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Application of *Cinnamomum zeylanicum* essential oil in vapour phase for heritage textiles disinfection

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ABSTRACT

The currently applied disinfection methods of heritage textiles tend to destroy the objects, thus the need arises to find novel, effective and safe approach. The aim of this study was to evaluate the antimicrobial effectiveness of CEO in vapour phase to disinfect new and heritage textiles, and its impact on the optical, mechanical and structural properties of materials. Minimal inhibitory concentrations of CEO in vapour phase were estimated as 5.625 μg ml^{-1} for moulds (*Aspergillus niger*, *Penicillium funiculosum*, *Trichoderma viride*), and 22.5 μg ml^{-1} for bacteria (*Streptomyces rutgersensis*, *Bacillus megaterium*, *Pseudomonas fluorescens*). Depending on the species tested, the number of viable microorganisms on textiles was reduced by 2 − 7 logarithmic units after CEO disinfection. No significant changes in the optical, mechanical and structural parameters of the textiles were observed after CEO disinfection. In this context, disinfection with CEO in vapour phase seems to be an effective, sustainable and safe method of heritage textiles disinfection.

1. Introduction

In humid air atmosphere, microorganisms are able to degrade historical textiles causing their discoloration, decomposition, reduction of material strength as well as producing specific odours (Forlani et al., 2000; Gutarowska et al., 2016). The most vulnerable are the textiles made of natural materials, such as cotton, linen, sisal (cellulose), wool (keratin), and silk (fibroin) (Montegut et al., 1991; Seves et al., 1998; Szostak-Kotowa, 2004). Moreover, the overgrowth of many microorganisms cause serious health risks at workplaces in museums and archives (Krumbein, 2003; Wiszniewska et al., 2009). Organisms frequently associated with the biological degradation of historical textiles are fungi from genera *Penicillium, Chaetomium, Aspergillus, Botrytis,* and *Cladosporium,* and bacteria *Micrococcus*, *Bacillus*, *Streptomyces,* and *Nocardia* (Seves et al., 1998; Abdel-Kareem, 2010a, 2010b; Gutarowska et al., 2016).

To prevent biodeterioration, objects need to be disinfected before including them to the collection. Prerequisites of an agent to qualify as a disinfectant include the ability to inhibit growth and metabolic activity of microorganisms, while having no adverse effect on the material. In the current conservation practice, ethylene oxide fumigation is still the most popular method for textile disinfection. However, this gas is an irritant and a dangerous carcinogen for humans, and its use is therefore being discontinued (Sequeira et al., 2012).

The plethora of biological properties of essential oils makes them a new group of disinfectants used in various industries, including the protection of cultural heritage. Essential oils (EO's) are a mixture of plant origin fragrances, consisting of hundreds of components with different concentrations and properties. They are mainly the mono- and sesquiterpenes and phenylpropane derivatives, including hydrocarbons, alcohols, aldehydes, ketones, esters and ethers (Zachariah and Leela, 2006). Many reports in literature indicate the *in vitro* inhibitory activity against Gram-positive and Gram-negative bacteria, filamentous fungi, viruses, and protozoa, but their antimicrobial mechanism has not been fully recognized (Lambert et al., 2001) (Kalemba and Kunicka, 2003;

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Krisch et al., 2013).

However, essential oils as preservative compounds in cosmetics (Kunicka-Styczyńska et al., 2011) and food matrices (Bakkali et al., 2008; Krisch et al., 2013) are described more extensively, there are a few studies concerning essential oils (eucalyptus, clove, thyme, oregano) and plant extracts (greater burdock, cornflour) in cultural heritage conservation, mainly to protect paper documents (Guiamet and Gomez De Saravia, 2005; Guiamet et al., 2006, 2008; Borrego et al., 2016).

Cinnamon oil is obtained from barks, leaves and fruit of various species of the cinnamon tree (*Cinnamomum* Scheffer). Around 60 compounds are detected in cinnamon essential oils (Senanayake et al., 1977), with cinnamic aldehyde and eugenol having the highest antimicrobial activity; however, a whole range of these compounds are responsible for high biocidal activity of the essential oils (Unlu et al., 2010). So far, there are no reports on the use of cinnamon essential oil for textile disinfection. This was the main purpose to undertake the first study of cinnamon essential oil (CEO) application for heritage textile disinfection.

The aim of the research was to evaluate the antimicrobial effect of cinnamon oil in vapour phase disinfection on new and heritage textiles, and its impact on the optical, mechanical and structural properties of the material. Furthermore, in our study the chemical composition of cinnamon essential oil in the vapour phase, the oil compounds absorbed by the textiles after disinfection, and the minimum inhibitory concentration (MIC) of CEO in vapour phase against the tested strains were determined.

2. Materials and methods

2.1. Textiles

Three new woven fabrics made from plant cellulose fibres (cotton, linen) and animal protein fibre (silk) were used in model study. The cotton and linen fabrics were scoured and not bleached. Sericin was removed from the silk. All fabrics used contained no dyes or chemical auxiliary agents. Their characteristics are presented in Table 1. Textiles used for microbiological analysis were cut into 10 cm^2 pieces (2 cm × 5 cm) and for mechanical properties analysis into 30 cm^2 pieces (2 cm × 15 cm). The new textiles were sterilized (121 °C, 1 atm., 20 min) before inoculation with microorganisms.

This study also included 4 heritage (20th century) textiles procured from the Museum of Archaeology and Ethnography, Lodz Poland, Department of Costume and Folk Textile: cotton pillowcase (1950), polyester ribbon (1980), cotton trousers (1940), and silk coif (1918).

2.2. Accelerated thermal ageing

To assess the impact of ageing on heritage textiles, the new fabric samples (cotton, linen and silk) were artificially thermally aged for 52 h, at temperature 130 °C in air atmosphere, using an electronic convection oven Model SLW 32STD (POL-EKO APARATURA, Poland). Based on the crude approximation at this temperature, the rate of material deterioration will double for each rise of 10 °C, this was estimated to be equivalent to about 50 years of ageing under normal conditions (El-Gaoudy et al., 2011).

2.3. Microorganisms

In the model study, six microorganisms were originated from Pure Culture Collection at Institute of Fermentation Technology and Microbiology, Lodz University of Technology (ŁOCK 105), and American Type Culture Collection (ATCC): *Streptomyces rutgersensis* (ŁOCK 0894), *Bacillus megaterium* (ŁOCK 105), *Pseudomonans fluorescens* (ŁOCK POM2123), *Aspergillus niger* (ATCC 16404), *Penicillium funiculosum* (ŁOCK 0587) and *Trichoderma viride* (ŁOCK E153). Microorganisms used in this study were selected due to previously reported cellulolytic activity of fungi on cotton and linen (Szostak-Kotowa, 2004; Abdel-Kareem, 2010b; Gutarowska et al., 2016), and proteolytic activity of bacteria on silk (Seves et al., 1998; Forlani et al., 2000; Szostak-Kotowa, 2004). The bacteria were cultivated on TSA (Triptic Soy Agar, Merck, Germany) and incubated 48 h at 30 °C; moulds were cultivated on MEA (Malt Extract Agar, Merck, Germany) for 72 h at 27 °C.

2.4. Cultivation of microorganisms on aged textiles

All microorganisms were cultured on artificially aged cotton, linen and silk, and placed on M_0 medium ($MgSO_4 \cdot 7H_2O$ - 5 g; $(NH_4)_2SO_4$ - 3 g; KH_2PO_4 - 1 g; glucose - 20 g; agar – 15 g per 1000 ml H_2O). Pieces of textiles were inoculated with a 250 μl suspension of microorganism in saline solution moulds - $4.73 \times 10^5 - 3.93 \times 10^6$ CFU ml^{-1}, and bacteria - $6.66 \times 10^6 - 1.27 \times 10^7$ CFU ml^{-1} (Colony Forming Units per cm^3). Cotton and linen were inoculated with *A. niger*, *P. funiculosum* and *T. viride*, while silk was inoculated with *B. megaterium, P. fluorescens* and *S. rutgersensis* The textiles after inoculation were incubated for 21 days at 28 °C, and relative humidity of the air RH 80%, in a climatic chamber (KBF720; Binder, Germany).

To determine the mould and bacterial growth on textiles, the AATCC 100 plate method was used. After 21 days post inoculation and incubation, the pieces of textiles were transferred to 50 ml of sterile distilled water containing Tween 80, and shaken for 5 min to remove cells from the textile. After serially diluting the resultant suspension, the bacteria were cultivated on TSA (Tryptic Soy Agar, Merck, Germany) and incubated for 48 h at 30 °C; the moulds were cultivated on MEA (Malt Extract Agar, Merck, Germany) for 72 h at 27 °C. After the incubation, colonies were counted and expressed as Colony Forming Units per 10 cm^2 of the sample (CFU 10 cm^{-2}). The analyses were made in triplicate.

2.5. Assessment of antimicrobial activity of essential oils

Commercial cinnamon essential oil (CEO), extracted from the bark of *Cinnamomum zeylanicum* Blume with ISO 9001 certificate was used in the studies; it originated from Pollena-Aroma Sp. z o.o. Poland.

The MIC (minimal inhibitory concentration) of CEO in vapour phase was estimated by the microatmosphere method. The TSA and MEA media were inoculated with 100 μl of bacteria and fungi

Table 1
Textiles characteristics.

Fiber	Mass per unit area (g m^{-2})	Thickness (mm)	Porosity (%)	Finishing	Manufacturer
Cotton	278	0.76	76	Unbleached	Andropol S.A. (Poland)
Linen	285	0.70	73	Natural colour	Świat Lnu (Poland)
Silk	52	0.12	67	Natural colour Degummed	Fei–Long Inc. (China)

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