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# Fungal contamination of textile objects preserved in Slovene museums and religious institutions

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ABSTRACT

This investigation into fungal growth on historical textiles, including the canvases of easel paintings stored in museums and religious institutions (churches and cloisters) in Slovenia, initially indicated relatively widespread fungal contamination. Closer investigation revealed that only 21 objects out of 38 were positive for fungal contamination, with the other objects being discoloured or stained due to other factors. On the objects that were stored at low humidity and temperature, fungal growth remained restricted for several years, even if the objects were contaminated before storage. Although most of the textile specimens contaminated by fungi were from those institutions without any control of internal environmental conditions, the rate of textile degradation due to fungal growth was generally low. The dominant contaminant fungal species, detected by culture-dependent techniques and identified by the use of current molecular genus-specific barcodes, belonged to the genus *Penicillium*, followed by *Aspergillus* and *Cladosporium*. Microscopy analyses of the fungal growth revealed that on most of these objects fungal growth was limited to the surface. The enzymatic profile of selected isolates was determined. Most of the fungi were isolated from the flax of the linen objects, confirmed also by their enzyme activities, particularly by strong beta-glucosidase activity. Amylase activity of selected isolates was also evident; this is important since starch can be added as filling or glue to textile materials. Examination of the structural and physical changes to the fibres on contaminated and non-contaminated objects showed the most pronounced structural changes on flax and other cellulosic fibres, while proteinaceous fibres (e.g., wool and silk) were generally not affected.



## Introduction

One of the main aims of museums is the preservation of historical objects. During long-term storage of objects of historical value, the materials can change structurally due to exposure to different deteriorative conditions, e.g., UV irradiation, high humidity, and changing temperatures. Ultraviolet light causes oxidation of the polymers that constitute the natural fibres, which results in the breaking of intermolecular bonds and facilitates penetration of microbial enzymes (Tomšič et al., 2007; Zotti et al., 2008). High humidity accelerates microbial attack and the consequential degradation processes.

Textile objects are an important part of our cultural heritage objects, but unfortunately, since they are made of natural fibres, they are a target of microbial attack and degradation, resulting as discoloration, staining, and loss of structural strength (Tiano, 2002). In addition, textiles can also act as carriers of microorganisms such as pathogenic bacteria, odor-generating bacteria, and fungi. To forestall biodeterioration, textile manufacturers have for a long time been interested in the degree of fabric processing (e.g., Burgess, 1928) or in antimicrobial protection of textiles (Simončič and Tomšič, 2010). Currently research is also oriented toward the protection of historical textiles stored in museums against microbes (Ilec et al., 2012).

Since almost any material can be attacked by microbes, including those made of synthetic polymers (Gu et al., 1998, 2011; Gu, 2003; Singh and Sharma, 2008), historical textiles, which consist of mostly organic materials, are at special risk. The control of physical conditions in museums, especially the establishment

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and maintenance of appropriate temperature and relative humidity (16–18 °C and 40–65% RH, respectively) in storage and showrooms, are currently the accepted and effective ways to deal with fungal contamination and reduce consequent biodeterioration. Fungal contamination of stored objects has other undesirable effects as well, such as lessened air quality due to the production of volatile metabolites, which has an impact on environmental health. A problem appears also due to the fact that natural fibres have different rates of absorption and desorption of moisture (Fusek, 1985), and thus local, uncontrollable microclimatic conditions might occur that can affect the possibility of fungal contamination of natural fibers.

The degree and speed of degradation depend on the chemical and physical properties of the substrate, in terms of the chemical structure, molecular weight, and crystallinity, along with the environmental conditions, the dominant microbial contaminants, and the synergy of the infecting microbial community (Warscheid, 2000; Tomšič et al., 2007). Infecting microorganisms can change the structure and stability of stored materials by enzymatic reactions and excretion of metabolic products, such as organic acids, oligopeptides, secondary metabolites, dyes, and volatile organic compounds (Warscheid, 2000). Deterioration can result in discoloration, staining, and loss of structural strength (Tiano, 2002). In summary, inappropriate storage and microbial contamination can often badly disfigure objects of art.

Although both bacteria (Seves et al., 1998; Szostak-Kotowa, 2004; Capodicasa et al., 2010) and fungi (Abdel-Kareem, 2010) can be isolated from historical textiles, fungi in particular have been reported as the main deteriorative agents. The prerequisites that facilitate the contamination of objects by fungi are high humidity and initial oxidative degradation of hygroscopic natural fibres (Valentin, 2003). The main targets of fungal enzymatic degradation are cellulosic natural fibres, although fungi can also degrade natural proteinaceous materials, as well as non-organic materials (Caneva et al., 2005), and even synthetic ones (Breuker et al., 2003; Gu, 2003; Cappitelli et al., 2005). Different fungal species can cause staining of various colours and sizes; this can be difficult to remove, as the hyphae can grow not only on the surface, but also within the fibres (Strzelczyk, 2004).

The most common genera of fungi that are known to occur on modern natural textiles are *Alternaria*, *Aspergillus*, *Chaetomium*, *Cladosporium*, *Curvularia*, *Fusarium*, *Memnoniella, Myrothecium, Penicillium*, *Pestolotia*, *Pullularia*, *Rhizopus, Stachybotrys*, *Trichoderma*, and *Verticillium* (Marsh and Bollenbacher, 1949; Marsh et al., 1949; White et al., 1950; Raschle, 1989; Szostak-Kotowa, 2004; Kaese et al., 2008). However, a slightly narrower range of fungal genera has been reported to grow on historical textiles: *Alternaria*, *Aspergillus*, *Chaetomium*, *Ctenomyces*, *Fusarium*, *Memnoniella*, *Myrothecium*, *Neurospora*, *Penicillium, Scopulariopsis*, and *Stachybotrys* (Tiano, 2002; Cybulska et al., 2008; Kvavadze and Gagoshidze, 2008; Abdel-Kareem, 2010). Most of these fungi were isolated from historical cellulosic fibres, while *Aspergillus*, *Chrysosporium*, *Ctenomyces*, *Fusarium, Penicillium*, and *Trichoderma* have also been reported from historical proteinaceous fibres (Tiano, 2002; Cybulska et al., 2008). Interestingly, the dermatophytic fungal genera *Trichophyton* and *Microsporum* have been reported to grow on historical wool (Tiano, 2002).

In contrast to the relatively well-documented fungal biodeterioration of stone, wood, paintings, and paper cultural heritage objects (Zyska et al., 1997; Montemartini Corte et al., 2003; Strzelczyk, 2004; Caneva et al., 2005; Sterflinger, 2006; Zotti et al., 2008), the above listed genera of fungi isolated from historical textiles have been reported in only a few studies (Tiano, 2002; Cybulska et al., 2008; Kvavadze and Gagoshidze, 2008; Abdel-Kareem, 2010). These studies have been limited to the identification of the fungal species in the framework of general investigations into degraded archaeological textiles (Kvavadze and Gagoshidze, 2008), general introductions to the research of historical textiles (Cybulska et al., 2008), studies about microflora-promoted deterioration of historical textiles in Egyptian museums (Abdel-Kareem, 2010), and a case report of fungal deterioration of a 16th century painting (Capodicasa et al., 2010).

Along with the development of microbiological methods, identification of fungi from historical textiles no longer involves culturing techniques only, but also employs non-culture methods based on the isolation of total DNA (Di Bonaventura et al., 2003). Nonetheless, the documentation of an active culture together with its biodegradation potential, e.g., enzyme profiling, can give us important information before a restoration procedure is conducted.

The aim of this study was to determine the extent of damage and degradation of historical textiles stored under varying conditions in six museums and six religious buildings in Slovenia, and which were potentially contaminated by fungi. The oldest stored textile sample was from the Roman period, while the most recent was from the 21st century. All 38 objects that were sampled were woven exclusively of natural fibres. The fungi were isolated from the textile objects using classic culturing techniques, and were identified to the species level through established, classic, and molecular methods. The aim was to find any connections between storage conditions, type of material, presence of fungi, and the rate of degradation of these different materials, and to identify the "typical museum mycobiota."

## Materials and methods

### *Selection of samples*

The samples originated from six museums (the National Gallery of Slovenia, National Museum of Slovenia, Slovene Ethnographic Museum, Museum of Christianity in Slovenia, Provincial Museum of Ptuj, and the Provincial Museum of Murska Sobota) and six religious buildings (Ursuline Convent; Franciscan Monastery; subsidiary Church of St. Radegunda, near Šenčur; Provost Church in Novo Mesto; Parish Church of St. Jacob, in Ljubljana; St. Nicolas Cathedral of Ljubljana), all in Slovenia. They were taken either from storage rooms in the museums or from the conservation workshops in the Slovenian Restoration Centre. In all, 35 different textile and three leather objects were obtained from three national museums (two, six, and eight objects), one national gallery (one object), one provincial museum (seven objects), and the Restoration Centre (14 objects), with these last originally stored in four churches, a provincial museum, and two cloisters. The choice of the numbers of objects examined from each institution was made at random, and was based on the selection of the curators and restorers. The selection criterion was the presence of stains appearing to be fungal contamination, or the presence of fungal mycelia on the surface of the objects examined. Where several different types of stains appeared, more than one smear sample was taken, which resulted in 60 sampled sites on these above-listed objects.

### *Storage conditions*

Different types of museums that had different storage conditions for their historical objects were chosen. With the exception of the National Gallery, the conditions in the museum storage rooms were not controlled, and thus changed according to the outdoor conditions (Table 1). The conditions were measured on various occasions.

### *Sampling of fabric and identification of textile fibres*

With the objects that would not be additionally damaged by sampling, pieces of fabric, loose fibres, or threads were taken for