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MOLDS IN MUSEUM ENVIRONMENTS: BIODETERIORATION OF ART PHOTOGRAPHS AND WOODEN SCULPTURES

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Abstract - Pieces of art stored in museum depots and display rooms are subject to fungal colonization that leads to biodeterioration processes. Deteriorated wooden sculptures and art photographs temporarily stored in the quarantine room of the Cultural Center of Belgrade were subject to mycological analyses. Twelve fungal species were identified on the wooden substratum and five species were detected on photograph surfaces. *Trichoderma viride*, *Chaetomium globosum* and *Alternaria* sp. were the fungi with proven cellulolytic activity detected on the examined cellulose substrata. Indoor air mycobiota were estimated to 210.09 ± 8.06 CFU m^{-3}, and the conidia of fungus *Aspergillus niger* were the dominant fungal propagules in the air of the examined room.

Key words: art objects, biodeterioration, cellulose substrata, fungi, indoor air, museum environment.

INTRODUCTION

The fungal colonization of pieces of art presented in display rooms of museums, galleries or stored in depots is nowadays a significant problem for cultural heritage conservators (Sterflinger, 2010). Pieces of art are made of all types of organic and inorganic materials. It is well known that fungi are capable of colonizing, altering and degrading all kinds of materials, and pieces of art are no exception. There are many reports concerning the fungal deterioration of art objects such as paintings (Vukojević and Ljaljević Grbić, 2011), stone monuments and masonry (Ljaljević Grbić et al., 2010), wooden sculptures (Fazio et al., 2011), paper and parchment materials (Cappiteli and Sorlini, 2005), cinematographic films (Abrusci et al., 2005), textiles (Szostak-Kotowa, 2004) etc. Viable fungi isolated from pieces of art presented in an indoor environment in most cases come from the indoor air. The dominant fungal structures in indoor air are the conidia of mitosporic fungi (Florian, 2002). Fungi can be introduced into an indoor environment such as museum depots through transport by workers and visitors via their bodies, clothes and carried items or with outdoor air through "natural gates" such as doors and windows (Niesler et al., 2010). Incorrectly operating air-conditioning system may also be a source of fungal propagules (Ljaljević Grbić et al., 2008). The presence of fungal propagules in indoor air causes adverse health effects, especially allergies and asthma (Bush and Portnoy, 2001). When fungal propagules in an indoor environment settle on different surface conidia germination and mycelia formation can occur. The key factors that determine the germination and growth of fungi are the chemical and structural composition and water activity of the substratum and prevailing environmental factors of temperature, gas composition, pH and

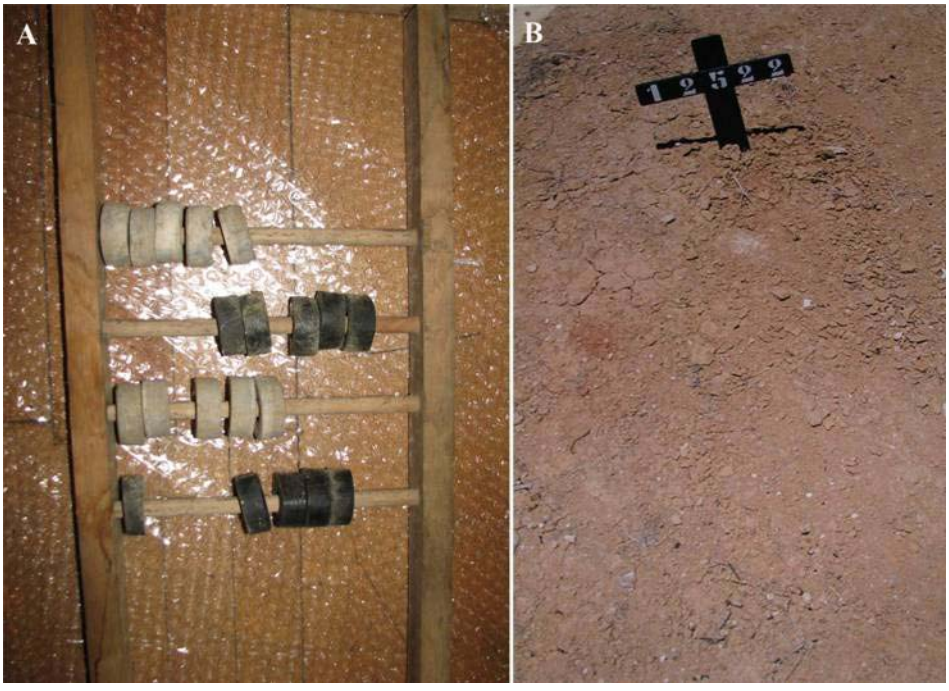

Fig. 1. Sampling objects for mycological analyses. A. "Educational sculpture" by Marko Crnobrnja, B. Art photograph from collection "Earth" by Aleksandar Rafajlović.

light (Saiz-Jimenez, 1993). A fungal infestation on a piece of art contains fungal structures and metabolic products, such as enzymes, citric acid cycle products, secondary metabolites, pigments, odors, etc. Materials colonized by fungi usually undergo changes in their chemical and physical characteristics (Florian, 2002). Fungal infestation on pieces of art leads to biodeterioration and must not be neglected due to the increasing aesthetic value of art objects as well as the impact on health of conservators.

MATERIALS AND METHODS

Case report

The collection consisted of deteriorated art photographs (Fig. 1B), 24 pieces of two artworks "Sky" and "Earth" made by the eminent photographer Aleksandar Rafajlović (part of the collection of the Museum of Contemporary Art in Belgrade), wooden sculptures (Fig. 1A) made by the artist Marko Crnobrnja as well as different textile and terracotta artworks. The deteriorated wooden sculptures and photographs were subjected to mycological analyses. The artworks were sent to Istanbul (Turkey) for an exhibition, "Belgrade's experience: The October Salon", as reputable pieces of contemporary art in Serbia. During the process of preparing the exhibition Istanbul was devastated by a flood and seawater seriously impaired the condition of the photographs and sculptures and they lost their artistic value. The sampling took place in a quarantine room of the Cultural Center of Belgrade (CCB) where the deteriorated art objects were temporarily stored.

Sampling of aeromycobiota

Sampling of aeromycobiota was carried out in a temporary quarantine room of the CCB by the passive sedimentation method described by Omeliansky (1940). Petri dishes containing malt extract agar (MEA) were placed open at approximately 2 m above the floor and were exposed for 30 min. The antibiotic streptomycin was added during the preparation of the medium in order to suppress bacterial growth. After 7 days of cultivation at 25˚C the fungal colo-

nies were counted. The CFU (colony-forming unit) number per cubic meter of air (CFU m^{-3}) was estimated according to Omelyansky's formula:

$$N=5a \times 10^{4}(bt)^{-1}$$

where N is fungal CFU m^{-3}, a is the number of fungal colonies per Petri dish, b is the Petri dish surface (cm^2), t is the exposure time (min). Relative fungal distribution was conducted according to Smith (1980) i.e. the number of colonies of genera or species/total number of colonies of all genera or species x 100.

Sampling of surface mycobiota

According to the surfaces, the examined samples were classified as photographic paper and wooden samples. Sampling was performed from 2 cm^2 of each photograph and each wooden sculpture with sterile cotton swabs.

Isolation and identification of fungi

The swabs were immersed and homogenized in a sterile physiological solution and serial dilutions were made. Each dilution was inoculated (0.1 ml) on MEA with streptomycin added. After 7 days of cultivation at 25˚C, identification of the fungi was performed. Cultural and micromorphological characteristics of fungal colonies were observed and identification was performed using identification keys (Ainsworth et al., 1973; Arx, 1974; Ellis and Ellis, 1997; Pitt, 1979; Raper, and Fennel 1965; Samson et al., 2004).

RESULTS

The fungal concentration of air in the quarantine room of the CCB was estimated at 210.09 ± 8.06 CFU m^{-3}. The prevailing fungal species documented in the air was *Aspergillus niger* Tiegh (62.5%), followed by *Neurospora crassa* Shear & B.O. Dodge (25%) and *Trichoderma viride* Pers. (12.5%) (Fig 2).

The examined objects in quarantine room of the CCB showed clear signs of biodeterioration. Superficial colonies of fungi were clearly visible and abundant on the wooden sculptures and boxes (Fig 3A, B, C). The lightening of original dyes and discoloration phenomena occurred on some parts of the photographs (Fig. 3D).

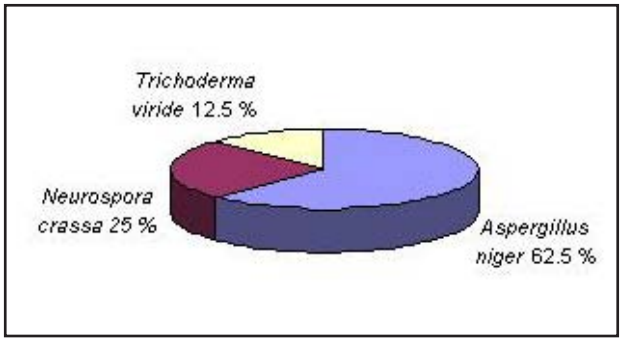

Fig. 2. Relative distribution (%) of fungal species documented in air of quarantine room of the Cultural Center of Belgrade.

A total of 16 fungal species were identified from all analyzed samples with 12 taxa identified on the wooden substratum, followed by 5 taxa identified on photographs (Table 1, Fig. 4). Fungi documented on the wooden substratum belonged to the genera *Absidia*, *Alternaria*, *Aspergillus*, *Chaetomium*, *Neurospora*, *Penicillium*, *Rhizopus*, *Syncephalastrum* and *Trichoderma* (Fig 4.), while *Fusarium*, *Humicola*, *Paecilomyces*, *Trichoderma* and *Ulocladium* species were isolated from the photographs (Fig. 4).

The most abundant group of fungi, regardless of the substratum, was Hyphomycetes with 11 taxa. *Absidia corymbifera* (Cohn) Sacc. & Trotter, *Rhizopus stolonifer* (Ehrenb.) Vuill. and *Syncephalastrum racemosum* Cohn were Zygomycetes identified on wooden substratum. *Chaetomium globosum* Kunze and *Neurospora crassa* were the Ascomycetes identified on the wooden substratum. During the cultivation on MEA, the development of *Chrysonilia crassa* (Shear & B.O. Dodge) Arx, an anamorphic state of *N. crassa*, was recorded.

DISCUSSION

In this investigation, air sampling was done by passive sedimentation, and microbial prevalence was determined using Omeliansky's formula. Although there

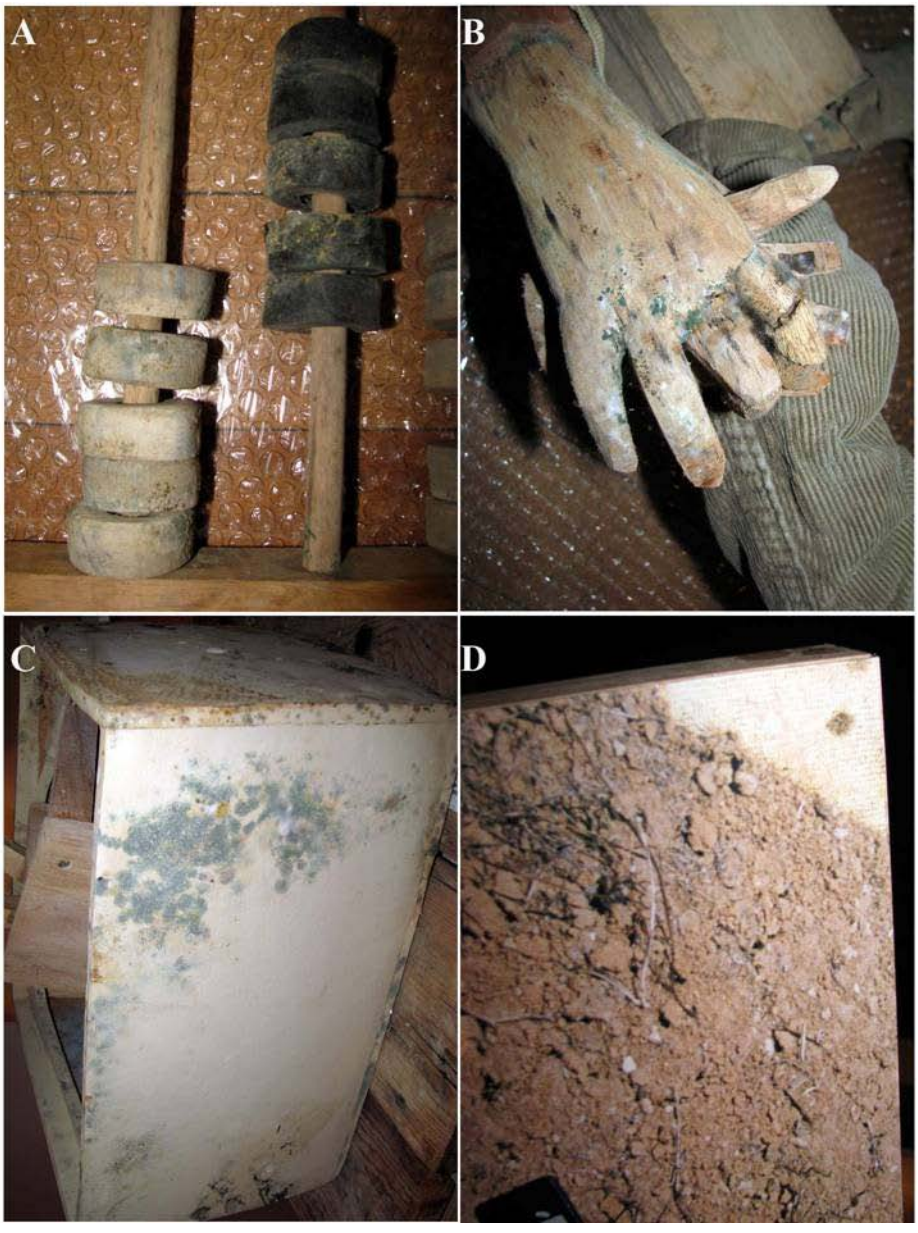

Fig. 3. Biodeterioration of art photographs and wooden sculptures in quarantine room in the Cultural Center of Belgrade. A, B, C. Visible mold growth on wooden substrata. D. Discoloration of photograph.

are no data available to correlate Omeliansky's method with other active sampling methods, passive sedimentation was used only to compare obtained results of indoor mycobiota concentration in the quarantine room of the CCB with international standards of indoor air quality. Omeliansky's method is frequently reported for the estimation of fungal prevalence in indoor air. Borrego et al. (2010) used Omeliansky's method to determine fungal prevalence inside the building of the Photographic Library of the National Archive of the Republic of Cuba and of the Historical Archive of the Museum of La Plata. Bogomolova and Kirtsideli (2009) estimated fungal prevalence in four stations of the St. Petersburg railway under-

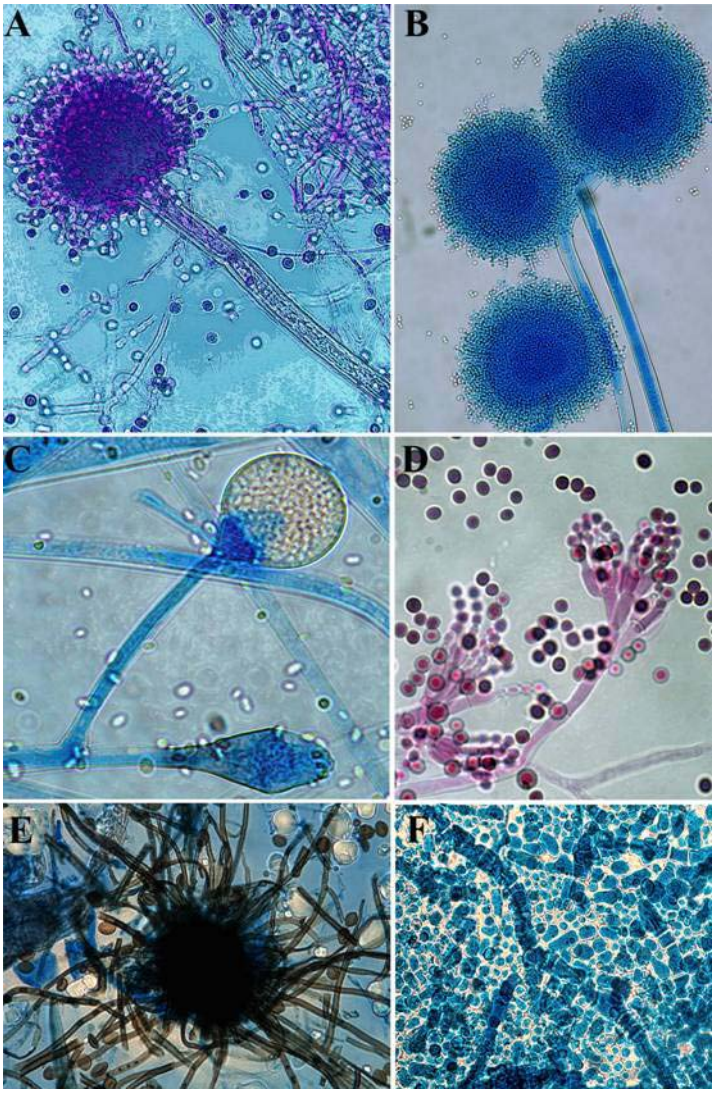

Fig. 4. Fungi isolated from wooden sculptures and art photographs in temporary quarantine room of the Cultural Center of Belgrade: A. *Aspergillus flavus*, conidiogenous apparatus B. *Aspergillus ochraceus*, conidiogenous apparatus C. *Absidia corymbifera*, sporangiophores with sporangia D. *Penicillium* sp., conidiogenous apparatus E. *Chaetomium globosum*, perithecia F. *Neurospora crassa*, conidia chains o of anamorphic state *Chrysonilia crassa*.

ground system using this method. According to the recommendation of the World Health Organization (WHO) from 1990, the fungal density in an indoor environment should be lower than 500 CFU m^{-3}. The obtained value (210.09 ± 8.06 CFU m^{-3}), which is only approximate, is below WHO recommendations. However, due to fungal ability to cause the biodeterioration of art objects deposited in depots and have a negative impact on human health, this value should not be neglected. *Aspergillus niger* was found to be the dominant air-borne fungus in the air of the CCB quarantine room. This species produces small, globose or subglobose conidia up to 5 μm in diameter which are easily dispersed through the air and settle on different surfaces (Florian, 2002). *A. niger* is a common contaminant on various substrates and due to production of the toxic secondary metabolites naphtho-γ-pyrones and malformins (Samson et al.,

Table 1. Fungi isolated from deteriorated art photograph surface and wooden sculptures in quarantine room of CCB.

Fungi	substratum	
	photographs	wooden sculptures
Absidia corymbifera (Cohn) Sacc. & Trotter		+
Alternaria Nees sp.		+
Aspergillus flavus Link		+
Aspergillus niger Tiegh		+
Aspergillus ochraceus G. Wilh.		+
Aspergillus repens (L.) Link		+
Chaetomium globosum Kunze		+
Fusarium Link sp.	+	
Humicola Traaen sp.	+	
Neurospora crassa Shear & B.O. Dodge		+
Paecilomyces variotii Bainier	+	
Penicillium verrucosum Dierckx		+
Rhizopus stolonifer (Ehrenb.) Vuill.		+
Syncephalastrum racemosum Cohn		+
Trichoderma viride Pers.	+	+
Ulocladium Preuss sp.	+	
Total	5	12

2004) as well as the allergens Asp n 14 and Asp n 18 (Knutsen *et al*., 2011), the presence of this fungus in indoor environments is very important.

The significantly larger number of fungal taxa documented on wooden and photographic layer surfaces than in the air suggested that the initial colonization of fungi occurred while the exhibition was stored in Turkey. Flooding damaged the art objects and increased the water activity (a_w) which made these surfaces more suitable for fungal colonization. Abundant superficial fungal colonies were found on the surfaces of wooden sculptures during *in situ* observation. Wooden material in museum heritage objects rarely supports active fungal growth unless the surface has been wet for a period of time (Florian, 2002). Opportunistic species that utilize available sugars, hemicellulose, proteins and amino acids are the primary colonizers of wooden objects in art collections. Most of the wood-degrading fungi that digest cellulose and lignin require a long period of wet conditions in order to colonize successfully wooden substrata (Florian, 2002). Some wood-degrading fungi were found on the wooden sculptures inside the quarantine room of the CCB. *Chaetomium globosum* is a soft-rot fungi capable of degrading cellulose in the S_2 layer of the secondary cell wall of plants (Popescu et al., 2011). Hyphomycetes *Trichoderma viride* and *Alternaria* sp. produce a variety of enzymes capable of hydrolyzing cellulose to glucose (Shafique et al., 2009; Sohail et al., 2011).

Biodeterioration is a common problem in photograph collections, but only a few studies have been carried out on this topic. Photographs have a stratigraphic structure composed of three generic

components: paper support, image forming materials, and gelatin as a binder. The most biosusceptible photographic materials are the gelatin and the paper, because they are organic and hygroscopic (Lourenço and Sampaio, 2009). Some external "materials", such as dust, grease from fingerprints and glues, are important factors in encouraging microbial development on photographs (Eaton, 1985). Many filamentous fungi exhibit cellulolytic and proteolytic activity and they are capable of degrading the paper support and gelatin binder of photographs. In the case presented here, it can be concluded that infestation of photographs occurred after the flood in Turkey. The microfungi identified on the photographic surfaces were the causative agents of biodeterioration. According to Borego et al. (2010), the main cause of the biodeterioration of the photograph collections in the Photographic Library of the National Archive of the Republic of Cuba and in the Historical Archive of the Museum La Plata were the yeasts and filamentous fungi of *Aspergillus* and *Penicillium* genera.

It can be concluded that the irreversible changes in the analyzed artworks was caused by fungal infestation. Due to the total devastation of the examined artworks, the collections were destroyed because of their complete loss of artistic value. In addition, contaminated artwork collections could be potential source for the spread of infestation to surrounding artworks and environment.

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