ANTIFUNGAL AND ANTIBACTERIAL TREATMENTS BASED ON NATURAL COMPOUNDS FOR LINING LEATHER AND FOOTWEAR ARTICLES

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ANTIFUNGAL AND ANTIBACTERIAL TREATMENTS BASED ON NATURAL COMPOUNDS FOR LINING LEATHER AND FOOTWEAR ARTICLES

ABSTRACT. The purpose of this research is to obtain antifungal and antibacterial treatments based on natural compounds of essential oils of geranium, pine, and rosemary for cotton and leather linings to make leather, fur articles, and footwear. The main characteristic absorption bands for the functional groups of geranium, pine and rosemary essential oils were investigated by Fourier transform infrared spectroscopy-attenuated total reflectance (FTIR-ATR). Microbiological antifungal test was performed in the presence of *Candida albicans* ATCC 10231 fungus and antibacterial activity was determined in the presence of *Staphylococcus aureus* ATCC 25923 (Gram-positive bacteria), and *Escherichia coli* ATCC 25922 (Gram-negative bacteria). The absorption method involved the inoculation of the bacteriological test inoculum directly on the treated samples. Microbiological tests have revealed a high antifungal and antibacterial activity of the essential oils of *Aetheroleum pini sylvestris*, *Aetheroleum geranii*, *Rosmarinus officinalis* on cotton and leather linings and the possibility to be used in various compositions for the treatment of different lining materials for gloves, caps, shoes or other articles with essential bioactive properties for health and environmental protection.

KEY WORDS: natural compounds, antifungal and antibacterial treatments, cotton cloth lining, leather lining, health and environmental protection

TRATAMENTE ANTIFUNGICE ŞI ANTIBACTERIENE PE BAZĂ DE COMPUŞI NATURALI PENTRU CĂPTUŞELI ARTICOLE DIN PIELE ŞI ÎNCĂLŢĂMINTE

REZUMAT. Scopul acestei cercetări este de a obţine tratamente antifungice şi antibacteriene bazate pe compuşi naturali ai uleiurilor esenţiale de geraniu, pin şi rozmarin pentru căptuşelile din bumbac şi meşină utilizate la confecţionarea articolelor din piele, blană şi încălţăminte. Principalele benzi de absorbţie caracteristice grupărilor funcţionale ale uleiurilor esenţiale de geraniu, pin şi rozmarin au fost determinate prin spectroscopie în infraroşu cu transformată Fourier - reflexie totală atenuată (FTIR-ATR). Testul antifungic microbiologic a fost efectuat în prezenţa *Candida albicans* ATCC 10231, iar activitatea antibacteriană a fost determinată în prezenţa *Staphylococcus aureus* ATCC 25923 (bacterie Gram-pozitivă) şi *Escherichia coli* ATCC 25922 (bacterie Gram-negativă). Metoda de absorbţie a implicat inocularea directă a inoculului de test bacteriologic pe eşantioanele tratate. Testele microbiologice au relevat o activitate antifungică şi antibacteriană ridicată a uleiurilor esenţiale de *Aetheroleum pini sylvestris*, *Aetheroleum geranii*, *Rosmarinus officinalis* pe căptuşelile din bumbac şi meşină, precum şi posibilitatea de a fi utilizate în diverse compoziţii pentru tratarea diferitelor materiale de căptuşeală pentru mănuşi, şepci, pantofi sau alte articole cu proprietăţi bioactive esenţiale pentru protecţia sănătăţii şi a mediului.

CUVINTE CHEIE: compuşi naturali, tratamente antifungice şi antibacteriene, căptuşeală din pânză de bumbac, căptuşeală din meşină, protecţia sănătăţii şi a mediului

TRAITEMENTS ANTIFONGIQUES ET ANTIBACTÉRIENS À BASE DE COMPOSÉS NATURELS POUR LA DOUBLURE D'ARTICLES EN CUIR ET CHAUSSURES

RÉSUMÉ. Le but de cette recherche est d'obtenir des traitements antifongiques et antibactériens à base de composés naturels d'huiles essentielles de géranium, de pin et de romarin pour les doublures en coton et leathere destinés à la confection du cuir, des articles en fourrure et des chaussures. Les principales bandes d'absorption caractéristiques des groupes fonctionnels des huiles essentielles de géranium, de pin et de romarin ont été étudiées par spectroscopie infrarouge à transformée de Fourier-réflectance totale atténuée (FTIR-ATR). Un test antifongique microbiologique a été réalisé en présence du champignon *Candida albicans* ATCC 10231 et l'activité antibactérienne a été déterminée en présence de *Staphylococcus aureus* ATCC 25923 (bactérie à Gram positif) et *Escherichia coli* ATCC 25922 (bactérie à Gram négatif). La méthode d'absorption a impliqué l'inoculation de l'inoculum de test bactériologique directement sur les échantillons traités. Des tests microbiologiques ont révélé une activité antifongique et antibactérienne élevée des huiles essentielles d'*Aetheroleum pini sylvestris*, d'*Aetheroleum geranii* et de *Rosmarinus officinalis* sur les doublures en coton et leathere et la possibilité d'être utilisées dans diverses compositions pour le traitement de différents matériaux de doublure pour gants, bonnets, chaussures ou autres articles dotés de propriétés bioactives essentielles à la protection de la santé et de l'environnement.

MOTS CLÉS: composés naturels, traitements antifongiques et antibactériens, doublure en tissu de coton, doublure en leathere, protection de la santé et de l'environnement

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INTRODUCTION

The interest in using of essential oils extracted from plants with bioactive properties to prevent and stop the development of fungi and bacteria has increased considerably worldwide because many of them have no side effects on the human body or on the environment as they have bioactive compounds obtained by synthesis [1]. Plants with bioactive properties are part of the important group of plants traditionally used to prevent and treat the development of fungi and bacteria [2, 3]. Essential oils from plants are highly concentrated compositions in chemical compounds with important bioactivity, which have several properties: antiseptic, antibacterial, immunostimulant, regenerative, anticancer [4-10]. Essential oils are liquid, volatile, clear, or colored, soluble in lipids and organic solvents, having densities generally lower than water [11-13]. They can be synthesized by all the organs of the plant, like buds, flowers, leaves, stems, twigs, seeds, fruits, roots, wood or bark and are kept in secretory cells, cavities, channels, epidermal cells or glandular trichomes [11]. The antifungal and antibacterial effects of the essential oils extracted from the plants can inhibit their growth by different mechanisms initiated by the constituent compounds [14, 15]. Essential oils are complex mixtures of low molecular weight compounds extracted from plants by hydrodistillation and various solvents. Terpenoids and polyphenols are major components that give the characteristic aroma and biological properties of essential oils. Essential oils are prescribed for a variety of problems in traditional medicine around the world. They are assigned various biological and pharmaceutical activities such as antibacterial and antifungal properties. Extensive phytochemical analyses have led to the identification and characterization of the major components of the essential oils that are of great interest especially for the pharmaceutical and cosmetic industries [16-21]. The purpose of this research is to obtain antifungal and antibacterial treatments based on natural compounds extracted from different essential oils like *Aetheroleum pini sylvestris*, *Aetheroleum geranii*, *Rosmarinus officinalis* for cotton and leather linings that could be used to obtain leather and fur articles (gloves, caps) and shoes with essential bioactive properties for health and environmental protection.

MATERIALS AND METHODS

Materials

Aetheroleum pini sylvestris, *Aetheroleum geranii*, and *Rosmarinus officinalis* essential oils were acquired from S.C. Herbavit S.R.L. Oradea, Romania. "Flower" emulsion (dodecandioyl-diglycine / microcrystalline cellulose (1:1 ratio) / silica / ethanol / water) was obtained by the National Research and Development Institute for Textiles and Leather - Division: Leather and Footwear Research Institute (INCDTP-ICPI), Bucharest. Cotton cloth was obtained in the National Research and Development Institute for Textiles and Leather - INCDTP Bucharest. Sheepskin lining leather was processed at the National Research and Development Institute for Textiles and Leather - Division: Leather and Footwear Research Institute (INCDTP-ICPI), Bucharest. *Candida albicans* ATCC 10231 fungi, *Escherichia coli* ATCC 25922 (Gram-negative bacteria) and *Staphylococcus aureus* ATCC 25923 (Gram-positive bacteria) biological materials are purchased from SC Sanimed International Impex SRL.

Methods

Obtaining Cotton Cloth and Sheepskin Lining Leathers

In order to obtain the treated samples of cotton cloth or sheepskin lining leathers (Table 1), they were immersed in 200% aqueous float with 5% essential oil (and 15% "flower" emulsion respectively), relative to the weight of the lining materials, at 25°C for 30 minutes with stirring and then drying at 25°C.

Table 1: The description of samples tested

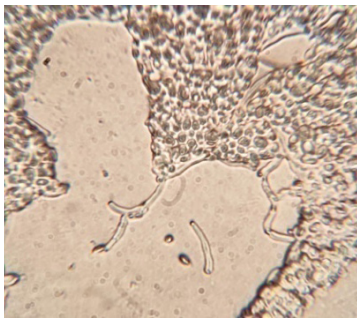
Control sheepskin lining leather	Sheepskin lining leather treated with geranium essential oil	Sheepskin lining leather treated with pine tree essential oil	Sheepskin lining leather treated with rosemary essential oil	Sheepskin lining leather treated with rosemary essential oil and "flower" emulsion
Control cotton cloth	Cotton cloth treated with geranium essential oil	Cotton cloth treated with pin tree essential oil	Cotton cloth treated with rosemary essential oil	Cotton cloth treated with rosemary essential oil and "flower" emulsion

Fourier Transform Infrared Spectroscopy-Attenuated Total Reflectance (FTIR-ATR) Analysis

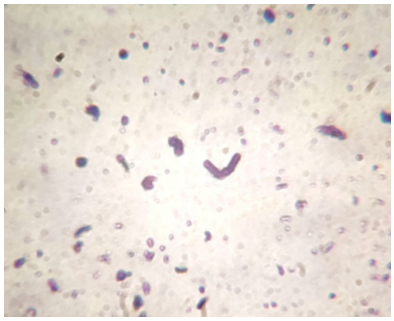
The chemical structures of investigated samples were investigated by use of FT-IR/ATR spectrometer (Jasco 4200) operating in the range of 4000-650 cm^{-1} with spectral resolution of 0.5 cm^{-1}. The device is equipped with a Michelson interferometer with incident angle of 45°, with Digital Signal Processing technology (DSP), cubic angular mirrors with self-aligning mechanism and standard thermostatic DLATGS Peltier detector used for the structure identification.

Microbiological Investigations

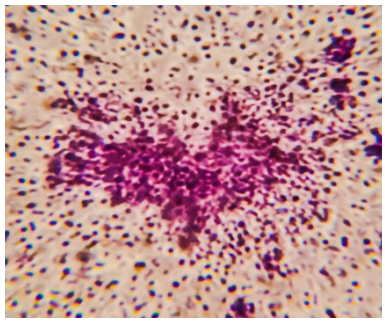
Antifungal activity was determined in the presence of Candida albicans ATCC 10231 according to ISO 20743: 2007 (Figure 1). The antibacterial activity was determined in the presence of Escherichia coli ATCC 25922 and Staphylococcus aureus ATCC 25923 (Figure 1) according to ISO 20743: 2007.



Candida albicans ATCC 10231



Escherichia coli ATCC 25922



Staphylococcus aureus ATCC 25923

Figure 1. Optical microscopy images for *Candida albicans*, *Escherichia coli*, and *Staphylococcus aureus*

Quantitative testing methods to determine the antifungal and antibacterial activity of the treated samples were performed according to ISO 20743:2007, Textiles — Determination of antibacterial activity of antibacterial finished products. The absorption method was used, which involves the inoculation of the bacteriological test inoculum directly on the treated samples.

The initial cell concentration was determined previously, by decimal dilutions (10^{-4}) in sterile deionized water, and from the last dilution, for each strain, 100 µL were taken and displayed on Sabouraud Dextrose Agar nutrient medium. The counts on the plate were carried out at 24h of incubation, these being kept as a reference for the cell developments in the control sample from the sample set. Thus, plates with a cell density similar to that of 10^{-4} dilution were considered to have similar Colony Forming Units (CFU) values (2.8x104 CFU/mL Escherichia coli, 3.42x104 CFU/mL for Staphylococcus aureus, and Candida albicans 2.48x104 CFU/mL).

The counts on the plate were made at 24h of incubation, in order to be able to detect the colony forming cellular units. The pictures

of the Petri dishes were made after 48h of incubation. To quantify the antibacterial and antifungal efficiency, the degree reduction of microorganisms and logarithmic reduction of each sample were calculated, based on the initial cell concentration.

Optical Microscopy Investigation

Optical microscopy images were captured using a Leica stereomicroscope S8AP0 model with optical fiber cold light source, L2, with three levels of intensity, and 40X magnification.

RESULTS AND DISCUSSION

Fourier Transform Infrared Spectroscopy-Attenuated Total Reflectance (FTIR-ATR) Analysis

The essential oils used in these experiments are rich in compounds with antifungal and antibacterial activity. Thus, geranium essential oil is rich in citronellol and geraniol, pine essential oil has predominantly limonene and α-pinene, and rosemary essential oil is rich in eucalyptol and camphor and α-pinene [11, 16, 18, 20] (Figure 2). The characteristic absorption bands for the functional groups of geranium, pine and rosemary essential oil are shown in Figures 3, 5, and 7.

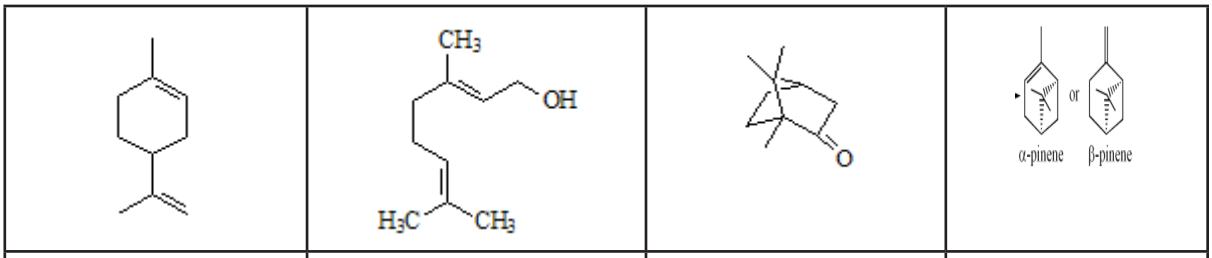
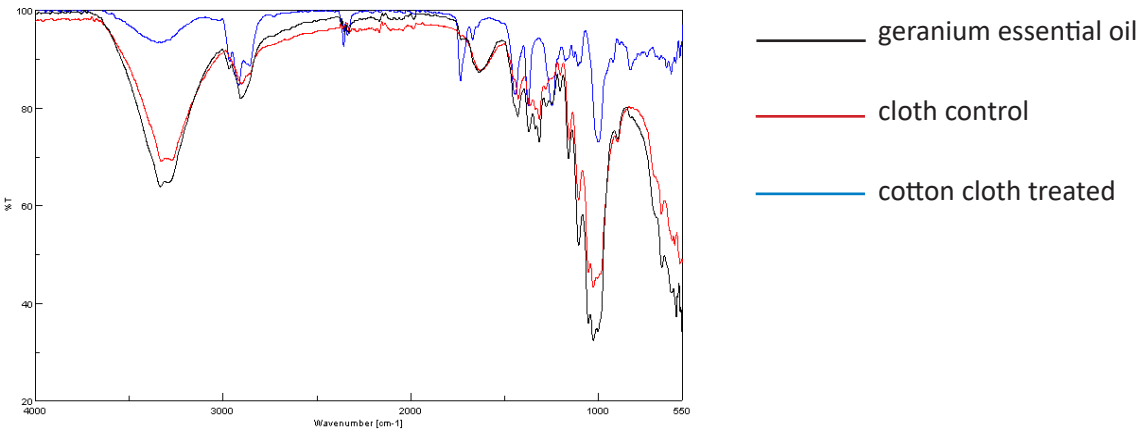
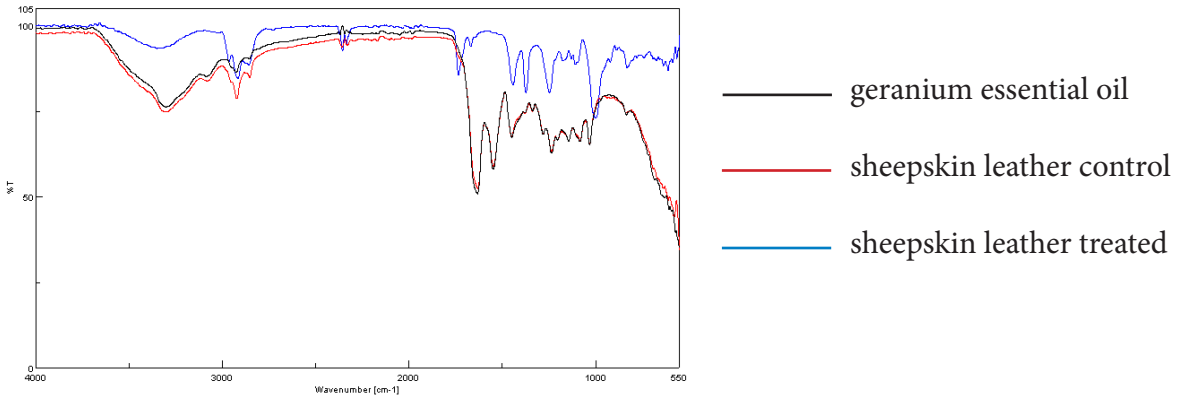


Figure 2. Main compounds of the essential oils used in experiments

From the FT/IR-ATR spectra in Figure 3(A) with geranium essential oil, control cotton cloth, cotton cloth treated with geranium essential oil and Figure 3(B) with geranium essential oil, control sheepskin leather, sheepskin leather treated with geranium essential oil the main peaks are recorded at: 830 cm^{-1} - corresponding to the C-H bond; 998 cm^{-1} - corresponding to the C-H bond; 1107 cm^{-1} - corresponding to the C-O bond, 1734 cm^{-1} - corresponding to the connection C = C; 2916 cm^{-1} - corresponding to the C-H bond; 3351 cm^{-1} - corresponding to the aromatic C-H bond.



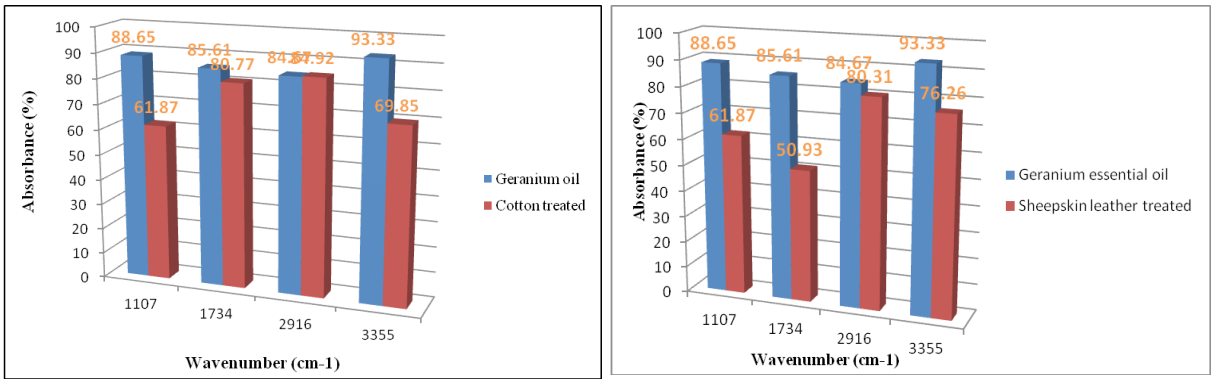
A



B

Figure 3. FTIR-ATR spectra for: (A) geranium essential oil, control cloth, cotton cloth treated with geranium essential oil, and (B) geranium essential oil, control sheepskin lining leather, sheepskin lining leather treated with geranium essential oil

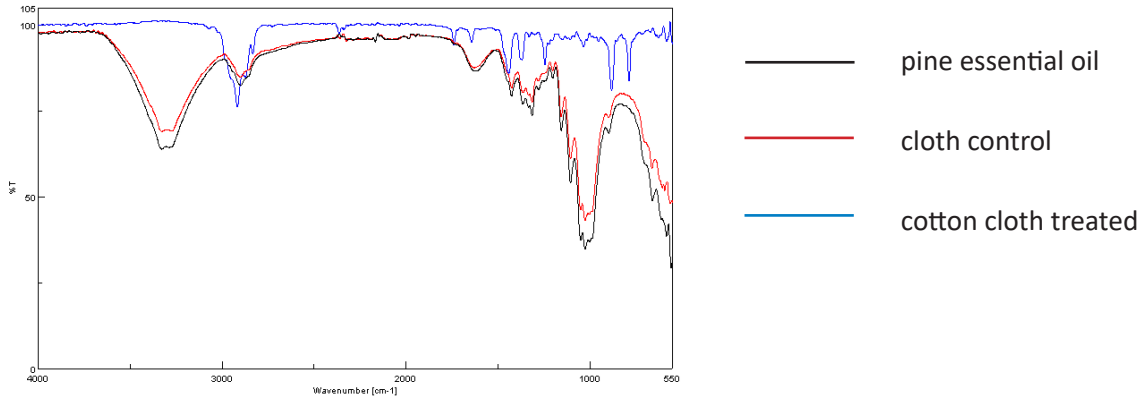
From the dependence of absorbance on the wavenumber, the fixation of the geranium essential oil compounds in the treated sample of cotton cloth (A) and sheepskin lining leather (B) is observed, through the decreasing of the absorbance values in the support samples compared to the value of the geranium essential oil (Figure 4).



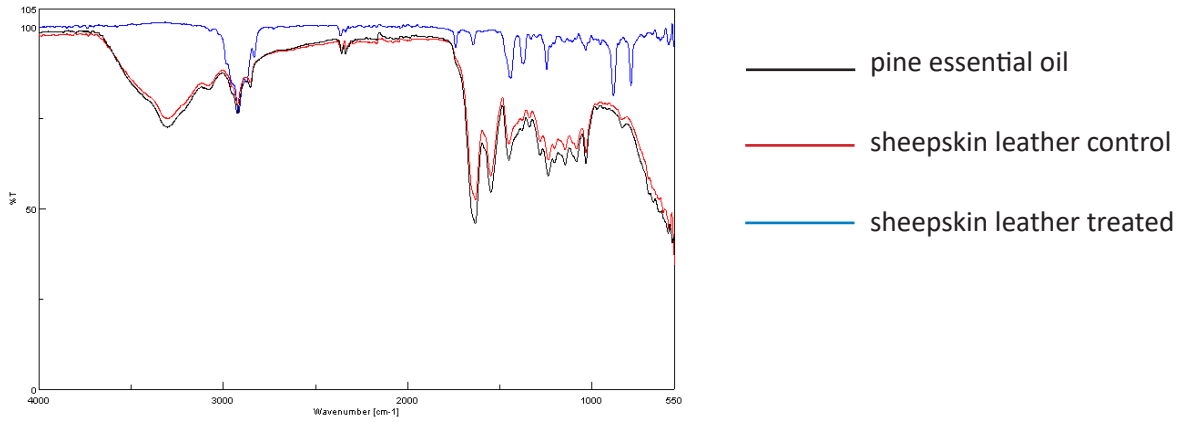
A) B)

Figure 4. Dependence of absorbance on the wavenumber for: (A) geranium essential oil, cotton cloth treated with geranium essential oil, and (B) geranium essential oil, sheepskin lining leather treated with geranium essential oil

From the FT/IR-ATR spectrum in Figure 5(A) with pine essential oil, control cotton cloth, cotton cloth treated with pine essential oil and Figure 5(B) with pine essential oil, control sheepskin leather, sheepskin leather treated with pine essential oil the main peaks are recorded at: 882 cm^{-1} - corresponding to the C-H bond; 954 cm^{-1} - corresponding to the C-H bond; 1033 cm^{-1} - corresponding to the C-O bond in the secondary alcohols; 1105 cm^{-1} - corresponding to the C-O-C bond; 1244 cm^{-1} - corresponding to the OH vibration; 1330 cm^{-1} - corresponding to the CH group and 1440 cm^{-1} - corresponding to the connection C = O.



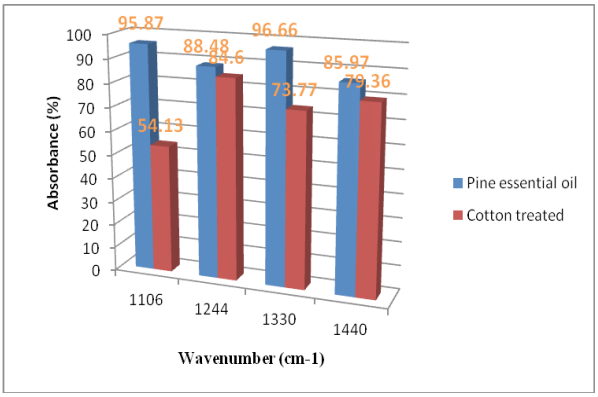
A



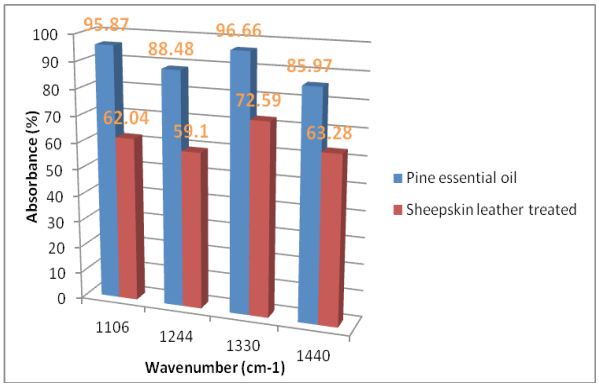
B

Figure 5. FTIR-ATR spectra for: (A) pine essential oil, control cloth, cotton cloth treated with pine essential oil, and (B) pine essential oil, control sheepskin lining leather, sheepskin lining leather treated with pine essential oil

From the dependence of absorbance on the wavenumber, the fixation of the pine essential oil compounds in the treated sample of cotton cloth (A) and sheepskin lining leather (B) is observed, through the decreasing of the absorbance values in the support samples compared to the value of the pine essential oil (Figure 6).



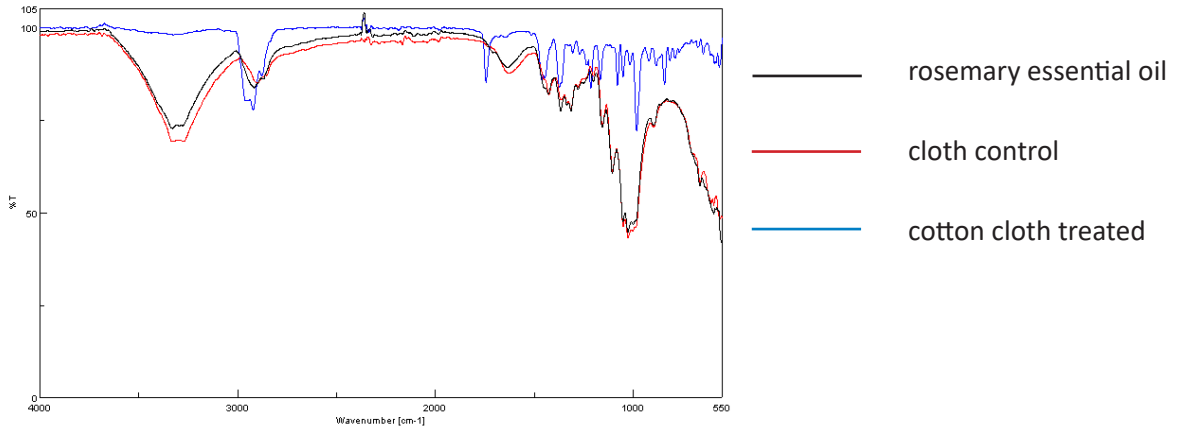
A)



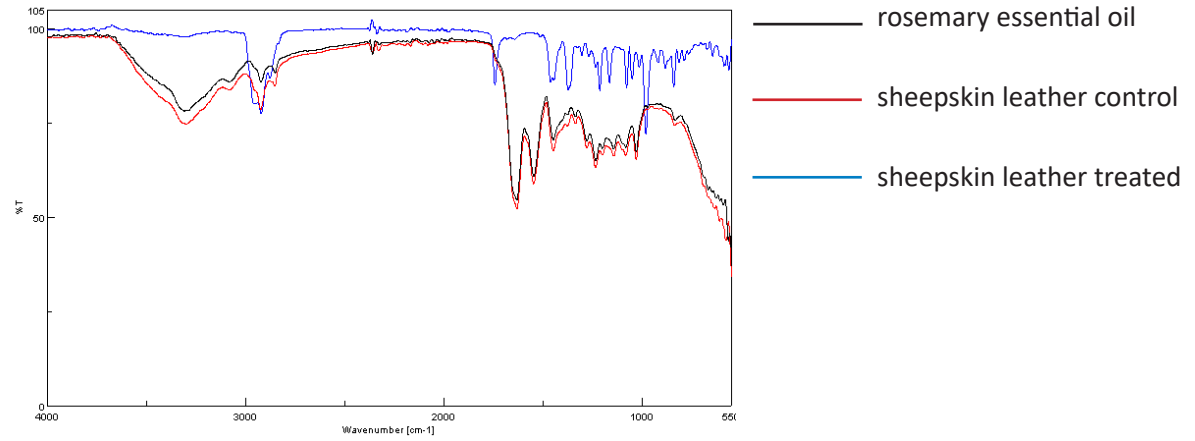
(B)

Figure 6. Dependence of absorbance on the wavenumber for: (A) pine essential oil, cotton cloth treated with pine essential oil, and (B) pine essential oil, sheepskin lining leather treated with pine essential oil

Figure 7 (A) showed the FTIR-ATR spectra with rosemary essential oil, control cotton cloth, and cotton cloth treated with rosemary essential oil, while Figure 7 (B) showed the spectra for rosemary essential oil, control sheepskin lining leather, and sheepskin lining leather treated with rosemary essential oil. The main peaks are recorded at: 885 cm^{-1}, and 992 cm^{-1}, 2878 cm^{-1}, and 3323 cm^{-1} (C-H bond); 1016 cm^{-1} (C-O bond in the secondary alcohols); 1166 cm^{-1} (C-O bond specific to terpenoids); 1743 cm^{-1} (C=C bond).



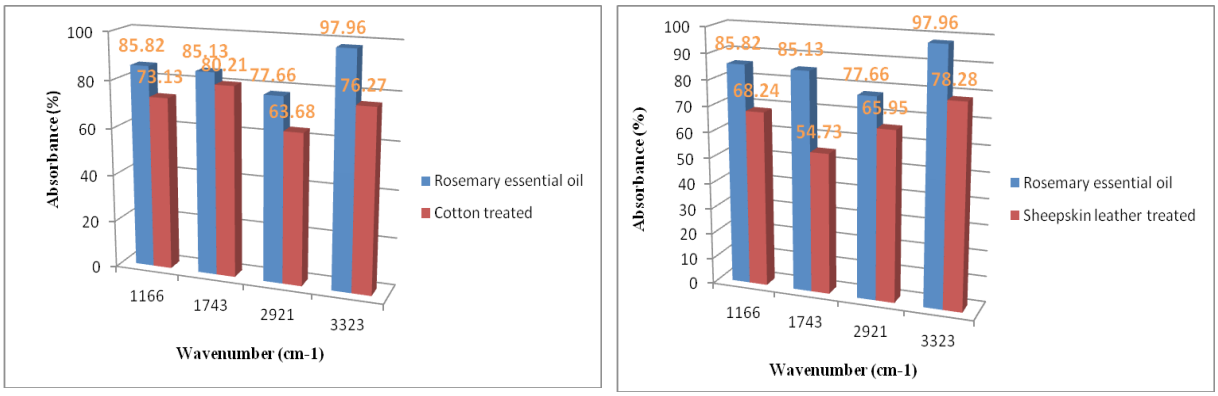
A



B

Figure 7. FTIR-ATR spectra for: (A) rosemary essential oil, control cloth, cotton cloth treated with rosemary essential oil (B) rosemary essential oil, control sheepskin lining leather, sheepskin lining leather treated with rosemary essential oil

From the dependence of absorbance on the wavenumber, the fixation of the rosemary essential oil compounds in the treated sample of cotton cloth (Figure 7(A) and sheepskin lining leather (Figure 7(B)) is observed, by decreasing of the absorbance values in the support samples compared to the value of the essential oil (Figure 8).



(A) (B)

Figure 8. Dependence of absorbance on the wavenumber for: (A) rosemary essential oil, cotton cloth treated with rosemary essential oil, and (B) rosemary essential oil, and sheepskin lining leather treated with rosemary essential oil

It is noted that the introduction of a mixture of tenside base constituted from a dodecandioyl-diglycine / sucrose diester (1:1 ratio) / ethanol / water in pine oil composition, as a nanostructured "flower" emulsion [22, 23], helps to fix the essential oil on both the cotton cloth and sheepskin lining leather treated (Figures 9 and 10).

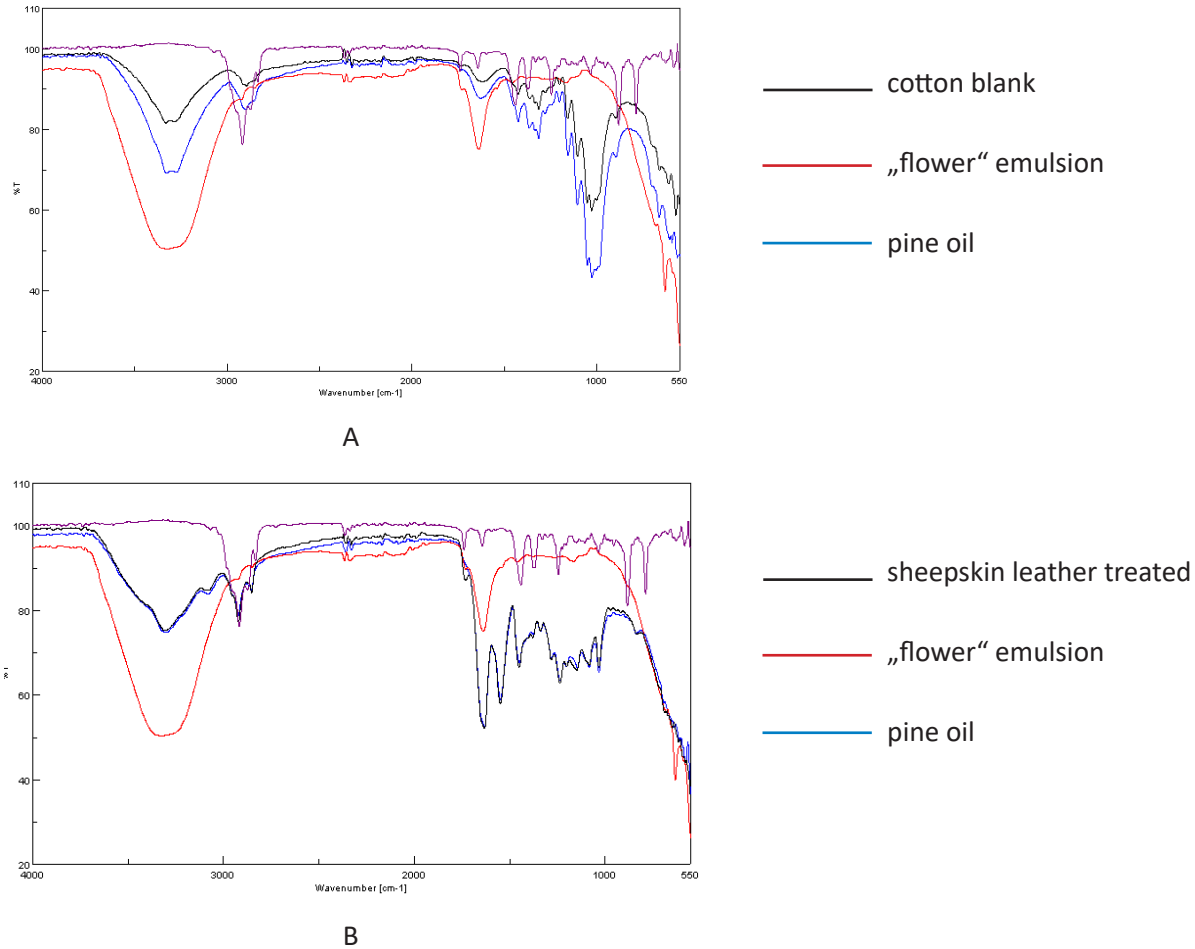


Figure 9. FT/IR-ATR spectra for: (A) pine essential oil, control cloth, cotton cloth treated with pine essential oil and "flower" emulsion, and (B) pine essential oil, control sheepskin lining leather, sheepskin lining leather treated with pine essential oil and "flower" emulsion

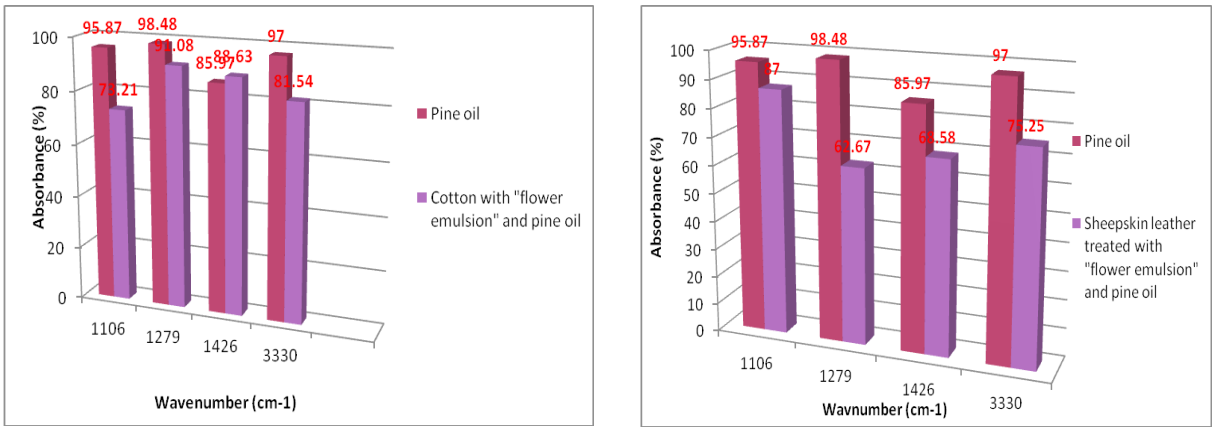


Figure 10. Dependence of absorbance on the wavenumber for: (A) pine essential oil, cotton cloth treated with pine essential oil and "flower" emulsion; (B) pine essential oil, sheepskin lining leather treated with pine essential oil and "flower" emulsion

Microbiological Investigations

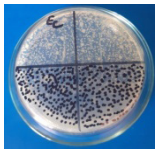
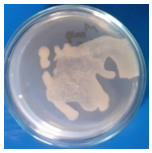
The microbiological tests were determined in the presence of *Candida albicans* fungus and *Escherichia coli* and *Staphylococcus aureus* bacteria.

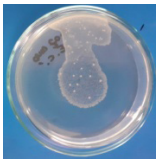
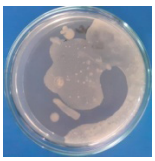
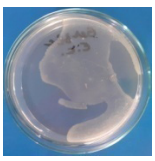
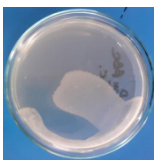
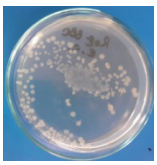
Tests on Escherichia coli

Escherichia coli (*E. coli*) is a group of gram-negative bacteria that normally resides in the gut of healthy people, but some strains can cause infections in the digestive tract and urinary tract [24]. *Escherichia coli* is the most common cause of urinary tract infections in the world, accounting more than 80%, both in the community and nosocomial cases [25]. In recent years, the emergence of same *Escherichia coli* resistant strains has made the treatment of patients infected with these organisms more difficult and complex [26, 27]. This *Escherichia coli* resistant strains have raised many concerns for physicians to choose the appropriate antibiotic in the treatment process [24].

The cotton cloth and sheepskin lining leather treated with geranium essential oil showed antibacterial properties against *Escherichia coli* with a reduction of 99.14% and 100% of colony forming units, followed by the essential oil of pine with a reduction of 98.43% and 99.96% and rosemary with a reduction of 98.21% and 94.86% (Table 2).

Table 2: Antibacterial activity of treated materials against *Escherichia coli*

Sample	Result	Image	R%	Log_{10} red.
Inoculum concentration	T_0= 2.8x10^4 CFU/mL		-	-
Control sample of sheepskin lining leather	T_0= 2.8x10^4 CFU/mL T_{24}= 2x10^2 CFU/mL		92.86	1.15
Sheepskin lining leather treated with geranium essential oil	T_0= 2.8X10^4 CFU/ML T_{24}= 4.4X10^1 CFU/ML		99.14	2.07

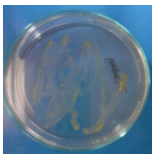
Sheepskin lining leather treated with pine tree essential oil	T_0= 2.8X10^4 CFU/ML T_{24}= 2.4X10^{1}CFU/ML		98.43	1.80
Sheepskin lining leather treated with rosemary essential oil	T_0=2.8x10^{4}CFU/mL T_{24}=5x10^{1}CFU/mL		98.21	1.75
Control sample of cotton cloth	T_0= 2.8x10^{4}CFU/mL T_{24}= 1.6x10^{2}CFU/mL		94.14	1.23
Cotton cloth treated with geranium essential oil	T_0=2.8x10^{4}CFU/mL T_{24}=0 CFU/mL		100	-
Cotton cloth treated with pine tree essential oil	T_0=2.8x10^{4}CFU/mL T_{24}=1x10^{1}CFU/mL		99.96	3.45
Cotton cloth treated with rosemary essential oil	T_0=2.8x10^{4}CFU/mL T_{24}=1.4x10^{2}CFU/mL		94.86	1.29

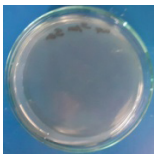
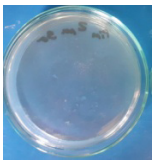
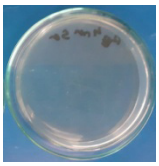
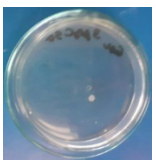
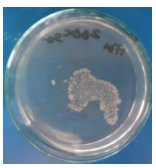
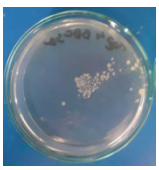
Tests on Staphylococcus aureus

Staphylococcus aureus is the most dangerous of all the many common staphylococcal bacteria. These gram-positive, sphere-shaped bacteria often cause skin infections, but they can cause pneumonia, heart valve infections and bone infections. These bacteria are spread by direct contact with an infected person, by the use of a contaminated object or by inhalation of infected drops dispersed by sneezing or coughing. Skin infections are common, but bacteria can spread through the bloodstream and can infect distant organs [28-34].

The cotton cloth and sheepskin lining leathers treated with geranium essential oil showed very good resistance against *Staphylococcus aureus* (with 100% reduction) followed by rosemary essential oil (with 100% and 96.20% reduction) and pine essential oil (with 100% and 81.29% reduction), as can be seen in Table 3.

Table 3: Antibacterial activity of treated materials against *Staphylococcus aureus*

Sample	Result	Image	R%	Log_{10} red.
Inoculum concentration	T_0= 3.42x10^4 CFU/mL		-	-

Control sample of sheepskin lining leather	T_0= 3.42x10^4 CFU/mL T_{24}=7.4x10^2 CFU/mL		78,36	0,66
Sheepskin lining leather treated with geranium essential oil	T_0= 3.42x10^4 CFU/mL T_{24}= 4.4x10^1 CFU/mL		100	-
Sheepskin lining leather treated with pine tree essential oil	T_0= 3.42x10^4 CFU/mL T_{24}= 2.4x10^{1}CFU/mL		100	-
Sheepskin lining leather treated with rosemary essential oil on leather	T_0= 3.42x10^4 CFU/mL T_{24}= 5x10^1 CFU/mL		100	-
Control sample of cotton cloth	T_0= 3.42x10^4 CFU/mL T_{24}=8.4x10^2 CFU/mL		75.44	0.61
Cotton cloth treated with geranium essential oil	T_0 = 3.42x10^4 CFU/mL T_{24} = 0 CFU/mL		100	-
Cotton cloth treated with pine tree essential oil	T_0 = 3.42x10^4 CFU/mL T_{24} = 6.4x10^2 CFU/mL		81.29	0.73
Cotton cloth treated with rosemary essential oil	T_0= 3.42x10^4 CFU/mL T_{24}= 1.3x10^2 CFU/mL		96.20	1.42

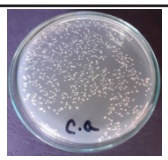
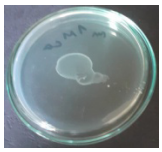
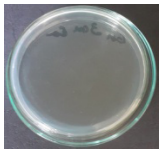
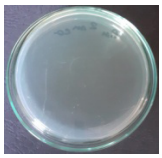
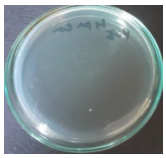
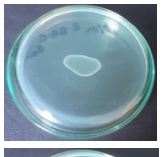
Tests on Candida albicans

Candida albicans is a diploid fungus that grows both as yeast and filamentous cell and a causative agent of opportunistic oral and genital infections in humans [35, 36], and candidal onychomycosis, a nail plate infection. At the same time, it can infect the skin, mucous membranes, nails and gastrointestinal tract. The incidence of candidal infection is increasing due to the increasing number of individuals with suppressed immune function caused by malignancy, antibiotic use, HIV infection, steroid use or chemotherapy [35, 36]. In addition, common health problems, including diabetes and obesity, may also predispose individuals to candidal skin infection [35, 36]. *Candida albicans* is a major cause of nosocomial infections (infections acquired during medical care); contaminated health workers and biomaterials are common sources of these infections [37]. *Candida albicans* is the most common fungus isolated from surgical wounds, so that candidal infection may delay wound

healing [38, 39]. In addition, *Candida albicans* is the most commonly isolated fungal species in patients in intensive care units (ICU); *Candida albicans* infection is associated with the mortality of patients in ICU [40].

Cotton cloths and sheepskin lining leathers treated with geranium essential oil showed a reduction of 100% of colony forming units of *Candida albicans* followed by the treated materials with pine essential oil with reduction of 99.68% and 100% respectively, and then rosemary with reduction of 98.79% and 100% respectively (Table 4).

Table 4: Antifungal activity of treated materials against *Candida albicans*

Sample	Result	Image	R%	Log_{10} red.
Inoculum concentration	T_0= 2.48x10^4 UFC/mL		-	-
Control sample of sheepskin lining leather	T_0= 2.48X10^4 CFU/ML T_{24}= 1.4X10^2 CFU/ML		94.35	1.25
Sheepskin lining leather treated with geranium essential oil	T_0= 2.48X10^4 CFU/ML T_{24}= 0 CFU/ML		100	-
Sheepskin lining leather treated with pine tree essential oil	T_0= 2.48X10^4 CFU/ML T_{24}= 0 CFU/ML		100	-
Sheepskin lining leather treated with rosemary essential oil	T_0= 2.48x10^4 CFU/mL T_{24}= 0 CFU/mL		100	-
Control sample of cotton cloth	T_0= 2.48x10^4 CFU/mL T_{24}= 1x10^2 CFU/mL		95.97	1.39
Cotton cloth treated with geranium essential oil	T_0= 2.48x10^4 CFU/mL T_{24}=0 CFU/mL		100	-
Cotton cloth treated with pine tree essential oil	T_0= 2.48x10^4 CFU/mL T_{24}= 8 CFU/mL		99.68	2.49
Cotton cloth treated with rosemary essential oil	T_0= 2.48x10^4 CFU/mL T_{24}=3x10^1 CFU/mL		98.79	1.92

CONCLUSIONS

Cotton cloth and sheepskin leather linings treated with geranium, pine and rosemary essential oils were obtained. FTIR-ATR analysis showed the characteristic absorption bands for the functional groups of compounds from geranium, pine and rosemary essential oils in the cotton cloth and sheepskin leather linings treated samples. Use of a nanostructured "flower" emulsion based on tensides in treatment fixed the essential oil on cotton cloth and sheepskin leather linings treated. Antifungal and antibacterial activity of essential oils of geranium (*Aetheroleum geranii*) pine (*Aetheroleum pini sylvestris*) and rosemary (*Rosmarinus officinalis*) were tested against *Candida albicans* fungus, Gram-negative bacteria *Escherichia coli* and Gram-positive bacteria *Staphylococcus aureus* on leather and cotton lining materials treated. The appearance and development of fungi and bacteria were inhibited by the high antifungal and antibacterial activity of the compounds of the essential oils used in experiments. The strongest biocidal activity was found for materials treated with geranium essential oil followed by pine and rosemary essential oils. The use of natural compounds with antifungal and antibacterial activity has high efficacy and is friendly to humans and the environment.

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REFERENCES

1. Niculescu, O., Leca, M., Moldovan, Z., Deselnicu, D.C., Research on Obtaining Products for Fragrance and Biological Protection on Natural Leathers and Furs, *Rev Chim - Bucharest*, **2015**, 66, 12, 1956-1959.
2. Saberali, S.F., Moradi, M., Effect of salinity on germination and seedling growth of *Trigonella foenum-graecum*, *Dracocephalum moldavica*, *Satureja hortensis* and *Anethum graveolens*, *Journal of the Saudi Society of Agricultural Sciences*, 2019, 18, 316–323, https://doi.org/10.1016/j.jssas.2017.09.004.
3. Valdiani, A., Abdul, M., Soon, K., Tan, G., Nain-e Havandi *Andrographis paniculata* present yesterday, absent today: a plenary review on underutilized herb of Iran's pharmaceutical plants, *Mol Biol Rep*, **2012**, 39, 5, 5409–5424, https://doi.org/10.1007/s11033-011-1341-x.
4. Surdu, L., Stelescu, M.D., Mănăila, E., Nicula, G., Iordache, O., Dincă, L.C., Berechet, M.D., Vameşu, M., Gurău, D., The improvement of the resistance to *Candida albicans* and *Trichophyton interdigitale* of some woven fabrics based on cotton, *Bioinorg Chem Appl*, **2014**, https://doi.org/10.1155/2014/763269.
5. Chirila, C., Deselnicu, V., Berechet, M.D., Footwear protection against fungi using thyme essential oil, Leather and Footwear Journal, **2017**, 17, 3, 173-178, https://doi.org/10.24264/lfj.17.3.7.
6. Chirila, C., Deselnicu, V., Berechet, M.D., Study Regarding Footwear Protection against Fungi with Essential Oils, 4th International Leather Engineering Congress "Innovative Aspects For Leather Industry", October 19-20, **2017**, Izmir, Turkey, 179-183.
7. Niculescu, O., Simion, D., Berechet, M.D., Gurau, D., Chirila, C., Testing of environmentally friendly materials based on essential oils to protect against damage from natural leather fungi and bacteria, 19th International Symposium The Environment and the Industry - SIMI **2016**, 13-14.10.2016, Bucharest, ISSN 2344-3898, 129-134.

8. Chirila, C., Berechet, M.D., Deselnicu, V., Thyme essential oil as natural leather preservative against fungi, Proceedings of The 6th International Conference on Advanced Materials and Systems - ICAMS **2016**, 20-22.10.2016, Bucharest, 227-232, https://doi.org/10.24264/icams-2016.II.6.

9. Berechet, M.D., Chirila, C., Deselnicu, V., Antifungal activity of thyme essential oil on woolen sheepskins, Proceedings of The 6th International Conference on Advanced Materials and Systems - ICAMS **2016**, 20-22.10.2016, Bucharest, 203-208, https://doi.org/10.24264/icams-2016.II.2.

10. Berechet, M.D., Chirila, C., Deselnicu, V., Antifungal Activity of some Essential Oils on Cotton Fabrics, Proceedings of The 6th International Conference on Advanced Materials and Systems - ICAMS **2016**, 20-22.10.2016, Bucharest, 197-202, https://doi.org/10.24264/icams-2016.II.1.

11. Mănăila, E., Berechet, M.D., Stelescu, M.D., Crăciun, G., Mihaiescu, D.E., Purcareanu, B., Călinescu, I., Fudulu, A., Radu, M., Comparison between chemical compositions of some essential oil obtained by hydrodistillation from citrius peels, *Rev Chim - Bucharest*, **2016**, 67, 1, 106-112.

12. Berechet, M.D., Călinescu, I., Stelescu, M.D., Mănăila, E., Crăciun, G., Purcareanu, B., Mihaiescu, D.E., Roșca, S., Fudulu, A., Niculescu-Aron, I.G., Radu, M., Composition of the essential oil of *Rosa Damascena* Mill. Cultivated in Romania, *Rev Chim - Bucharest*, **2015**, 66, 12, 1986-1991.

13. Berechet, M.D., Stelescu, M.D., Manaila, E., Craciun, G., Chemical composition of the essential oil of *Artemisia Absinthium* from Romania, *Rev Chim - Bucharest*, **2015**, 66, 11, 1814-1818.

14. Modarresi, M., Farahpour, M.R., Baradaran, B., Topical application of *Mentha piperita* essential oil accelerates wound healing in infected mice model, *Inflammopharmacology*, **2019**, 27, 3, 531–537, https://doi.org/10.1007/s10787-018-0510-0.

15. Kaur, G.J., Arora, D.S., Bioactive potential of *Anethum graveolens*, *Foeniculum vulgare* and *Trachyspermum ammi* belonging to the family Umbelliferae – Current status, *J Med Plants Res*, **2010**, 4, 87–94, https://doi.org/10.5897/JMPR09.018.

16. Hassanvanda, F., Nejada, A.R., Fanourakis, D., Morphological and physiological components mediating the silicon-induced enhancement of geranium essential oil yield under saline conditions, *Ind Crop Prod*, **2019**, 134, 19-25, https://doi.org/10.1016/j.indcrop.2019.03.049.

17. Kartnig, T., Still, F., Reinthalerb, F., Antimicrobial activity of the essential oil of young pine shoots v icea abies L.), *J Ethnopharmacol*, **1991**, 35, 155-151, Elsevier Scientific Publishers Ireland Ltd., https://doi.org/10.1016/0378-8741(91)90067-N.

18. López, M.H., Correa-Pacheco, Z.N., Bautista-Baños, S., Zavaleta-Avejar, L., Benítez-Jiménez, J.J., Sabino-Gutiérrez, M.A., Ortega-Gudiño, P., Bio-based composite fibers from pine essential oil and PLA/PBAT polymer blend. Morphological, physicochemical, thermal and mechanical characterization, *Mater Chem Phys*, **2019**, 234, 345-353, https://doi.org/10.1016/j.matchemphys.2019.01.034.

19. Martin-Piñero, M.J., Ramirez, P., Muñoz, J., Alfaro, M.C., Development of rosemary essential oil nanoemulsions using a wheat biomass-derived surfactant, *Colloids Surf B Biointerfaces*, **2019**, 173, 486-492, https://doi.org/10.1016/j.colsurfb.2018.10.024.

20. Alizadeh, L., Abdolmaleki, K., Nayebzadeh, K., Shahin, R., Effects of tocopherol, rosemary essential oil and *Ferulago angulata* extract on oxidative stability of mayonnaise during its shelf life: A comparative study, *Food Chem*, **2019**, 285, 46-52, https://doi.org/10.1016/j.foodchem.2019.01.028.

21. Berechet, M.D., Manaila, E., Stelescu, M.D., Craciun, G., The composition of essential oils obtained from *Achilea Millefolium* and *Matricaria Chamomilla* L., originary from Romania, *Rev Chim - Bucharest*, **2017**, 68, 12, 2787-2795.

22. Simion, D., Gaidau, C., Jianzhong, M., Zhang, W., Qunna, X., New hybrid nanocomposite applied to the leather finishing process, with favourable environmental impact, 16-19 October **2018**, Xi'an, China, Conference Handbook, 38.

23. Simion, D., Gaidau, C., Berechet, D., New micro and nano-structured emulsions based on collagen and keratin hydrolysates, International Scientific Conference, Innovative solutions for sustainable development of textiles and leather industry, 25th-26th of May 2018, Oradea, Romania, Annals of the University of Oradea: Fascicle of Textiles, Leatherwork, vol. XIX, **2018**, no.1, ISSN 1843-813x, 149-154.

24. Zaniania, F.R., Savarib, M., Montazerib, E.A., Nejadc, R.M., Khoshnoodd, S., Distribution of fosfomycin and AmpC β-lactamase resistance genes in urinary *Escherichia coli* isolates obtained from patients admitted to an educational hospital in Ahvaz, southwest Iran, *Gene Rep*, **2019**, 17, 100533, https://doi.org/10.1016/j.genrep.2019.100533.

25. Gajdacs, M., Abrok, M., Lazar, A., Burian, K., Comparative epidemiology and resistance trends of common urinary pathogens in a tertiary-care hospital: a 10-year surveillance study, *Medicina*, **2019**, 55, 7, 356, https://doi.org/10.3390/medicina55070356.

26. Ramírez-Castillo, F.Y., Moreno-Flores, A.C., Avelar-González, F.J., Márquez-Díaz, F., Harel, J., Guerrero-Barrera, A.L., An evaluation of multidrug-resistant *Escherichia coli* isolates in urinary tract infections from Aguascalientes, Mexico: crosssectional study, *Ann Clin Microbiol Antimicrob*, **2018**, 17, 1, 34, https://doi.org/10.1186/s12941-018-0286-5.

27. Alkhudhairy, M.K., Saki, M., Seyed–Mohammadi, S., Jomehzadeh, N., Khoshnood, S., Moradzadeh, M., Yazdansetad, S., Integron frequency of *Escherichia coli* strains from patients with urinary tract infection in southwest of Iran, *J Acute Dis*, **2019**, 8, 3, 113–117, https://doi.org/10.4103/2221-6189.259110.

28. Gatadia, S., Madhavia, Y.V., Choprab, S., Nanduria, S., Promising antibacterial agents against multidrug resistant *Staphylococcus aureus*, *Bioorg Chem*, **2019**, 92, 103252, https://doi.org/10.1016/j.bioorg.2019.103252.

29. Sugden, R., Kelly, R., Davies, S., Combating antimicrobial resistance globally, *Nat Microbiol*, **2016**, 16187, https://doi.org/10.1038/nmicrobiol.2016.187.

30. Ventola, C.L., The antibiotic resistance crisis: part 2: management strategies and new agents, *Pharm Ther*, **2015**, 40, 344–352.

31. Fridkin, S.K., Steward, C.D., Edwards, J.R., Pryor, E.R., McGowanJr, J.E., Archibald, L.K., Gaynes, F.C., Tenover, R.P., P.I.C.A.R.E. Hospitals, Surveillance of antimicrobial use and antimicrobial resistance in United States hospitals: project ICARE phase 2, *Clin Infect Dis*, **1999**, 29, 245–252, https://doi.org/10.1086/520193.

32. Toner, E., Adalja, A., Gronvall, G.K., Cicero, A., Inglesby, T.V., Antimicrobial resistance is a global healt hemergency, *Health Secur*, **2015**, 13, 3, 153–155, https://doi.org/10.1089/hs.2014.0088.

33. Rice, L.B., Federal funding for the study of antimicrobial resistance in nosocomial pathogens: noESKAPE, *J Infect Dis*, **2008**, 197, 1079–1081, https://doi.org/10.1086/533452.

34. Bassetti, M., Merelli, M., Temperoni, C., Astilean, A., New antibiotics for bad bugs: where are we? *Ann Clin Microbiol Antimicrob*, **2013**, 12, 22, https://doi.org/10.1186/1476-0711-12-22.

35. Ryan, K.J., Ray, C.G., Eds., Sherris Medical Microbiology, McGraw Hill, 4th edition, **2004**.

36. d'Enfert, C., Hube, B., Candida: Comparative and Functional Genomics, Caister Academic Press, **2007**.

37. Pfaller, M.A., Nosocomial candidiasis: emerging species, reservoirs, and modes of transmission, *Clin Infect Dis*, **1996**, 22, 2, S89–S94, https://doi.org/10.1093/clinids/22.Supplement_2.S89

38. Kaya, D., Agartan, C.A., Yucel, M., Fungal agents as a cause of surgical wound infections: an overview of host factors, *Wounds*, **2007**, 19, 8, 218–222.

39. Giandoni, M.B., Grabski, W.J., Cutaneous candidiasis as a cause of delayed surgical wound healing, *J Am Acad Dermatol*, **1994**, 30, 6, 981–984, https://doi.org/10.1016/S0190-9622(94)70122-9.

40. Picazo, J.J., Gonz´alez-Romo, F., Candel, F.J., Candidemia in the critically ill patient, *Int J Antimicrob Agents*, **2008**, 32, 2, S83–S85, https://doi.org/10.1016/S0924-8579(08)70005-0.