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Original article

Fungal deterioration of a woollen textile dyed with cochineal

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ABSTRACT

Microbiological destruction of woollen textiles may occur as a result of the influence of both bacteria and fungi and it is connected with their nutrition. However, in view of the conditions endured by the fabrics during transport, storage or museum exhibitions, fungi pose the greatest threat, due to their physiology. Fungal activity, by causing irreparable damage to woollen textiles, may lead to the irreversible loss of cultural properties. In this work, assessment of the mode of action of selected fungal species on cochineal-dyed woollen textiles was performed. Furthermore, determination of the impact of enriching a microbiological medium with additional nutrients upon the degree of biodeterioration of the dyed textiles was carried out. Experiments were conducted using the pure culture method. To analyse the type and extent of microbial deterioration of the cochineal-dyed woollen textile's tensile strength, elongation tests and spectrophotometric measurements of colour were applied. Additionally, selected samples were analysed by both transmitted light and scanning electron microscopy (SEM). The undertaken research showed that all the fungi tested cause structural and aesthetic damage, of varying degrees, to the woollen textile. Moreover, the presence of additional nutrients in the medium is a significant factor, which determines the susceptibility of a particular textile to microbial deterioration.

1. Research aims

Currently, the literature provides very little information on fungal species responsible for the damage of woollen textiles and there is a paucity of works concerning the testing of the devastating power of microorganisms isolated from this type of textile. Moreover, the topic of the influence of pure cultures of fungi on the deterioration of dyed woollen textiles has hardly been investigated to date. No less important is recognition of the effect of the presence of additional nutrients for fungi in the process of textile degradation, as easily accessible food ingredients are present in dust, which may cover textiles during any stage of their life cycle. This paper discusses the influence of fungi isolated from antique and contemporary woollen textiles and of additional nutrients present in the medium on the biodeterioration of a cochineal-dyed woollen textile.

2. Introduction

Biodeterioration is a widespread problem, since microorganisms are present in every environment; additionally, they display remarkably versatile metabolic abilities. In the field of textile biodeterioration the recognition of a microorganism species responsible for the destruction of a given object, and subsequently all factors influencing the range of microbial damage to that object, should be considered as basic tasks. In fact, a major problem encountered in researching the deterioration of historic textiles is the determination of whether the observed damage to the object was caused by microorganisms; and, if so, to what extent isolated strains are responsible. Only after a thorough understanding of the etiological factor of destruction is gained can the object be adequately protected.

Among fungi capable of feeding on keratin substrates, two groups are specified: keratinolytic organisms (which are potentially pathogenic to humans and animals) that produce specialised enzymes (keratinases) and are capable of digesting α-keratins, and keratinophilic organisms that use keratin-related materials or compounds produced in the course of keratin's partial decay. Wool fibres containing keratin may also be a food source for microorganisms that do not belong to any of the mentioned groups that will use various components directly related to the substrate, such as contaminants, dyestuffs, etc. The first signs of microorganism growth on a given object are surface changes, such as changes in colour saturation, obliteration of the original appearance of an object, or the characteristic smell of mould. Subsequently, unsightly and difficult-to-remove stains and discolouration of various types may occur. Continuous growth and metabolic activity of microorganisms lead to the structural decomposition of the fabric with chemical changes in textile fibres. As a consequence, a decrease in textile strength characteristics or complete loss of

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Fig. 1. Cochineal breeding on prickly pear near Cantalloc Aqueducts, Nazca region, Peru.

the fabric may follow. The rate of fungal growth and the extent of related destruction are regulated by the organism's physiological potential, which enables the use of nutrients provided by the material on which the organism grows, as well as environmental factors. There are interspecific differences in the time needed for germination, formation of mycelium and reproductive organs. Similarly, the manner of fabric decay resulting from the activity of various fungal strains is also different. Detailed information on fungal deterioration of keratin materials and on factors affecting the growth of fungi in wool can be found in [1–4].

From the dawn of history until the second half of the 19th century, during which synthetic dyes were invented, only natural dyes were used, so they are inherent in antique textiles. One of the main dyes used for many centuries throughout the world was cochineal, a dye of historical importance. It is the strongest dye of those, which are derived from insects. The source of the dye is female *Dactylopius coccus* Costa insects belonging to the suborder *Coccoidea*. They live only on cacti, preferring spikeless prickly pears *Opuntia cochenillifera*, or nopal *Nopalea cochenilli* (Fig. 1). They are native to Mexico, Central and South America. Cochineal was the main red dye used in these regions before the Spanish Conquest. Inca women applied cochineal as a blusher, potters used it as a decoration, home decorators put it on walls, and artists painted with it in their frescos. But most frequently of all it was used in textiles. The Incas were masters of the production of cochineal-dyed fabrics. Cochineal dye began to be used occasionally on animal fibres as early as the first millennium BCE [5–7].

Soon after the discovery of Mexico by the Spaniards in 1512, the demand for cochineal, which was extremely hard to come by, grew throughout the world and even ignited significant conflicts, because the quality of the dye exceeded by many times that obtained from the insects of the Old World (e.g., kermes). Cochineal was the most important red dye in European textiles from the 16th to the 19th century, as well as in 18th- and 19th-century Asian textiles [8]. The process of dyeing with cochineal involved first saturating the fabric with a mordant. To fix the colour, the ancient Meso-Americans mixed it either with tin or with alum, the latter being the mordant most often used over the centuries [6]. Some examples of an application of the cochineal dye are ancient Peruvian textiles, American colonial embroideries; and, among later textiles, scarlet Venetian clothes, tapestries from Gobelin, Persian carpets and scarlet coats.

3. Materials and methods

3.1. Fungi

All fungal species used in this work were isolated from biodeteriorated antique (tapestries of Sigismund Augustus Jagiellon, which were woven about the middle of the 16th century in Brussels to the monarch's order [9]) and contemporary woollen textiles from areas with stains of black, rust, brown and grey colouring, spots with a prominent whitish coating, brighter colour, thinning and holes. In order to isolate as broad a range as possible of microorganisms responsible for the deterioration of textiles analysed, several microbiological media were applied and incubation was conducted for 6 months. From among all microorganisms obtained (fungi and bacteria, including actinomycetes), fungi were selected as the object of the analysis because this group of microorganisms is the most dangerous for textiles, if one takes into consideration the conditions textiles may encounter during museum exhibition, storage or transport. All the fungi obtained were identified by means of classical and molecular techniques (Table 1). Experiments were carried out with the use of 7 pure cultures of fungal strains determined by the author to be the most harmful to wool fibres, namely *Acremonium camptosporum*, *Alternaria alternata*, *Chaetomium globosum*, *Myceliophthora sp.*, *Gymnoascus arxii*, *Microascus cirrosus* and *Penicillium chrysogenum*. Four of them were isolated from antique woollen textiles and 3 from a contemporary one (Table 1). More information on the fungi can be found in [2,3].

The inoculum was made of 14-day-old microbial cultures. Fungal spores were suspended in sterile 0.9% NaCl solution, the density of the spore suspension per 10^6 CFU mL^{-1} was determined. The prepared suspended matter was used to inoculate textile specimens.

3.2. Textile

The textile used in the experimental part of the research was made of 100% Australian merino wool, plain weave, of a weight per unit area of 162 g/m^2, without chemical treatment. The textile was dyed with an application of a natural cochineal dye with the use of alum mordant. Effective dyestuffs identified in a cochineal dye are carminic acid (94–98%), flavokermesic acid (0.4–2.2%), an unknown component called dcII (1.4–3.8%) and traces of kermesic acid [8]. The mordant bath contained 15% aluminium potassium sulphate ($KAl(SO_4)_2 \times 12H_20$); the dye bath contained 20% cochineal dye. Detailed information on the applied cochineal dye and the dyeing process can be found in [4].

The dyed textile specimens were cut warp-wise into strips of 15×120 mm and into squares of 60×60 mm and disinfected in 70% ethyl alcohol.

3.3. The pure culture method

Microbiological testing was conducted using the pure culture method. Two kinds of microbiological media were used, one of which was a mineral medium, i.e., without any source of carbon and nitrogen, containing only essential salts. The other was an enriched medium, supplemented with glucose and yeast extract as an additional source of these 2 basic elements [4].

The textile strips and squares were placed in Petri dishes and inoculated with fungal spore suspension. The dishes containing cultures were placed in the incubator at $28 \pm 2\,^{\circ}C$ with a relative humidity of $65 \pm 2\%$. After 4 weeks of incubation the strips were taken out, washed with running water to remove mycelium and spores and dried for 24 hours at room temperature. In the growth zone method [10] dishes with samples were taken out of the incubator every seventh day of the experiment. To measure a textile surface covered with growth of a given fungus, a 60×60 mm