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Contamination of mural paintings by indoor airborne fungal spores

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SUMMARY. The processes of biodeterioration on mural paintings have often been discussed, whereas the causes of contamination have seldom been examined.
Many microorganisms responsible for the biodeterioration of paintings are of airborne origin. It follows that an investigation on the aerial microbial concentration and air movements in painted indoors is very useful.
This paper reviews the literature of mural painting biodeterioration and the aerobiological studies of painted indoors. Hypogean environments, for their particular microclimatic conditions, are not considered.
The fungal species most frequently found in the biodeterioration of wall-paintings are reported, as well as comparisons of surface contamination and aerobiological investigation.
This review shows the necessity of finding the best sampling methodologies for cultural heritage studies. The control of airborne contamination and proper sampling methods are highly important in determining treatment strategies for the conservation and prevention of microbial attack on painted surfaces.

Keywords: airborne fungi, indoors, mural paintings, fungal deterioration.

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INTRODUCTION

The main techniques of mural painting are the «fresco» and the «secco». The fresco is generally known as a painting on fresh plaster (intonaco) whereby the color is absorbed by the wet plaster. This method is known as «true» fresco. The «secco» technique is a painting done on plaster that has already dried; to make colours adhere to dried intonaco, the artist adds an adhesive or binder to the pigments.

The degradation of mural paintings is mainly linked to the high porosity of the substrate, its carbonatic nature, the presence of water in the

walls and the microclimatic conditions of the conservation environment. The most frequent forms of damage are efflorescence, swelling and detachment of plaster parts, and acid corrosion, a consequence of condensation.

Apart from these types of chemico-physical damage, alterations due to microbial development are frequently found on mural painting surfaces. The «secco» paintings are more susceptible to biodeterioration than true frescoes. Biodeterioration arise from interactions among substratum, environment and organisms.

A biological attack will occur when conditions of temperature and relative humidity are favourable to the growth of microorganisms and spores are present on the substratum. On indoor mural paintings, such as in churches, cathedrals and museums, fungi are the most commonly isolated microorganisms. The heterotrophic characteristics of myceti and the mainly inorganic nature of mural painting substratum appear to be incompatible. As a matter of fact, organic enrichment of surfaces through the deposit of atmospheric particulate matter, capillarity absorption of ground water or organic paint binders can promote the development of many fungal strains and in particular those characterized by modest nutritional needs, such as the species belonging to the genus *Cladosporium.*

However, environmental conditions such as a relative humidity above 60%, temperature between 10°C and 30° C, high water content of the painted wall (due to water absorption by capillarity or condensation) and poor ventilation are often found in these environments. These conditions are particularly favourable to fungal growth.

It has been demonstrated that fungal growth induces serious deterioration, varying from superficial to profound alterations of the painting structure, such as variously coloured stains, alteration of pigments, detachment of fragments by hyphal penetration.

Mechanism and phenomenology of damage due to fungal growth on mural paintings are widely studied, whereas there is very little research analyzing the correlation between fungal air contamination and contamination of fresco surfaces.

Aerobiological studies in environments where works of art are kept represent therefore an important new field to investigate.

The aim of this review is to provide information on the actual state of research in order to promote investigations and standardize methodologies in this field.

RESULTS

The bibliographical review has evidenced that much has been written about biodeterioration of mural paintings by fungi in indoor unhypogean environments, (Giacobini and Lacerna, 1965; Krumbein and Lange, 1978; Strzelczyk, 1981; Rebrikova, 1984; Agrawal *et al.*, 1989; Garg *et al.*, 1990; Caneva *et al.*, 1991; Giacobini *et al.*, 1991). Only few papers deal with qualitative and quantitative investigations. In Tab. Ia and Ib the fungal species found on mural paintings are reported (Gargani, 1968; Savulescu and Ionita, 1971; Bianchi *et al.*, 1980; Saiz-Jimenez and Samson, 1981a and b; Tiano and Gargani, 1981; Agarossi *et al.*, 1986; Bettini *et al.*, 1986; Realini *et al.*, 1988; Karpovich-Tate and Rebrikova, 1990; Jeffries, 1991). Fungi isolated from mural paintings are rarely correlated to an alteration (Savulescu and Ionita, 1971; Bianchi *et al.*, 1980; Saiz-Jimenez and Samson, 1981a; Realini *et al.*, 1988; Karpovich-Tate and Rebrikova, 1990; Jeffries, 1991). However, a specific knowledge of the species responsible for the biodeterioration of wall paintings should be required to evaluate the risk arising from airborne contamination.

Table I. Fungi isolated from indoor mural paintings.

Species	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*
Acremonium sp.	+		+																			
Acr. camptosporum				+																		
Acr. charticola																					+	
Alternaria sp.	+			+		+																
Alt. alternata			+					+			+		+								+	
Alt. tenuis								+			+		+		+							
Anixiopsis sp.	+																					
Arthrinium sp.						+															+	
Aspergillus sp.	+		+		+																	
Asp. amstelodami									+				+			+	+	+				
Asp. glaucus						+																
Asp. niger													+			+		+				
Asp. ruber				+																		
Asp. terreus													+			+		+				
Asp. versicolor				+			+				+						+				+	
Beauveria alba																						+
B. bassiana																				+		
Botryotrichum sp.	+																					
Bot. atrogriseum											+	+	+									
Bot. piluliferum									+													
Botrytis cinerea																					+	
Chaetomium sp.	+					+															+	
Ch. elatum																					+	
Ch. globosum											+		+			+						
Ch. indicum																		+				
Ch. murorum								+	+									+				
Circinella sydowi																+						
Cladosporium sp.	+			+		+																+
C. cladosporioides		+																				
C. herbarum										+			+	+		+	+					
C. macrocarpum				+																		
C. sphaerospermum				+															+	+	+	
Cunninghamella echin.																+					+	
Engyodontium album																					+	
Epicoccum sp.	+																					
Exophiala sp.	+																					
Fusarium sp.	+																					
Geomyces pannorum																				+		
Geotrichum sp.	+																					
Glicladium sp.					+											+						
Gliomastix sp.			+																			
Humicola sp.	+																					
Mucor sp.					+																	
M. spinousus									+													
Paecilomyces sp.	+																					
Penicillium sp.	+		+	+																		
P. brevicompactum						+	+														+	
P. camembertii					+																	
P. charlesii						+																
P. chrysogenum				+																	+	
P. cyclopium						+																

(continued)

(Continued Table I)

Species	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*
P. citrinum			+		+	+															+	
P. commune			+		+																	
P. crustosum							+															
P. decumbens					+																+	
P. frequentans					+		+														+	
P. italicum						+	+															
P. lanoso coeruleum		+																				
P. lilacinum				+			+															
P. nigricans																					+	
P. notatum						+	+															
P. oxalicum			+																			
P. palitans						+																
P. purgurogenum					+																	
P. raciborskii																					+	
P. restrictum					+																	
P. roseo purpureum						+																
P. verrucosum																					+	
P. viridicatum							+															
Phoma sp.	+																					
Ph. glomerata																					+	
Ph. herbarum						+																
Scopulariopsis sp.	+																					
Sc. brevicaulis									+		+		+									
Sc. cartatum						+																
Stachybotrys sp.	+																					
S. atra										+		+				+						
St. cylindrospora								+														
Stemphylium sp.	+				+	+																
Stem. piriforme											+		+			+	+					
Torula herarum																+						
Trichocladium sp.	+																					
Trichoderma viride												+			+			+				
Ulocladium sp.	+																					
Uloc. botrytis						+																
Verticillum sp.				+																		
Vert. lamellicola																				+		
Vert. lateritium				+																		

Legend:

Italy: 1) Chapel of Scrovegni (Padova); 2) Church of S. Eusebio (Pavia); 3) Basilic of San Vincenzo (Galliano - Cantù); 4) Basilic of S. Clemente (Roma); 5) Various frescoes (Firenze); 6) Chapter of San Marco (Venezia); 7) Convent of Santa Croce (Firenze).

Rumania: 8) Monastery (Voronet-Moldavia); 9) Monastery (Sucevita - Moldavia); 10) Monastery (Humor - Moldavia); 11) Monastery (Patrauti - Moldavia); 12) Monastery (Arbore - Moldavia); 13) Monastery (Varatec - Moldavia); 14) Monastery (Agapia - Moldavia); 15) Monastery (Putña - Moldavia); 16) Monastery (Cozia); 17) Bolnita Church (Cozia); 18) Church (Curtea de Arges).

URSS: 19) Church of John the Teologian (Rostoy Veliky); 20) Cathedral of the Nativity of the Virgin (Pafnutii).

Spain: 21) Monastery of S. Maria de la Rabida (Huelva).

Great Britain: 22) Cathedral (Canterbury).

Table II. Fungi isolated from indoor air.

Species	*Scrovegni Chapel (*)*		*S. Maria del Popolo (**)*		*SS. Martiri Canadesi (**)*		*Chapter of San Marco (***)*		*Convent of S. Croce (***)*	
	CFU/m³	%	*CFU*	%	*CFU*	%	*CFU*	%	*CFU*	%
Alternaria sp.	37.5	2.2	4	1.9	6	5.5				
Aspergillus sp.	13	0.8	4	1.9						
Asp. flavipes					2	1.9				
Asp. flavus					1	0.9				
Asp. fumigatus			1	0.5	1	0.9				
Asp. nidulans			1	0.5					13	2.8
Asp. ochraceous			2	0.9	1	0.9			27	5.8
Asp. oryzae			3	1.4	1	0.9				
Asp. terreus			5	2.4						
Asp. versicolor			16	7.7			13	4.4	194	41.8
Arthrinium sp.							30	10.2		
Bipolaris sp.	13.4	0.8								
Botryosporium sp.			1	0.5						
Botrytis sp.	6.5	0.4								
B. cinerea			1	0.5						
Calcarisporium sp.			1	0.5						
Cehalosporium sp.			3	1.4	2	1.9				
Cheatomium sp.			1	0.5						
C. cellulosoliticum			82	39.4						
Cladosporium sp.	1216.7	72.5			65	68.8	29	9.9		
Epicoccum sp.	16.3	1.0								
Fusarium sp.	21.1	1.3	1	0.5	1	0.9				
Geniculosporium sp.			1	0.5						
Geotrichum sp.			2	0.9						
Mortierella alpina			1	0.5						
Mucor sp.	3.2	0.2								
Paecilomyces sp.	1.6	0.1								
Papularia arundinis			1	0.5						
Penicillium sp.	326.1	19.4	6	2.9	4	3.7				
P. canescens			1	0.5						
P. chrysogenum			3	1.4						
P. cyclopium			30	14.4	1	0.9	7	2.4		
P. decumbens			1	0.5						
P. frequentans			1	0.5	1	0.9				
P. italicum							13	4.4		
P. janthinellum			4	1.9	2	1.9				
P. notatum							165	56.3	176	37.9
P. palitans							6	2		
P. urticae					1	0.9				
Phytomyces sp.	9.7	0.6								
Rhizopus sp.	3.2	0.2								
Scopulariopsis sp.	1.6	0.1								
Sc. brevicaulis			1	0.5						
Sc. cartatum							15	5.1	27	5.8
Stemphylium sp.			1	0.5	10	9.2				
Trichoderma sp.			28	13.5						
Trichurus sp.	3.2	0.2								
Ulocladium sp.	5.6	0.3								
Ul. botrytis							15	5.1		

Legend:
Andersen method: (*) Mandrioli, 1982
Sedimentation plates method: (**) Poldi Alai, 1971-72;
(***) Tiano, 1981.

Moreover, only a few authors report the indoor airspora composition of painted environments, and fewer the relationship between the microbial contamination on frescoes and the microbial concentration of the air (Poldi Alai, 1971-72; Tiano and Gargani, 1976; Zanotti Censoni and Mandrioli, 1978; Saiz-Jimenez and Samson, 1981a).

The lack of aerobiological studies in environments such as churches, cathedrals and monasteries due to the following factors:

— there are no materials particularly subject to biodeterioration (the opposite factor suggested research in museums and showcases);

— relative humidity and temperature are not particularly high, and are not the optimum for microbial growth (the opposite factor suggested studies on hypogea, tombs or caves);

— there are no airborne biohazard for visitors such as in other public meeting places (the opposite situation suggested research in archives, libraries, hospitals, factories, etc.).

Nevertheless, interesting information can be drawn from this bibliographical review.

With regard to mural painting surfaces, a large part of the species isolated are cosmopolitan and aerodiffused. The genera most frequently mentioned (in decreasing order) are *Penicillium*, *Aspergillus*, *Cladosporium* and *Chaetomium* and, where quantitative analyses are carried out, the same genera are the dominating ones (Tiano and Gargani, 1976; Zanotti Censoni and Mandrioli, 1979; Saiz-Jimenez and Samson, 1981a; Karpovich-Tate and Rebrikova, 1990). The most serious biodeteriogen genus is believed to be *Cladosporium*. It can cause irremediable damage on frescoes (Giacobini and Lacerna, 1965; Saiz-Jimenez and Samson, 1981a and b; Agrawal *et al.*, 1989) and is sometimes the only colonizer on wall paintings, such as in the Basilica of S. Vincenzo at Cantù (Como), (Fig. 1 and Fig. 2), or in the Church of John the Theologian (Rostov Veliky) (Rebrikova 1984, Realini *et al.*, 1988). With regard to aerobiological investigations, the results reported are often partial and insubstantial. The sampling method most often used is sedimentation on agar Petri dishes (Savulescu and Ionita, 1971; Poldi Alai, 1971-72; Tiano and Gargani, 1981; Giacobini *et al.*, 1992); in only one case, the Scrovegni Chapel (Padua), an Andersen sampler was employed (Zanotti Censoni and Mandrioli, 1979; Zanotti Censoni *et al.*, 1980). In addition, studies comparing different sampling methods were never conducted.

The airborne fungal spores most frequently isolated from indoor painted environments are in the order: *Cladosporium*, *Penicillium*, *Aspergillus*, *Alternaria* and *Fusarium* (Tab. II). Few paper provide information on the occurrence and prevalence of the spores in the air in relation to their occurrence and prevalence on mural paintings. (Zanotti Censoni and Mandrioli, 1979; Zanotti Censoni *et al.*, 1980; Tiano and Gargani, 1981). Moreover, as Tiano and Gargani (1981) have noted, the prevalent airborne spores are not necessarily the origin of a painting biodeterioration.

Although there is a variation in the concentration of airborne fungal spores, as a function of hourly, daily, monthly and seasonal microclimatic changes (Tilak, 1989), only in one paper a complete seasonal monitoring has been taken into account, (Poldi Alai, 1971-1972). Data concerning the relation between the presence of visitors, an increase of airborne spores and the contamination of painted surfaces were also scanty.

Nevertheless the review has evidenced that biological degradation on wall-paintings is strongly affected by their distance from the ground, windows or other openings and by all factors that can influence air movements (Krumbein and Lange, 1978; Zanotti Censoni and Mandrioli, 1979; Zanotti Censoni *et al.*, 1982).

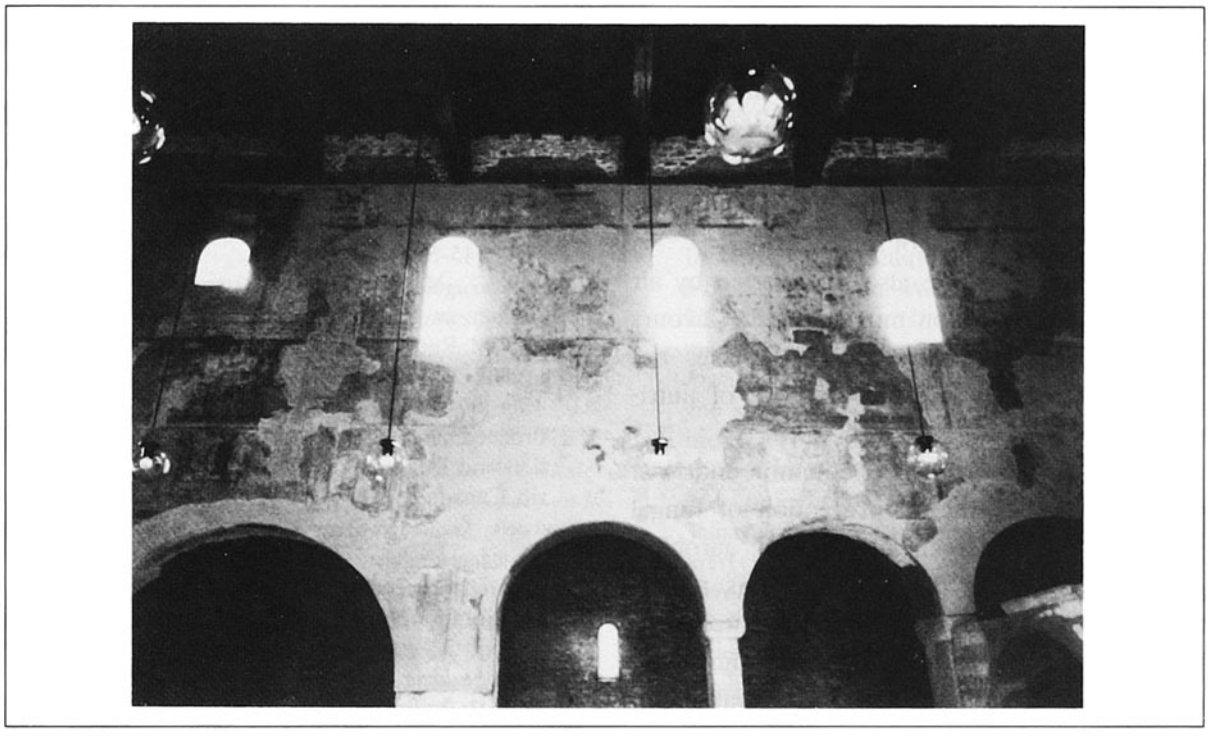

Figure 1. Mural paintings covered by black patina due to *Cladosporium* growth - Basilica of S. Vincenzo, Cantù (Como - Italy).

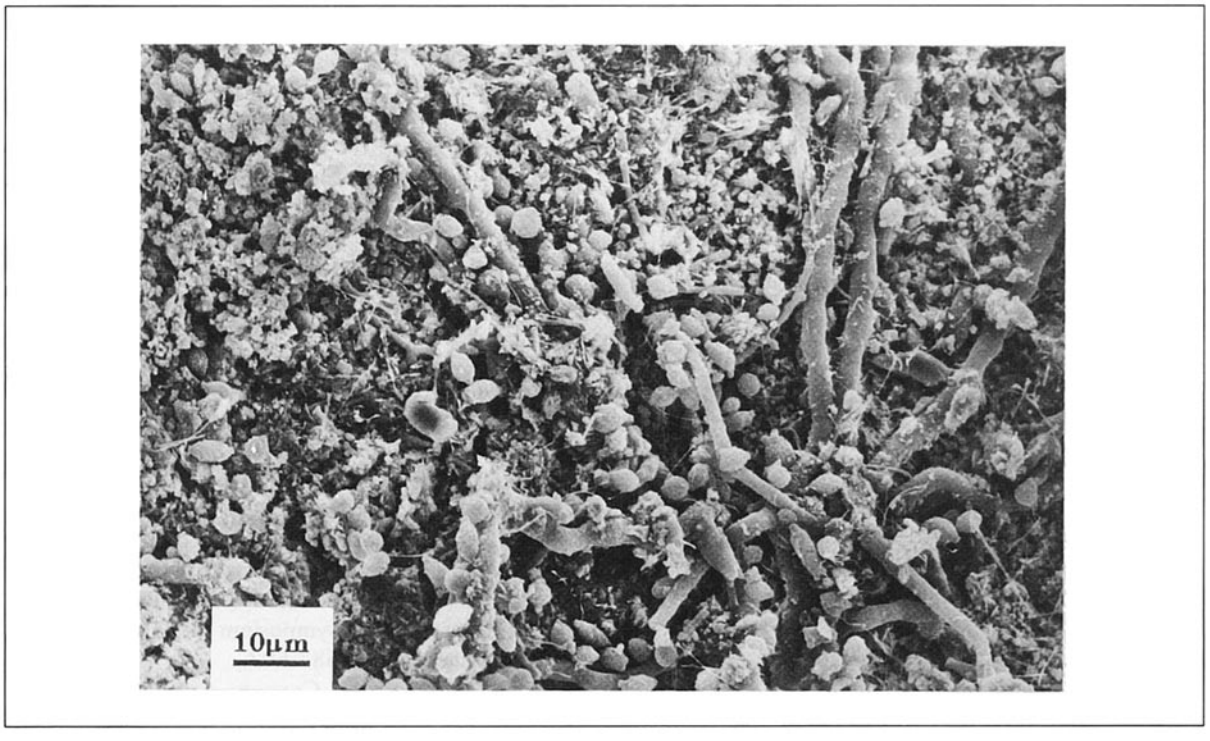

Figure 2. SEM micrograph of *Cladosporium* growing on paint layer - Basilica of S. Vincenzo, Cantù (Como - Italy).

CONCLUSIONS

A large part of microorganisms involved in the biodeterioration of painted surfaces, are aero-dispersed. Among fungi, the genus *Cladosporium* is the most frequently found in the air and the most dangerous for frescoes.

Organic particles are also transported by air and their deposition on mural painting favours the development of heterotrophic species because it increases the organic source of nutrition.

Considering that the most common and least intrusive method for the prevention of fungal growth is the environmental control, aerobiological studies might be considered as a prerequisite to find strategies for restoration programs and environmental conditioning. To evaluate the risk of contamination of wall-painting surfaces, it is necessary to consider air movements and concentrations of airborne spores, because they follow seasonal and daily microclimatic variations, visiting hours and architectural structures of environments (apertures, height of ceiling, location of frescoes, etc.).

Moreover the standardization of investigative methodologies is important to allow comparisons among environments with the same architectonical characteristics, such as small churches, cathedrals, buildings, monasteries and convents.

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