al.*, 2008).

Fungicides. Two selected fungicides were used in this study (Table II). The fungicides were selected according to the relevant references that confirmed that these fungicides are suitable and effective in treatment of textile artefacts against fungal deterioration (Abdel-Kareem and Radwan, 2004).

Preparation of samples. Unbleached linen fabric samples were cut into 10×2 cm (length × width) warp test specimens. The warp strips were produced by raveling away yarns on each side forming 1.5 cm wide strips with a 2.5 mm fringe down each side. Five samples were used for each test.

Treatments. Linen textile samples were treated with the selected polymers by using impregnation method (Abdel-Kareem, 2005), with some modification in the technique by adding the tested fungicides to the solution. The Preventol was used in 1% concentration and Neo-Desogen was used in 2% concentration (Table III).

Fungal treatment of samples. Treated and untreated linen textile samples were exposed to attack by pure culture of *Aspergillus niger*, *Chaetomium golobosum* and *Penicillium funiculosum* by using an agar plate test. These fungal species are the most dominant ones isolated from ancient Egyptian textiles textile samples in this study. It was confirmed in previous studies that the selected three fungi are considered to play the greatest role in the decomposition of

Table III
The suggested treatment for controlling the fungal growth.

	Polymer
0	untreated
1	Klucel G 4%
2	Klucel G 4% + Neo-Desogen
3	Klucel G 4% + Preventol
4	Lascaux 498 HV 10%
5	Lascaux 498 HV 10% + Neo-Desogen
6	Lascaux 498 HV 10% + Preventol
7	Mowilith 10%
8	Mowilith 10% + Neo-Desogen
9	Mowilith 10% + Preventol
10	Tylose 4%
11	Tylose 4% + Neo-Desogen
12	Tylose 4% + Preventol

cellulosic materials of all fungi isolated from historical Egyptian textiles (Abdel-Kareem and Szostak-Kotowa, 2005; Garg and Dhawan, 2005). Also, these fungi are commonly used for evaluation of the resistance of polymers to fungal deterioration (Whitney, 1996). Petri dishes containing Czapek-Dox agar medium modified without sugar were used (Abdel-Kareem *et al.*, 1997). The medium was inoculated with spore suspension (14-day old culture) of each one of the tested fungi. The spore suspension of the fungus was spread on the surface of the medium. The textile samples were put on the inoculated surface of medium. The plates were incubated at 28°C. Fourteen days later, linen textile samples were picked out and washed with water to remove mycelium. They were then air dried in room conditions. Before testing, the specimens were conditioned at 20±2°C and 65% 2 RH.

Evaluation methods

All treated and untreated samples before and after fungal deterioration were investigated with tensile tester and colorimeter.

Tensile strength and elongation. Tensile strength and elongation of all samples before and after the fungal treatment were tested using a testing machine, type Zwick 1445. These tests were done according to the ASTM (2000) D 5035-95. The initial distance of the jaws was 50 mm and the testing speed was 25 mm/min, temperature was 23°C, and R.H.65%. Five samples were used for each test and statistical data were calculated for all tested samples.

Colorimetric measurements. The colore values of all textile samples before and after deterioration by different fungi have been carried out with Optimacth 3100 color Spectrophotometer using the CIELab color system. The CIELab color coordinates for L (lightness), a (red/green axis), and b (yellow/blue

axis) values were recorded. Color changes for all samples after the fungal treatment was calculated and expressed as ΔL, Δa, Δb. Calculation of total color change (ΔE) is achieved by the use of the following equations: $\Delta E = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{0.5}$.

Results and Discussion

Isolation and identification of fungi

Fungi isolated from various biodeteriorated textile fabrics from storage area in the Egyptian museum are shown in Table IV. The obtained results show that 207 isolates, representing 31 species of fungi were identified on samples obtained from the Egyptian museum. The most dominant fungi on linen textile fabrics are *Aspergillus* (15 species), *Penicillium* (10 species), *Chaetomium* (4 species), *Alternaria* (1 species), and *Trichoderma* (1 species). The order of the occurrence of fungi on linen textile fabrics is as follows: *Aspergillus* > *Penicillium* > *Chaetomium* > *Alternaria* > *Trichoderma viride*.

Table IV
Isolated fungi from tested bio-deteriorated linen samples from the Egyptian museum in Cairo.

	Fungi	No of isolations
1	*Alternaria alternate* (Fr.) Keissler	8
2	*Aspergillus carbonarius* Bainier	6
3	*Aspergillus chrysellus* Kown & Fennell	3
4	*Aspergillus fischeri* Wehmer	2
5	*Aspergillus flavus* Link	12
6	*Aspergillus flaschentraegeri* Stolk	2
7	*Aspergillus fumigatus* Fresenius	15
8	*Aspergillus nidulans* Eidam	9
9	*Aspergillus niger* Tieghem	13
10	*Aspergillus terrus* Thom	11
11	*Aspergillus ustus* Thom & Church	2
12	*Aspergillus versicolor* (vuill.) Tiraboschi	4
13	*Aspergillus* sp.	5
14	*Aspergillus* sp.	4
15	*Aspergillus* sp.	4
16	*Chaetomium cochlioides* Palliser	11
17	*Chaetomium globosum* Kunze	14
18	*Chaetomium* sp.	7
19	*Chaetomium* sp.	6
20	*Penicillium asperum* (Shear) n. comb.	6
21	*Penicillium citrinum* Thom	8
22	*Penicillium chrysogenum* Thom	4
23	*Aspergillus chrysellus* Kown & Fennell	3
24	*Penicillium cyclopium* Westling	6
25	*Penicillium funiculosum* Thom	10
26	*Penicillium soppi* Zaleski	6
27	*Penicillium wortmanni* Klöcker	7
28	*Penicillium* sp.	4
29	*Penicillium* sp.	4
30	*Penicillium* sp.	4
31	*Trichoderma viride* Pers. Ex Fr.	7

Table V
Isolated fungi from tested bio-deteriorated linen samples from the Coptic Museum Cairo.

	Fungi	No of isolations
1	*Alternaria alternate* (Fr.) Keissler	11
2	*Alternaria tenuissima* Kunze	2
3	*Aspergillus auratus* Warcup	2
4	*Aspergillus carbonarius* Bainier	9
5	*Aspergillus chrysellus* Kown & Fennell	5
6	*Aspergillus fischeri* Wehmer	4
7	*Aspergillus flavus* Link	14
8	*Aspergillus flaschentraegeri* Stolk	4
9	*Aspergillus fumigatus* Fresenius	17
10	*Aspergillus nidulans* Eidam	11
11	*Aspergillus niger* Tieghem	14
12	*Aspergillus proliferans* Smith	3
13	*Aspergillus spinulosus* Warcup	3
14	*Aspergillus terrus* Thom	12
15	*Aspergillus ustus* Thom & Church	4
16	*Aspergillus versicolor* (vuill.) Tiraboschi	5
17	*Aspergillus* sp.	4
18	*Aspergillus* sp.	4
19	*Aspergillus* sp.	4
20	*Chaetomium cochlioides* Palliser	12
21	*Chaetomium globosum* Kunze	13
22	*Chaetomium* sp.	6
23	*Chaetomium* sp.	7
24	*Penicillium asperum* (Shear) n.comb.	8
25	*Penicillium biforme* Thom	2
26	*Penicillium citrinum* Thom	9
27	*Penicillium chrysogenum* Thom	10
28	*Aspergillus chrysellus* Kown & Fennell	12
29	*Penicillium cyclopium* Westling	8
30	*Penicillium funiculosum* Thom	12
31	*Penicillium raistrickii* Smith	2
32	*Penicillium soppi* Zaleski	5
33	*Penicillium wortmanni* Klöcker	9
34	*Penicillium* sp.	6
35	*Penicillium* sp.	5
36	*Penicillium* sp.	3
37	*Trichoderma viride* Pers. Ex Fr.	8

Fungi isolated from various biodeteriorated textile fabrics from a storage area in the Coptic museum are shown in Table V. The obtained results show that 269 isolates, representing 37 species of fungi were identified in samples obtained from the Egyptian museum. The most dominant fungi on linen textile fabrics are *Aspergillus* (18 species), *Penicillium* (12 species), *Chaetomium* (4 species), *Alternaria* (2 species), and *Trichoderma* (1 species). The order of the occurrence

Table VI
Isolated fungi from tested bio-deteriorated wool samples from the Coptic Museum Cairo.

	Fungi	No of isolations
1	*Alternaria alternate*,	5
2	*Aspergillus cervinus* Neill	3
3	*Aspergillus flavus* Link	4
4	*Aspergillus fischeri* Wehmer	3
5	*Aspergillus fumigatus* Fresenius	8
6	*Aspergillus nidulans* Stolk	3
7	*Aspergillus niger* Tieghem	7
8	*Aspergillus raperi* Stolk	2
9	*Aspergillus sparsus* Raper & Thom	2
10	*Aspergillus spinulosus* Warcup	5
11	*Aspergillus wentii* Wehmer	2
12	*Aspergillus* sp.	2
13	*Aspergillus* sp.	2
14	*Penicillium canescens* Sopp	2
15	*Penicillium cyclopium* Westling	2
16	*Penicillium granulatum* Bainier	3
17	*Penicillium lanoso viride* Thom	2
18	*Penicillium paxilli* Bainier	6
19	*Penicillium soppi* Zaleski	6
20	*Penicillium sp.*	2
21	*Penicillium sp.*	2
22	*Chaetomium globosum* Kunze	4

of fungi on linen textile fabrics is as follows: *Aspergillus* > *Penicillium* > *Chaetomium* > *Alternaria* > *Trichoderma viride*.

Fungi isolated from various biodeteriorated wool textile fabrics from storage area in the Coptic museum are presented in Table VI. The obtained results show that 77 isolates, representing 22 species of fungi, were identified on samples obtained from the Egyptian museum. The most dominant fungi on wool textile fabrics are *Aspergillus* (12 species), *Penicillium* (8 species), *Alternaria* (1 species), and *Chaetomium* (1 species). The order of the occurrence of fungi on wool textile fabrics is as follows: *Aspergillus* > *Penicillium* > *Chaetomium* > *Alternaria*.

The results showed that about 37 fungal species were isolated and identified on linen textiles from both investigated museums. Most of the identified fungi in the current study were isolated from other Egyptian textile objects in a previous study by Abdel-Kareem *et al.* (1997) who isolated and identified about 30 fungal species from ancient linen textiles. The results confirm that the textile samples in the current study are more deteriorated by fungi than in a previous study by Abdel-Kareem *et al.* (1997). It is should noticed that about 7 more fungal species were isolated in this study than in the previous one. This may be due to the fact that the examined samples were collected from storage rooms while the investigated samples in the previous study were collected from display showcases and excavations. This result indicates that the textiles in storage rooms in Egyptian museums suffer from fungal deterioration problem more than the textile collections in display areas. Also the results show that linen textiles are more infested by fungi than wool textiles as the number of identified fungi on linen is greater than on wool.

The number of isolated fungi from both investigated museums included in the research shows that their collections suffer from excessive fungal infestation. This is due to the fact that both museums use improper storage methods. The results show that the textile collection in the storage rooms at the Coptic museum are infested by fungi more than the textile collection in the storage rooms at the Egyptian Museum. This may due to that most of the textiles in the Egyptian Museum were excavated from dry tombs, while most of the textiles in the Coptic Museum were collected from churches or tombs in bad condition more than ancient Egyptian tombs. This may also be due to the environmental conditions in the storage area in both the Coptic Museum and the Egyptian Museum. However, the results show that the linen textile fabrics in the Coptic Museum are more liable to fungal deterioration than wool textile fabrics (see Tables V, VI). These results are in agreement with the results obtained by Abdel-Kareem *et al.*, who confirmed that all types of ancient textile fibres are liable to fungal attack; cellulosic fibres are more liable to fungal attack than animal fibres (Abdel-Kareem *et al.*, 1997).

The results show that most of identified fungi belong to the subdivision *Deuteromycetes* class or Fungi Imperfect. These fungi are called conidial fungi because their growth is initiated by conidia (Florian, 2004). These fungi are capable of rapid growth when the environmental conditions are favorable and are also able to survive under unfavorable conditions (Aranyanak, 1995). Most of identified fungal species were reported in previous studies to cause deterioration of textiles. Many authors consider that most of these fungal species are the most active fungi among all fungal genera identified on textiles in the degradation of historical textiles (Montegut *et al.*, 1991; Abdel-Kareem *et al.*, 1997; Agrawal, 2001, Bhatnagar and Mani, 2001; Grag and Dhawan, 2005). Most of identified fungi were reported that they contribute to discolouration of textiles (Aranyanak, 2005; Abdel-Kareem and Szostak-Kotowa, 2005; Abdel-Kareem, 2007). The results showed that the most dominant fungi on the investigated textile samples belong to *Aspergillus* and *Penicillium*. These two genera are very important, since they include species that can grow at relatively much lower conditions of moisture availability than other cellulolytic fungi. Under poor

Table VII
The tensile strength for the samples after treated with fungi.

Polymer	Control		*Aspergillus*		*Chaetomium*		*Penicillium*	
	N/mm^2	S.D.	N/mm^2	S.D.	N/mm^2	S.D.	N/mm^2	S.D.
0	34.35	0.94	4.02	0.70	4.24	1.22	5.98	1.12
1	36.30	1.13	11.30	1.09	13.48	1.27	15.00	1.41
2	36.41	0.94	33.04	1.36	33.48	0.94	34.46	1.22
3	36.74	0.81	28.59	1.05	35.11	1.25	31.63	1.10
4	37.50	1.37	19.02	0.89	19.89	1.22	20.87	1.24
5	37.39	1.30	31.52	0.99	30.87	1.08	35.43	1.07
6	37.28	0.96	31.20	1.43	33.04	0.82	32.50	1.30
7	37.07	1.33	16.63	1.16	17.50	1.34	21.74	1.28
8	37.28	0.85	34.02	1.26	33.26	1.24	34.35	1.35
9	37.50	1.07	33.59	1.25	34.78	1.17	36.09	1.21
10	38.15	0.93	14.59	1.39	15.65	1.17	17.83	1.16
11	38.26	1.02	31.96	1.28	34.02	1.40	32.28	1.41
12	38.37	1.27	26.41	1.14	30.11	1.12	33.15	1.29

Table VIII
The elongation for the samples after treated with fungi.

Polymer	Control		*Aspergillus*		*Chaetomium*		*Penicillium*	
	F max%	S.D.	F max%	S.D.	F max%	S.D.	F max%	S.D.
0	18.00	0.55	6.00	0.89	8.00	0.63	8.00	0.89
1	20.00	0.84	9.00	1.41	10.00	1.10	10.00	1.26
2	20.00	1.26	16.00	1.26	16.00	1.26	16.00	1.10
3	20.00	1.41	16.00	0.63	16.00	0.63	16.00	0.63
4	18.00	1.10	8.00	0.89	9.00	1.41	9.00	1.10
5	18.00	1.41	16.00	1.10	16.00	1.90	16.00	1.26
6	18.00	0.63	16.00	0.63	16.00	0.89	16.00	0.63
7	22.00	0.89	9.00	1.10	10.00	0.89	9.00	1.41
8	22.00	0.89	16.00	1.10	16.00	1.26	16.00	1.26
9	22.00	1.10	16.00	0.63	16.00	0.63	16.00	0.63
10	20.00	0.63	8.00	0.63	9.00	1.41	10.00	1.41
11	20.00	1.10	16.00	1.26	16.00	1.26	16.00	1.41
12	20.00	1.26	16.00	1.10	16.00	1.10	16.00	1.10

storage conditions, the water that such less demanding species produce as a result of their metabolism can accumulate, raising the moisture status of materials to levels at which more highly degradable species may flourish (Szostak-Kotowa, 2004).

For all previous causes there is a need to decontaminate the biodeteriorated textile objects from conidia and mycelium in order to reduce the fungal growth on these textile objects and prevent the contamination of other objects. For that the surface of the biodeteriorated textile objects should be vacuumed cleaned to remove mycelium and conidia. The vacuum cleaning method chosen should be acceptable by conservation standards to protect the integrity of the textile object. The main goal of this process is to reduce the fungal load to the minimal level of the infestation and prevent recontamination (Florian, 2004). A vacuum cleaning method should be applied at low suction power, and through a gauze sheet or fin netting fabric placed over the textile object in order to not disturb loose fibers (Museums & Galleries Commission, 1998). After decontaminating the biodeteriorated textile objects from conidia and mycelium the textile objects should be treated against fungal deterioration.

Evaluating the suggested polymers

Evaluation of the suggested polymers combined with fungicides was carried out based on the obtained results from the changes in the tensile strength and the colour values of treated and untreated linen samples after the fungal treatments.

Tensile strength and elongation. The results of tensile strength and the elongation of the control samples and the biodeteriorated samples are blotted in Table VII and VIII. The loss percent (%) in the

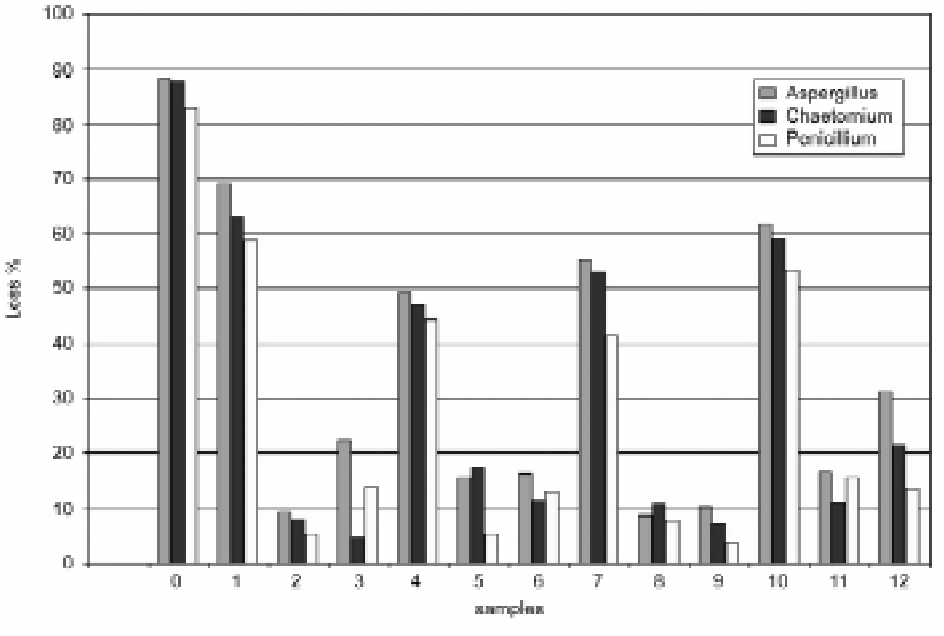

Fig. 1. The loss % in the tensile strength of the sampes after the fungal treatment.

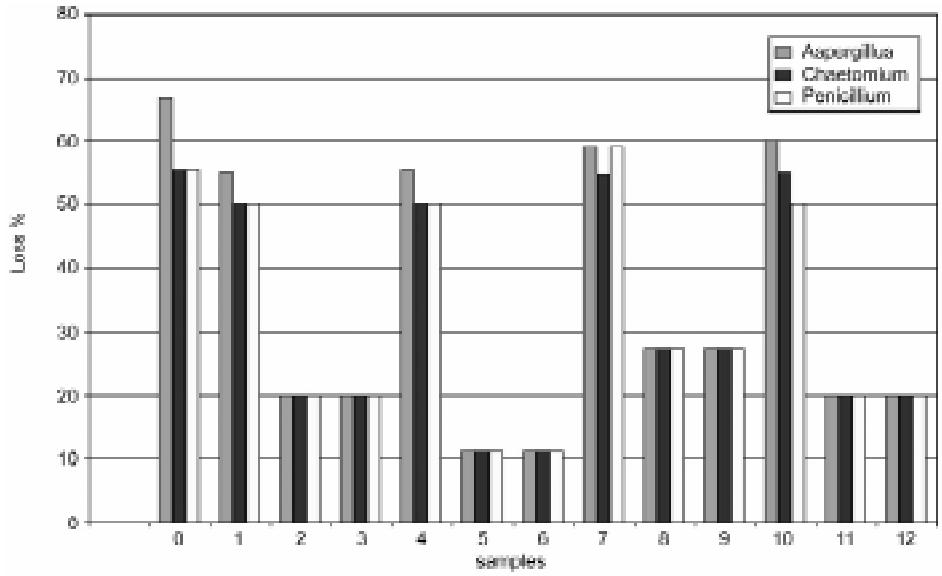

Fig. 2. The loss % in the elongation of the sampes after the fungal treatment.

tensile strength and the elongation of treated and untreated linen samples after fungal incubations are shown in figures 1 and 2. Tensile strength measurements showed that there were considerable differences in tensile strength and elongation between unconsolidated linen samples, linen samples treated with polymers only and linen samples treated with polymers contained different fungicides. The results showed that all tested polymers without fungicides contains have reduce the fungal deterioration of linen samples but not prevent the fungal deterioration completely. These results are in agreement with the results obtained by Abdel-Kareem (2000b). The results in figures 1, 2, show that the least changes in the tensile strength of all tested samples after the fungal treatment were on samples treated with Klucel G + Neo-Desogen. This result confirms that Klucel G + Neo-Desogen is the most effective treatment among all tested treatments that can control the fungal deterioration of linen textiles by all tested fungi. Also the results show that Neo-Desogen is the best fungicides among all tested fungicides can be added to all tested polymers for protection of linen textiles against fungal deterioration.

Colorimetric measurements. The changes in the colour values of treated and untreated linen samples after fungal incubations by *Aspergillus* are shown in Table IX. The changes in the colour values of treated and untreated linen samples after fungal incubations

Table IX
The changes in the color values for the samples after the fungal treatment with *Aspergillus.*

Polymer	dL	da	db	dE
0	–24.57	0.96	2.92	24.76
1	–5.82	0.56	0.78	5.90
2	0.77	0.37	–0.44	0.96
3	–1.86	0.25	–0.29	1.90
4	–9.12	–0.19	–0.31	9.13
5	–1.24	0.05	0.06	1.24
6	–0.75	0.22	–0.55	0.96
7	–9.84	0.4	–1	9.90
8	–2.06	0.94	0.83	2.41
9	–2.02	0.65	0.16	2.13
10	–10.38	0.55	–1.04	10.45
11	–1.69	0.44	–0.78	1.91
12	–1.28	0.51	0.37	1.43

Table X
The changes in the color values for the samples after the fungal treatment with *Chaetomium.*

Polymer	dL	da	db	dE
0	–26.39	1.51	3.13	26.62
1	–5.35	0.12	0.6	5.38
2	–0.55	0.7	0.04	0.89
3	–1.81	0.63	–0.38	1.95
4	–9.39	0.19	4.25	10.31
5	–1.64	0.12	0.62	1.76
6	–1.41	0.6	–0.26	1.55
7	–5.36	1.18	3.19	6.35
8	–1.02	0.5	0.19	1.15
9	–1.49	0.64	0.19	1.63
10	–7.97	0.54	1.35	8.10
11	–0.29	0.35	–0.52	0.69
12	–1.81	0.47	–0.53	1.94

by *Chaetomium* are shown in Table X. Also the changes in the colour values of treated and untreated linen samples after fungal incubations by *Pencillium* are shown in Table XI. Colorimetric measurements showed that there were considerable differences in colour values unconsolidated linen samples, linen samples treated with polymers only and linen samples treated with polymers contained different fungicides. The results showed that all tested polymers without fungicides contains have reduced the fungal deterioration of linen samples but not prevent the fungal deterioration completely. These results are in agreement with the results obtained by Abdel-Kareem (2005), who confirmed that polymers reduce the fungal deterioration of linen samples but not prevent the fungal deterioration completely. The results showed that all tested polymers contained fungicides prevent the fungal deterioration of linen samples completely.

TTable XI
The changes in the color values for the samples after the fungal treatment with *Pencillium.*

Polymer	dL	da	db	dE
0	–22.57	1.22	2.48	22.74
1	–5.07	0.05	4.71	6.92
2	–0.3	0.37	0.19	0.51
3	–1.41	0.64	–0.45	1.61
4	–7.68	–0.09	3.37	8.39
5	–1.03	0.04	0.66	1.22
6	–1.37	0.29	0.05	1.40
7	–10.77	0.13	4.73	11.76
8	–2.02	0.67	0.31	2.15
9	–0.3	0.57	–0.06	0.65
10	–5.3	0.32	3.36	6.28
11	–1.46	0.85	–0.68	1.82
12	–1.54	0.05	0.34	1.58

Suggested guidelines for controlling and prevention of the fungal deterioration on the textile collections in storage rooms of the studied museums

Prevention includes protecting the textile objects from the contamination by fungi and controlling the environment conditions in storage rooms to prevent the development and the growth of fungi (Florian, 1997; Florian, 2004). One of the best methods for protection of textile objects from fungal infestations in museums, can be achieved by controlling the environmental conditions surrounding textile objects (Abdel-Kareem and Morsy, 2004). The following measures should be undertaken: Elimination/prevention of airborne fungi using the considerations mentioned by (Florian, 2004), for example use of protective dust covers for textile objects in storage area. Cleaning dust covers regularly. Performing regular maintenance of storage areas. Environmental conditions should be controllable within the storage storerooms. Temperature should be 18–22°C and relative humidity (RH) 45–55%. This can be achieved by build new storerooms with air conditioning system. Also it is necessary to control in the RH in storerooms using suitable buffer materials such as silica gel. Repairing leaking ceiling in storage area. Placing portable ventilators in the storerooms. Setting a suitable fumigant in storerooms to reduce the chance of microorganisms growing on the collections in the museum.

Conclusion. There are obvious excessive fungal infestations in all tested textile objects in storage areas in both the Coptic Museum and the Egyptian Museum. The textile collection in the storage rooms in the Coptic museum is infested by fungi more than the textile collection in the storage room in the Egyptian Museum. The most dominant fungi isolated from

tested samples belong to *Aspergillus*, *Penicillium*, *Chaetomium*, *Alternaria* and *Trichoderma* species. The order of occurrence of fungi on linen textile fabrics is as follows: *Aspergillus* > *Chaetomium* > *Penicillium* > *Alternaria* > *Trichoderma viride*. The order of occurrence of fungi on wool textile fabrics is as follows: *Aspergillus* > *Penicillium* > *Chaetomium* > *Alternaria*. There is a necessity for using fungicides to be used for disinfection of the biodeteriorated textiles in both the Coptic Museum and the Egyptian Museum. In the cases where it is necessary to use polymers in the conservation of textile objects, the tested polymers containing one of the tested fungicides are very effective in preventing the fungal deterioration of textiles. Klucel G + Neo-Desogen is the most effective treatment among all tested treatments that can control the fungal deterioration of linen textiles by all the tested fungi. Neo-Desogen is the best fungicide among all the tested fungicides and can be added to all tested polymers for protection of linen textiles against fungal deterioration. This study should followed with another study to evaluate the long term effect of the tested polymers supplemented with fungicides on the properties of dyed and not dyed textiles.

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