

# Silver nanoparticles misting - an innovative method of archaeological object disinfection

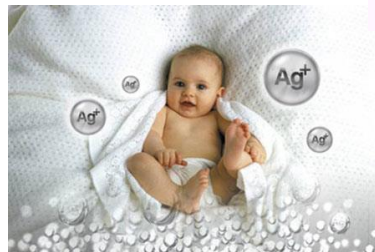
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**Anna Otlewska, Ph.D., Eng.**

Institute of Fermentation Technology and Microbiology  
Lodz University of Technology



# Silver nanoparticles application

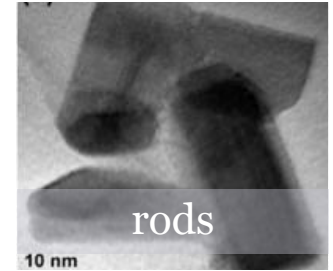
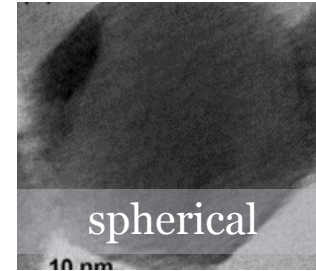
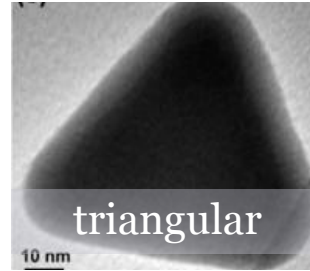
- filters for air purification
- filters for water purification
- stomatology
- dietary supplements
- implants
- textiles
- cosmetics, detergents
- home appliance
- computer hardware
- coatings, grouts, adhesives
- food packaging
- papermaking
- disinfection of historical object



# Silver nanoparticles (AgNPs)

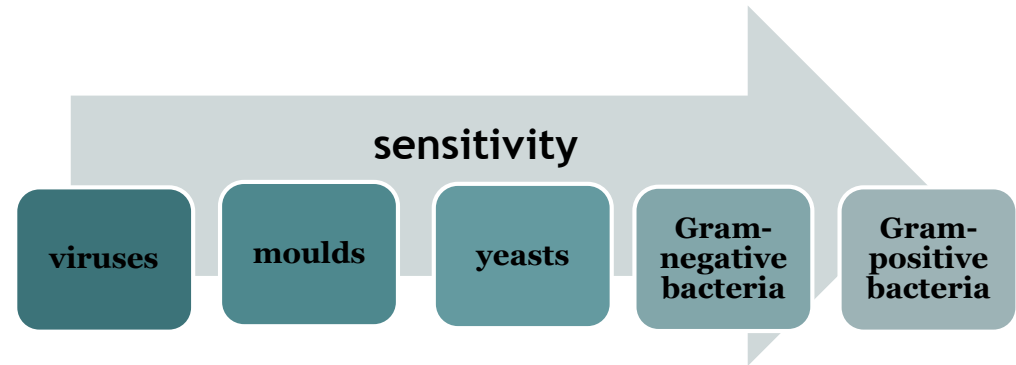
## Synthesis

- chemical
- physical
- biological

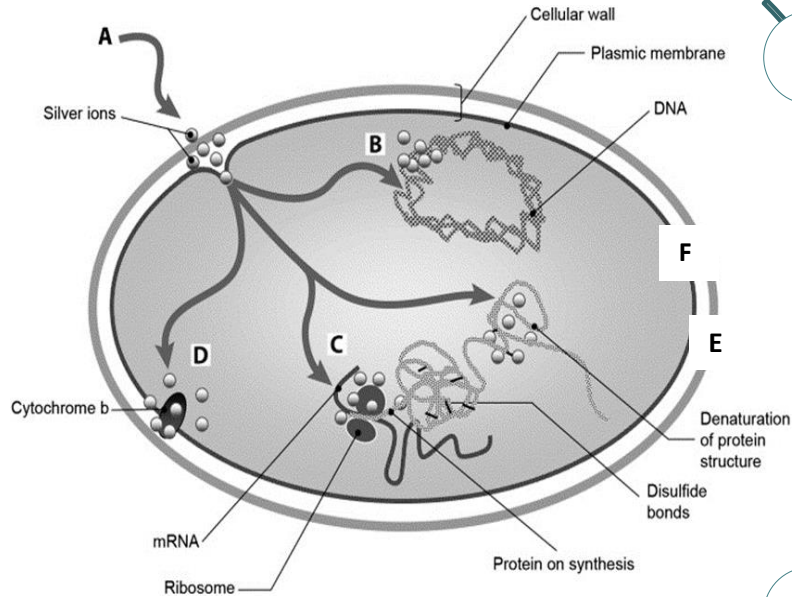


## Effectiveness

- shape
- form
- size
- concentration
- microorganisms



# Mechanism of antibacterial action of AgNPs



**A dysfunction of transport to the cell**

**B inhibition of DNA replication**

**C loss of the biological activity of the amino acid**

**D structural and functional changes in the cell membrane**

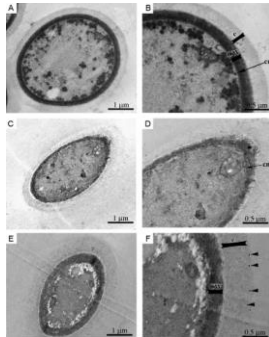
**E disturbance of the cell membrane electric potential**

**F outflow of protons and certain metabolites through the cytoplasmic membrane**

# Mechanism of antifungal action of AgNPs

## Yeasts

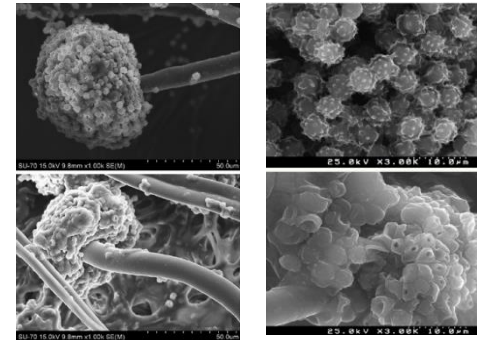
- changes of cell wall functions and structure
- creation of "pits" in the cell membrane
- disturbances of electric potential
- inhibition of budding process



Cells of *Cryptococcus neoformans*  
after AgNPs treatment

## Moulds

- inhibition of sporulation process
- changes of cell wall functions and structure
- cytoplasm outflow



Conidiophore and spores  
of *Aspergillus niger* after AgNPs treatment

# Aim and scope

Optimalization of AgNPs misting disinfection and its influence on microorganisms and disinfected materials.

1. Determination of the sensitivity of pure culture collection microorganisms and isolates from historical objects surfaces on the silver nanoparticles preparation.
2. Parameters optimization of the of effective disinfection of technical and historical materials with silver nanoparticles misting.
3. Assessment of the effectiveness and durability of disinfection depending on the microorganism, technical or historical material.
4. Analysis of the disinfection influence on mechanical and optical parameters of technical materials before and after artificial ageing.

# Materials

## Technical:

- paper\* (Sa, Hmp, Sy, CTMP, GW)
- leather (cowhide, dyed)
- textiles (wool, silk, cotton, linen)
- wood (beech, oak, pine)

## Historical:

- canvas (historical painting)
- parchment (conservation materials)
- wood (church floor; 17th c.)
- paper (map; 18th - 19th c.)
- textiles (wool, cotton, sisal; 13th – 15th c.)
- ceramics (6th – 13th c.)



Wool



Ceramics



Cotton

\*Sa - bleached pine kraft pulp; Hmp - bleached hemp kraft pulp; Sy - bleached spruce sulphite pulp; CTMP - chemi-thermomechanical pulp; GW - bleached groundwood from spruce (GW)

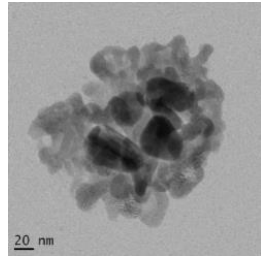
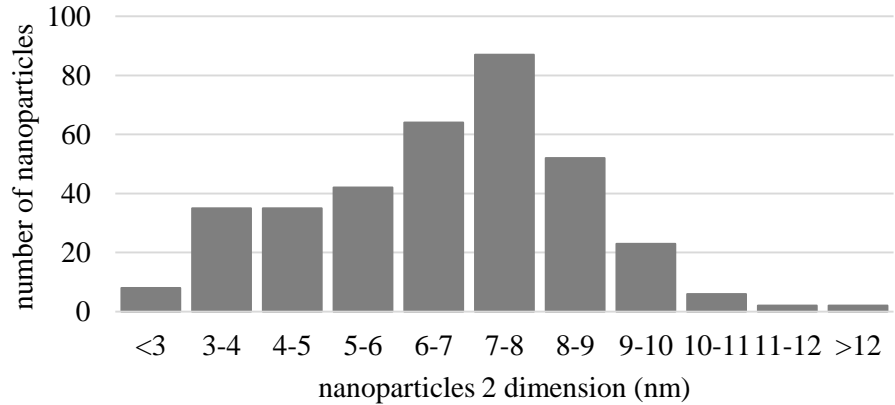
# Silver nanoparticles

Silver nanoparticles 1

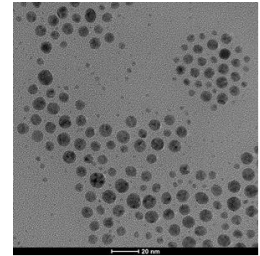
chemical reduction AgNO <sub>3</sub> , reductor: sodium citrate; stabilizer: polyvinylpyrrolidone
concentration: 90 ppm
particle size: 10-80 nm (10-15 nm – 60-70%; 50-80 nm – 30-40%)
Mennica Polska S.A.

Silver nanoparticles 2

thermal decomposition of silver compounds; stabilizer: paraffins
concentration: 1000 ppm
particle size: 3-8 nm
Amepox sp. z o.o.



SEM image of nanosilver 1



TEM image of nanosilver 2



# Microorganisms

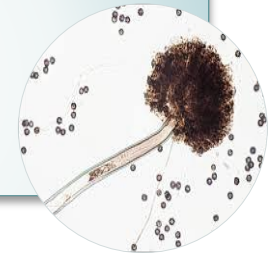
- *Aneurinibacillus aneurinilyticus*
- *Brevibacillus laterosporus*
- *Bacillus subtilis*
- *Bacillus megaterium*
- *Bacillus pumilus*
- *Bacillus licheniformis*
- *Sphingomonas paucimobilis*
- *Micrococcus* sp.
- *Micrococcus flavus*
- *Pseudomonas aeruginosa*
- *Staphylococcus aureus*
- *Staphylococcus lentus*
- *Staphylococcus xylosus*
- *Nocardia* sp.
- *Escherichia coli* (ATCC 10536)
- *Staphylococcus aureus* (ATCC 6538)
- *Bacillus subtilis* (NCAIM 01644)

## BACTERIA



- *Alternaria alternata*
- *Aspergillus versicolor*
- *Aspergillus niger*
- *Cladosporium cladosporioides*
- *Cladosporium herbarum*
- *Cladosporium macrocarpum*
- *Mucor racemosus*
- *Penicillium digitatum*
- *Penicillium carneum*
- *Penicillium crustosum*
- *Penicillium radicola*
- *Rhizopus nigricans*
- *Candida sphaerica*
- *Rhodotorula* sp.
- *Rhodotorula mucilaginosa*
- *Aspergillus niger* (ATCC 16404)
- *Penicillium chrysogenum* (ŁOCK 0531)
- *Candida albicans* (ATCC 10231)

## FUNGI



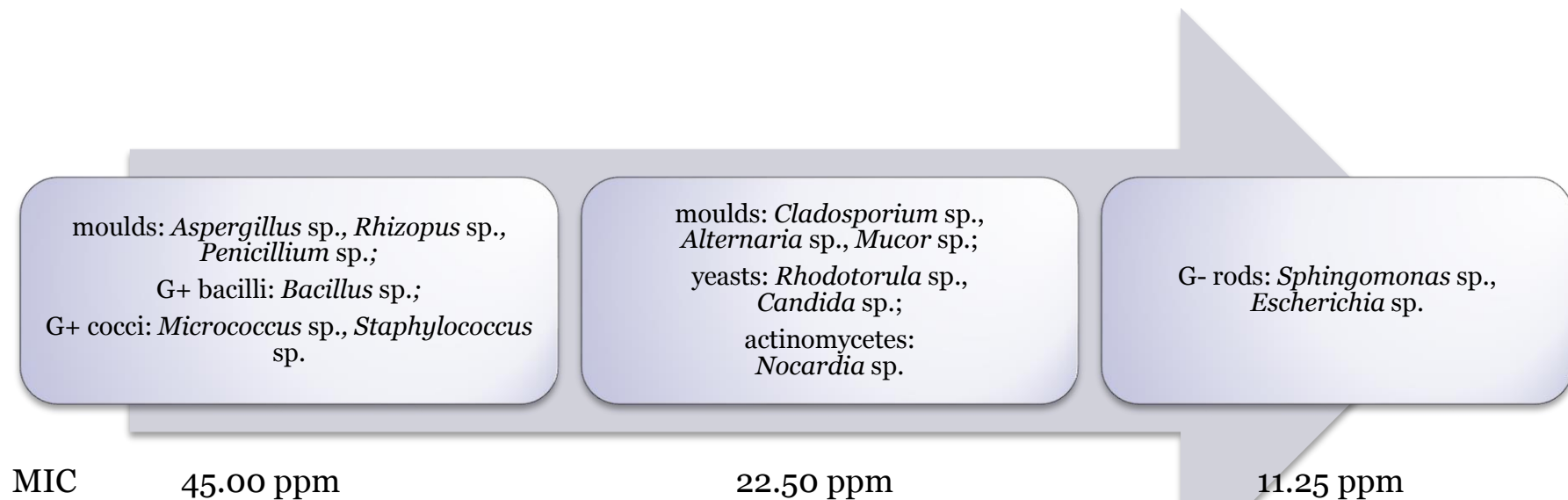
# Methods

Analysis	Method / Standard
<b>Silver nanoparticles</b>	
Characterization of preparation	SEM; TEM
Determination of AgNPs content	FAAS; LA-ICP-TOF-MS
<b>Microorganisms</b>	
Choosing the conditions for disinfection Evaluation of the effectiveness and durability of the disinfection technical materials and historical objects	AATCC Test Method 100-2012
Determination of microbial sensitivity (MIC and MBC)	ASTM E2149 – 01
<b>Materials</b>	
Assessment of mechanical parameters (breaking, elongation, tear, compression)	ISO 13934-1:1999 (textiles); ISO 3376:2005 (leather); ISO 20187:1993 (paper); ISO 1924-1:1998 (paper); BS EN 21974:2002 (paper); BS EN 384:2004 (wood)
Estimation of colour parameters	Metoda Tappi T 524 om-94 (paper); ISO 2470:1999 (paper); ISO 105-J01:2002 (leather, textiles); Metoda SCI (wood)

# Microbial sensitivity to AgNPs

Microorganisms	Origin	MIC (ppm)	MBC (ppm)
<i>Staphylococcus aureus</i>	ATCC	11.25	22.50
	Museum 1	22.50	45.00
<i>Bacillus subtilis</i>	ATCC	22.50	> 45.00
	Archives	22.50	> 45.00
	Museum 2	45.00	> 45.00
<i>Escherichia coli</i>	ATCC	11.25	22.50
<i>Nocardia</i> sp.	Library	11.25	22.50
<i>Aspergillus niger</i>	ATCC	22.50	45.00
	Museum 2	45.00	45.00
<i>Candida albicans</i>	ATCC	11.25	22.50
<i>Candida sphaerica</i>	Library	22.50	22.50

# Microbial sensitivity to AgNPs



moulds: *Aspergillus* sp., *Rhizopus* sp.,  
*Penicillium* sp.;

G+ bacilli: *Bacillus* sp.;

G+ cocci: *Micrococcus* sp., *Staphylococcus*  
sp.

moulds: *Cladosporium* sp.,  
*Alternaria* sp., *Mucor* sp.;

yeasts: *Rhodotorula* sp.,  
*Candida* sp.;

actinomycetes:  
*Nocardia* sp.

G- rods: *Sphingomonas* sp.,  
*Escherichia* sp.

MIC 45.00 ppm

22.50 ppm

11.25 ppm

Viruses

Mould

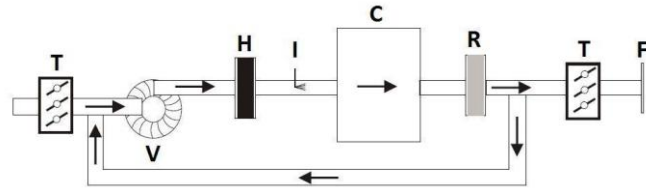
Yeast

Gram  
negative  
bacteria

Gram  
positive  
bacteria

# AgNPs misting chamber

**Capacity: 1.73 m<sup>3</sup> → 36-42 books A4**



T – throttling valve; V – ventilator; H – heater;  
I – silver colloid injection; C – chamber; R – radiator; F – filter

Wasiak R., Laskowski Z., Czyżyk J. The microbiological protection method of archive and museum objects and installation for the microbiological protection of archive and museum objects. Patent PL399507, Poland 2012

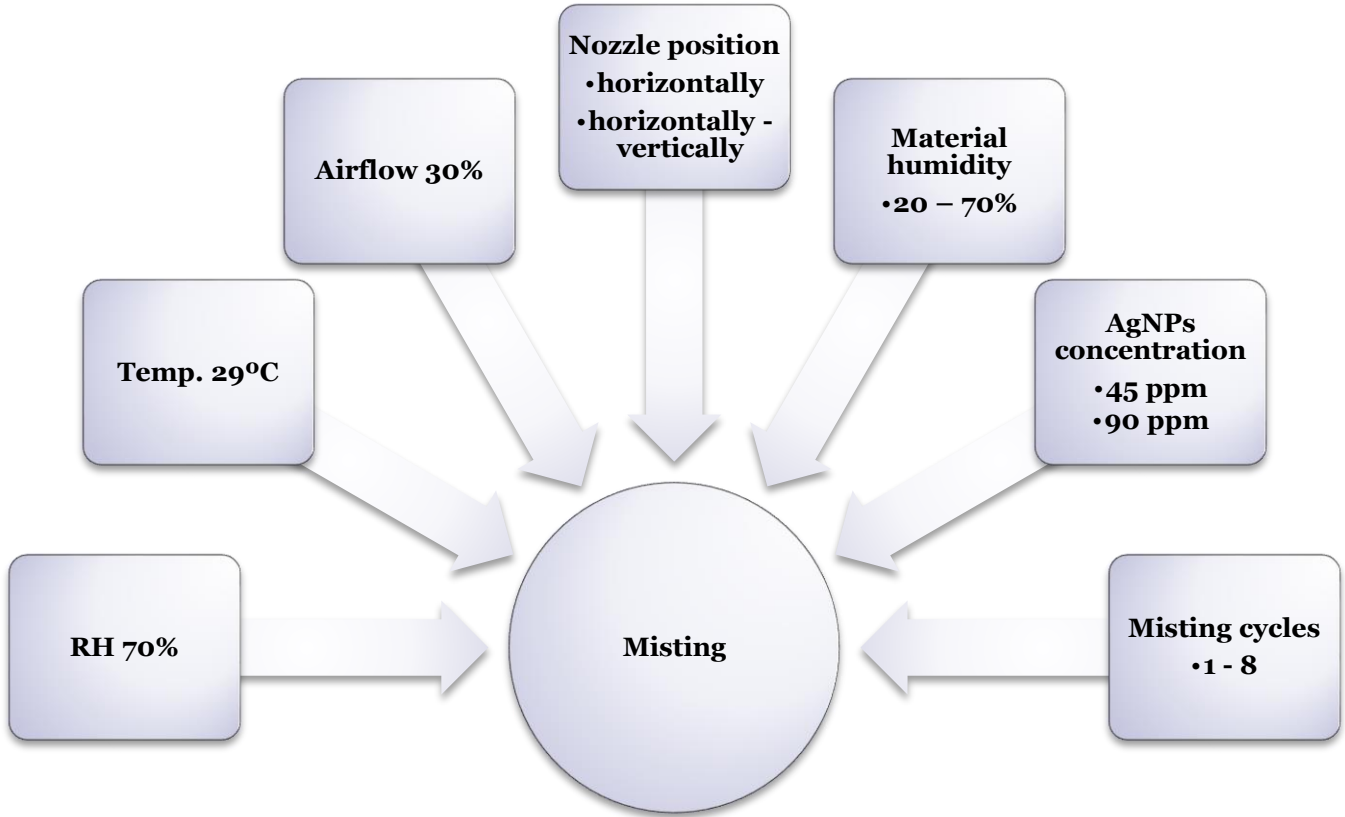


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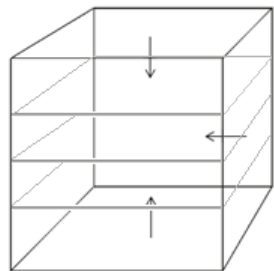
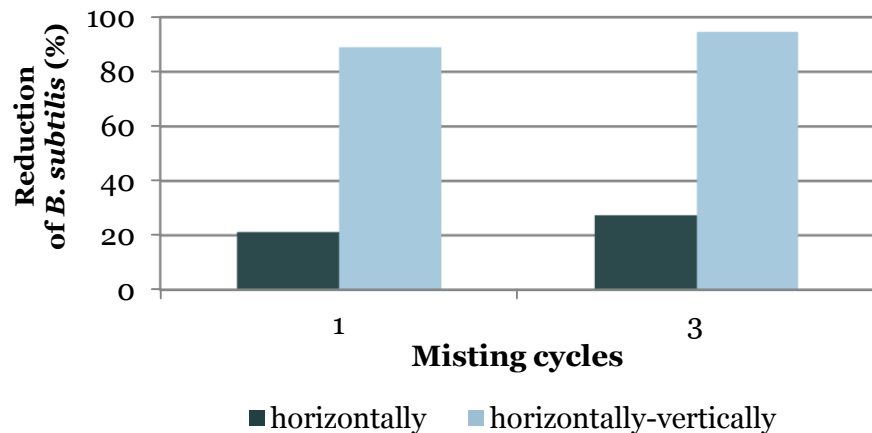
Siennicka 29, 04-394 Warsaw, Poland  
[www.instalwaw.com.pl](http://www.instalwaw.com.pl)



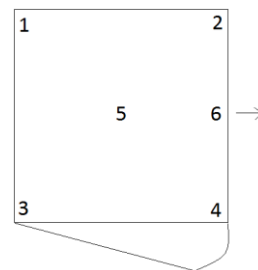
# Choosing the conditions for AgNPs misting



# Nozzle position and AgNPs distribution



Nozzle position  
(horizontally – vertically)

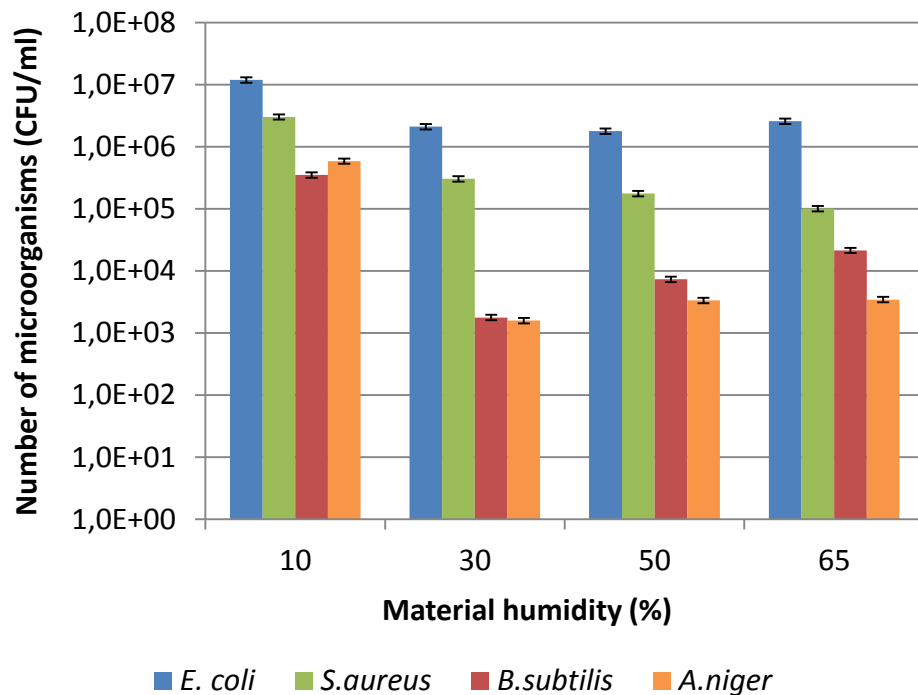
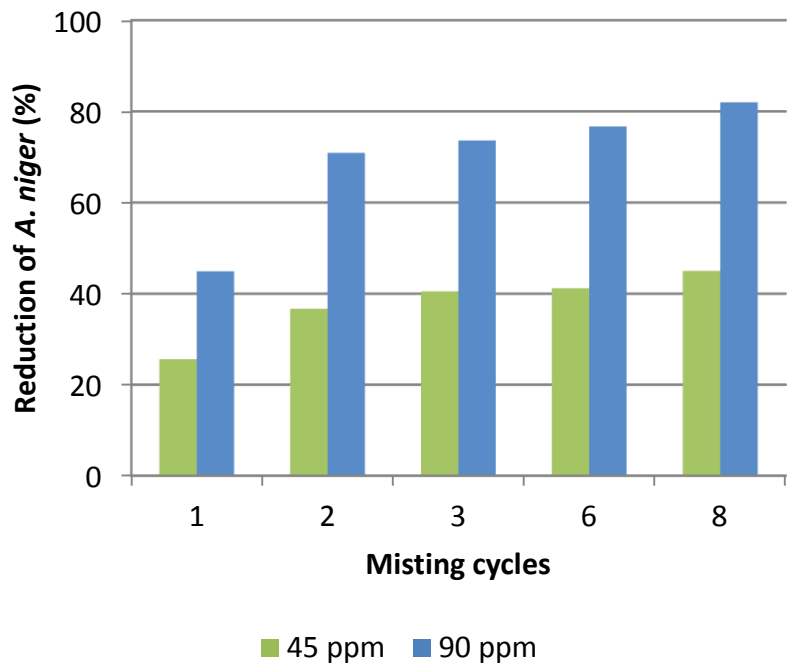


Sample points  
distribution

Sampling point	AgNPs amount (ppm/g)*
1	2.8
2	2.2
3	3.3
4	2.7
5	2.9
6	2.3

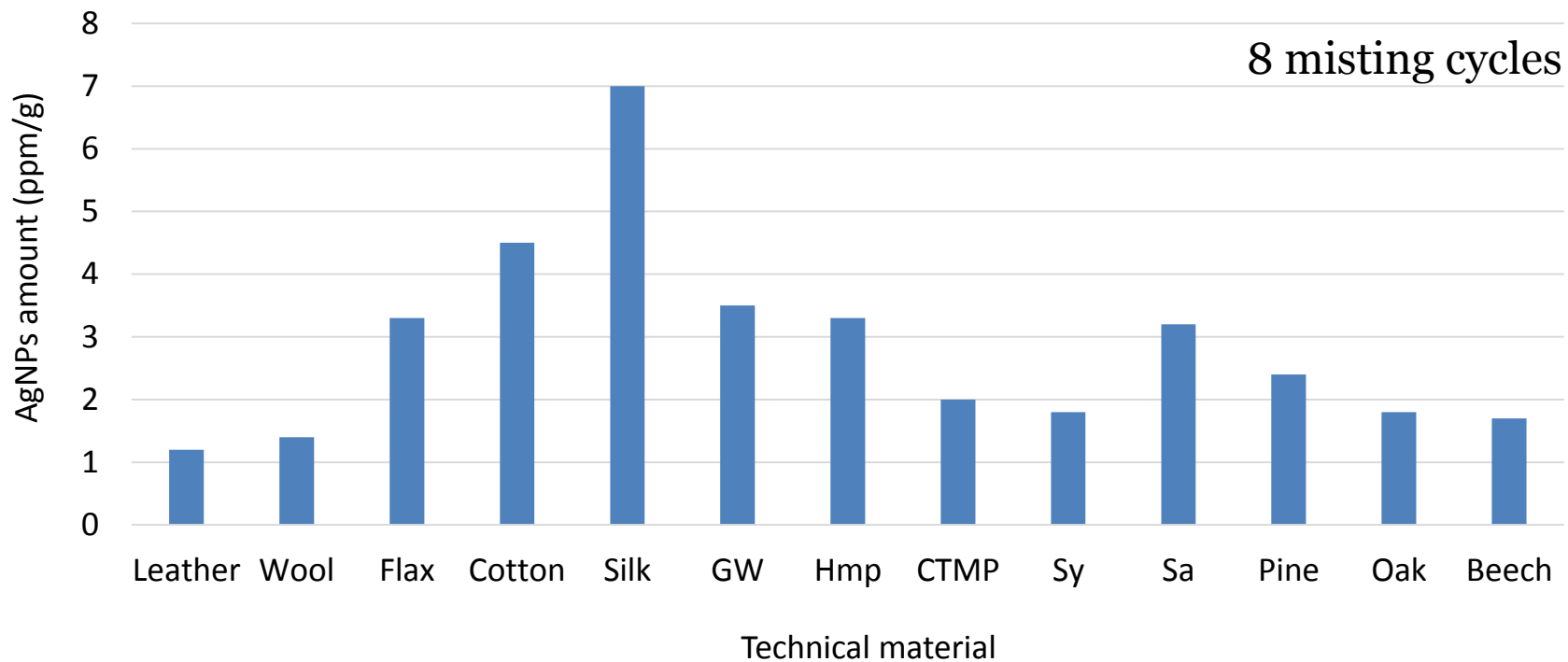
\* FAAS – Flame Atomic Absorbance Spectrometry

# Misting cycles, AgNPs concentration, material humidity



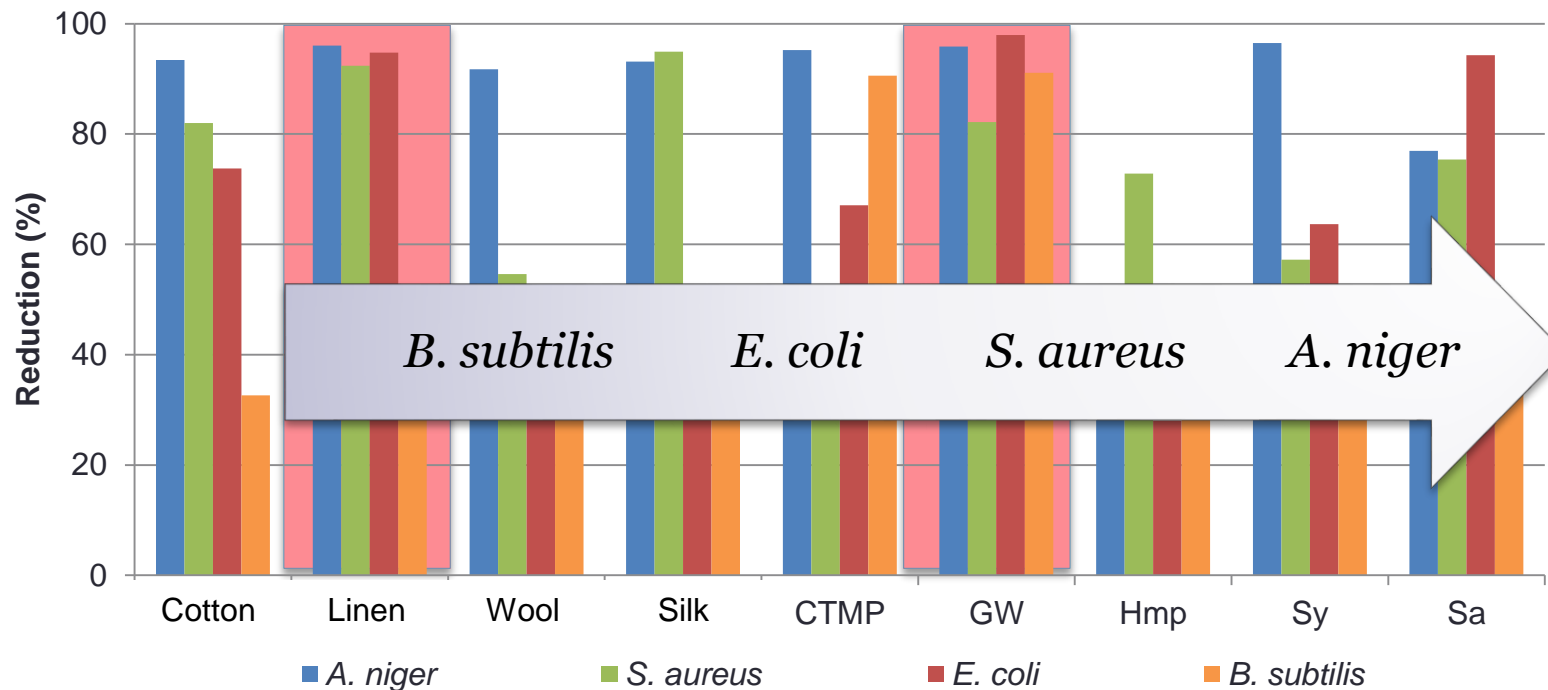


# Silver nanoparticles amount by FAAS



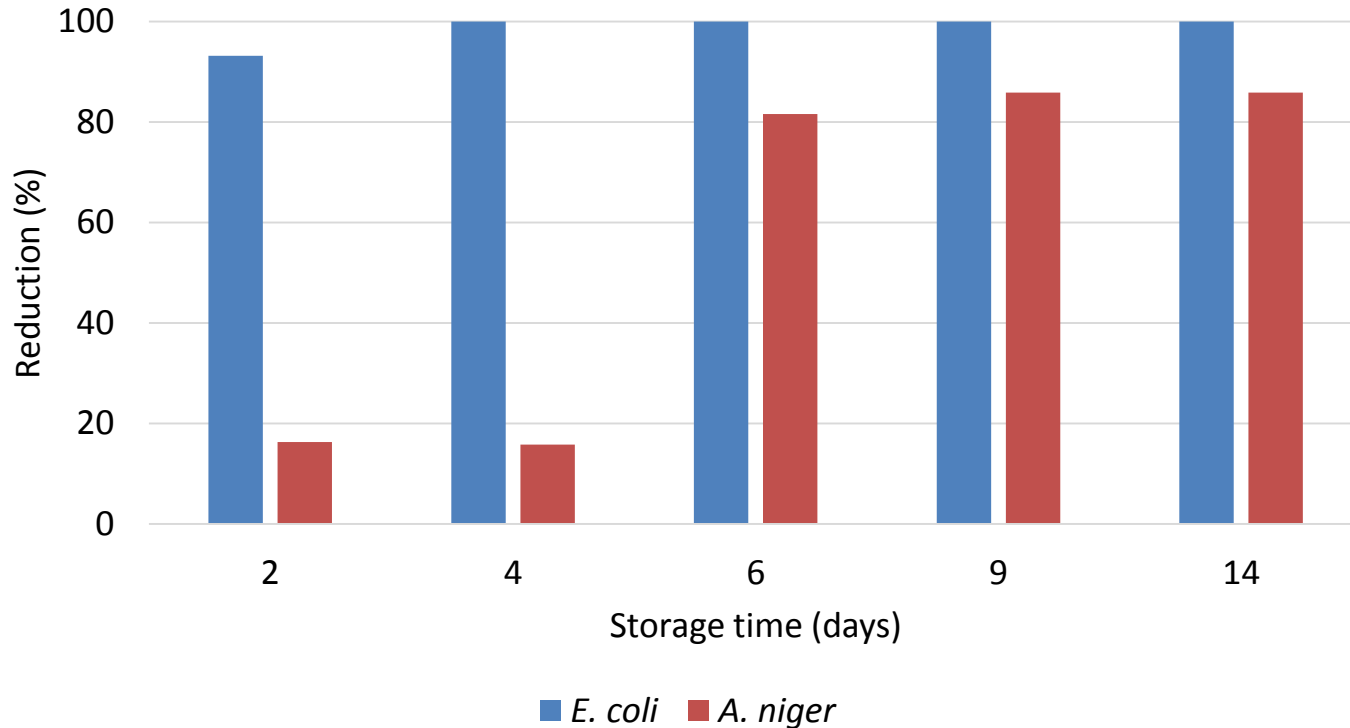
FAAS – Flame Atomic Absorbance Spectrometry; Sa - bleached pine kraft pulp; Hmp - bleached hemp kraft pulp; Sy - bleached spruce sulphite pulp; CTMP - chemi-thermomechanical pulp; GW - bleached groundwood from spruce (GW)

# Disinfection effectiveness on technical materials



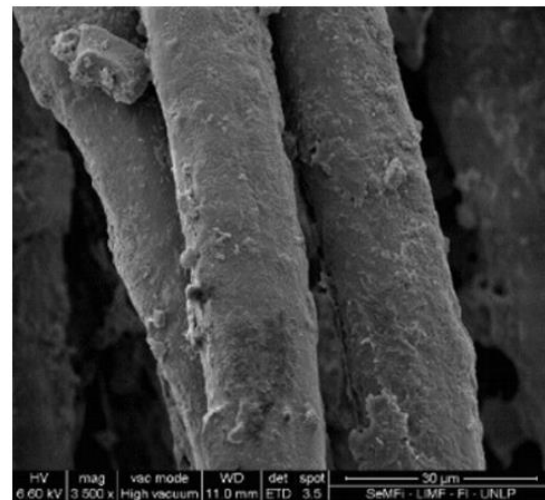
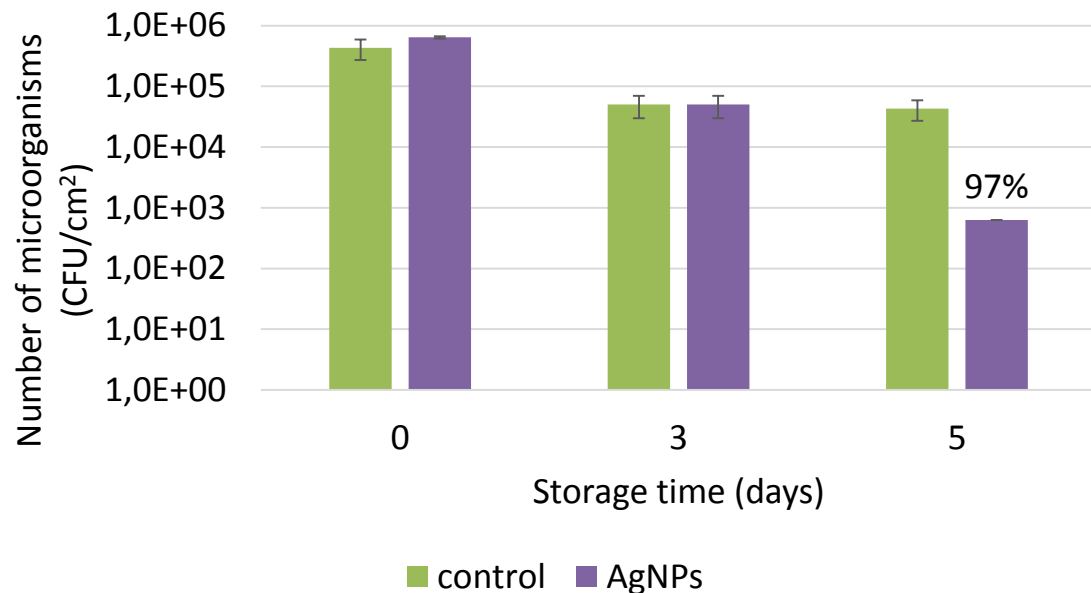
\*Sa - bleached pine kraft pulp; Hmp - bleached hemp kraft pulp; Sy - bleached spruce sulphite pulp; CTMP - chemi-thermomechanical pulp; GW - bleached groundwood from spruce (GW)

# AgNPs misting durability



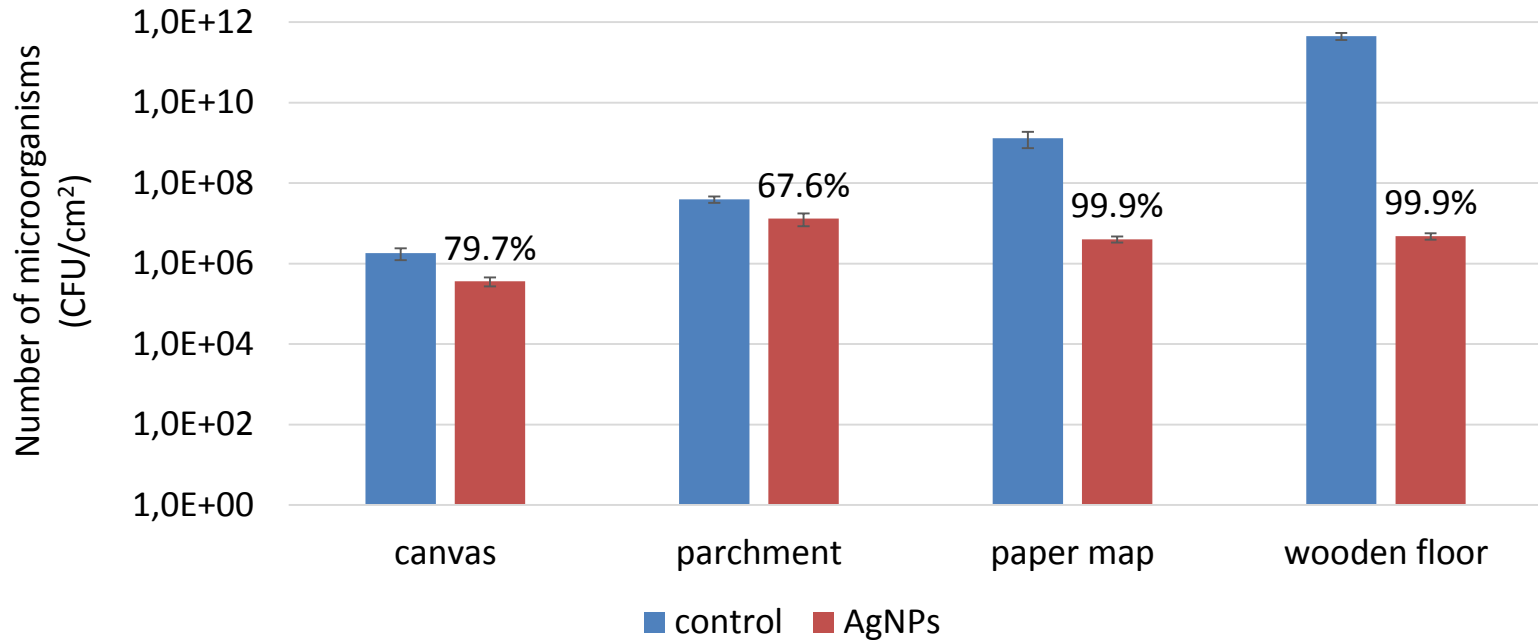
Storage conditions: 28°C, RH 80%

# Inhibition of *Pseudomonas aeruginosa* growth

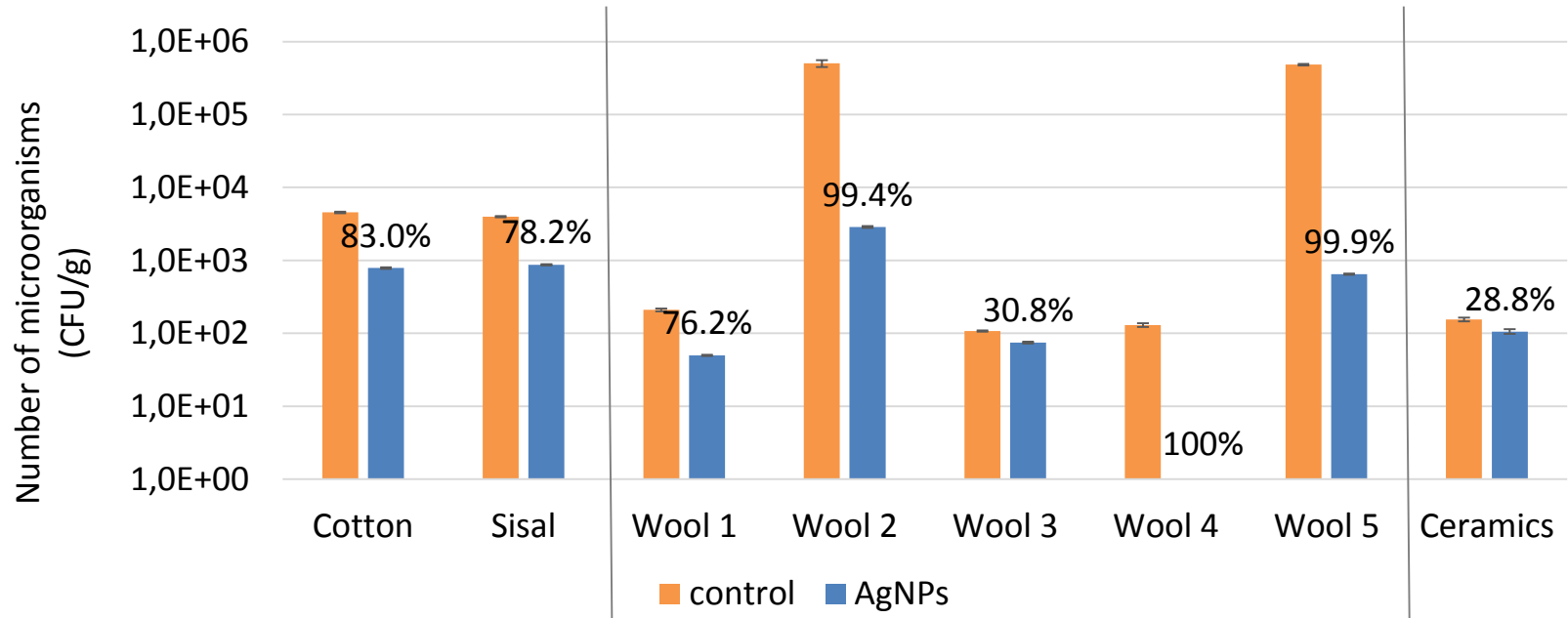


*Pseudomonas aeruginosa* on cotton fabric

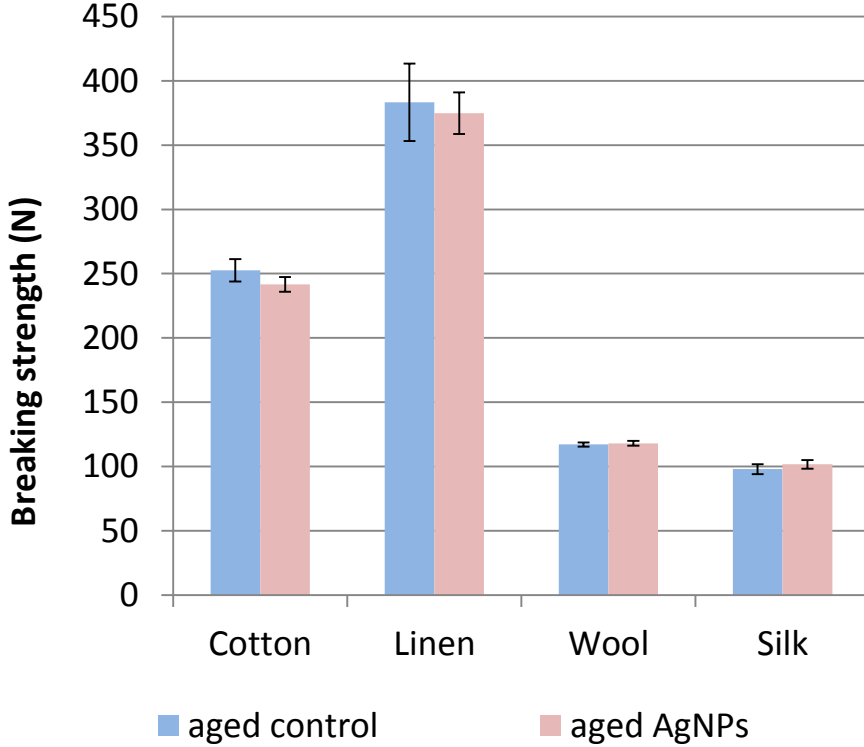
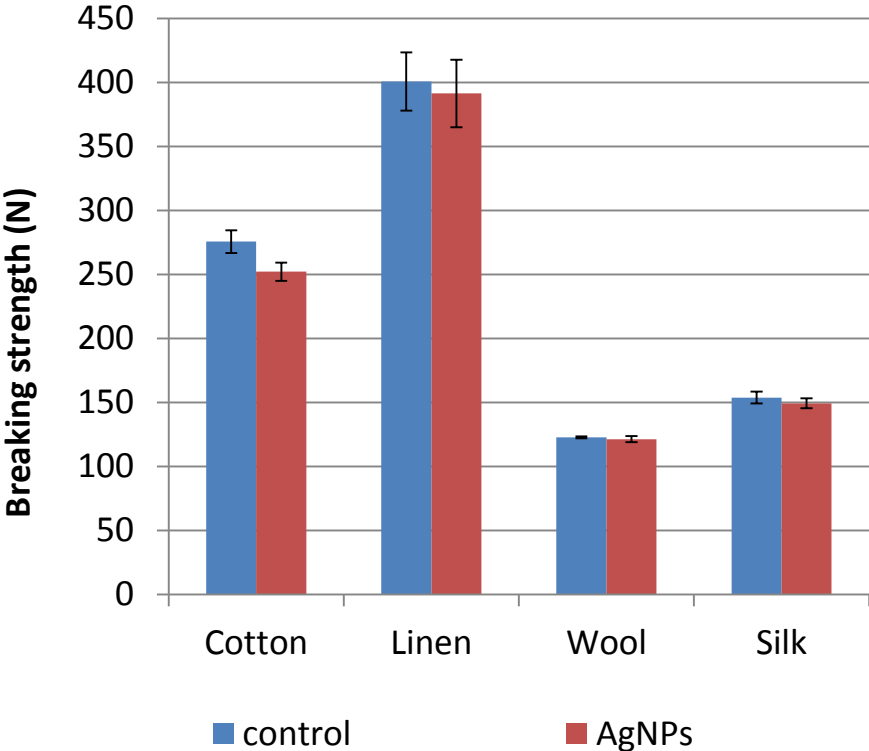
# Disinfection effectiveness on historical materials



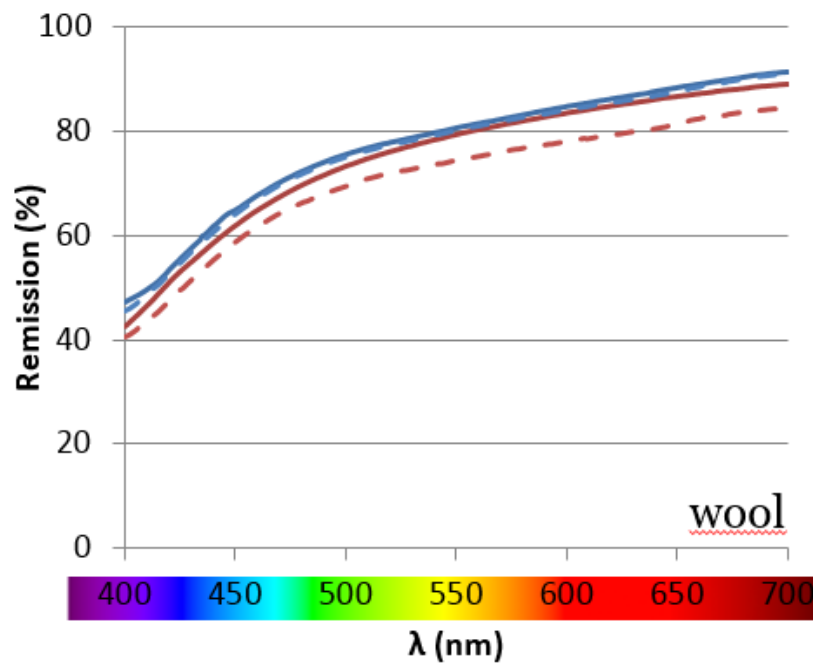
# Disinfection effectiveness on archaeological textiles



# Textiles mechanical parameters after ageing and AgNPs misting

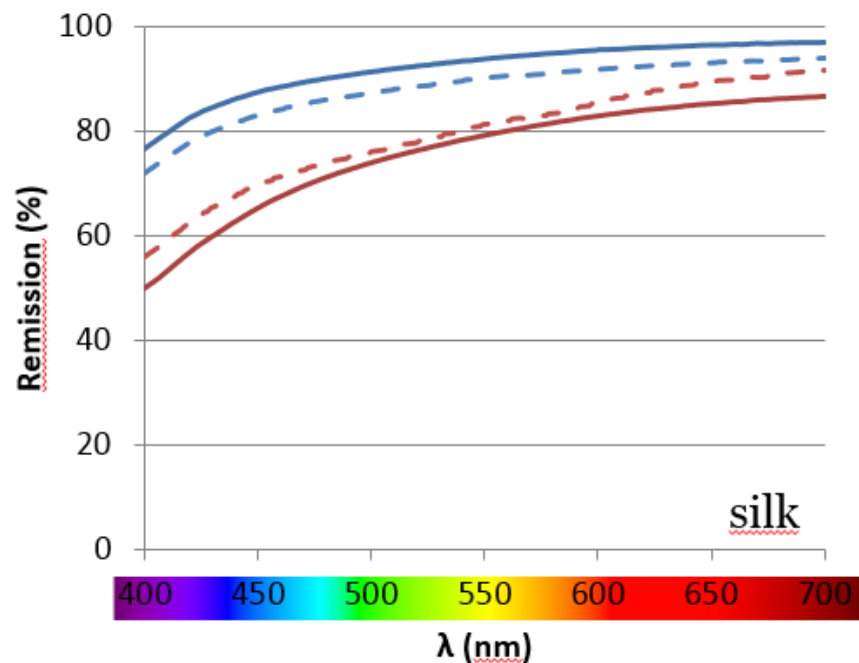


# Textiles optical parameters after ageing and AgNPs misting



— control

— AgNPs

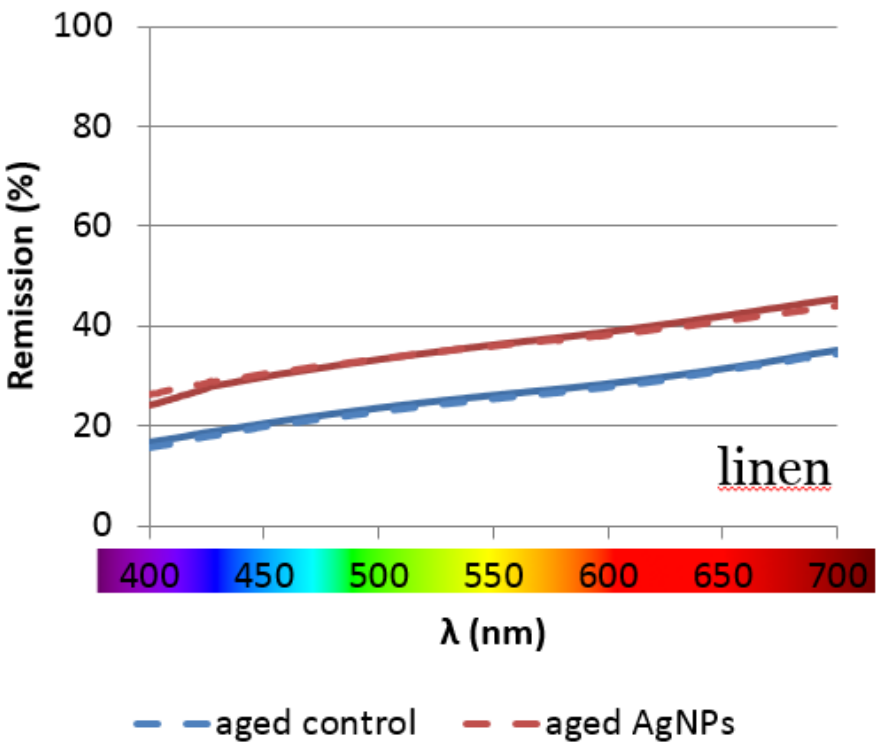
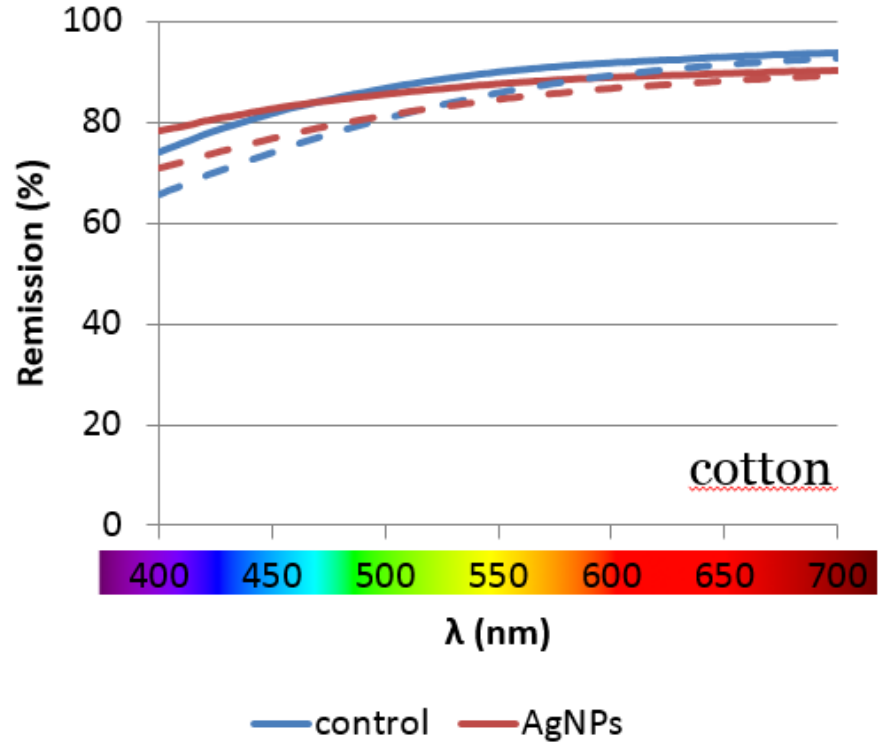


- - aged control

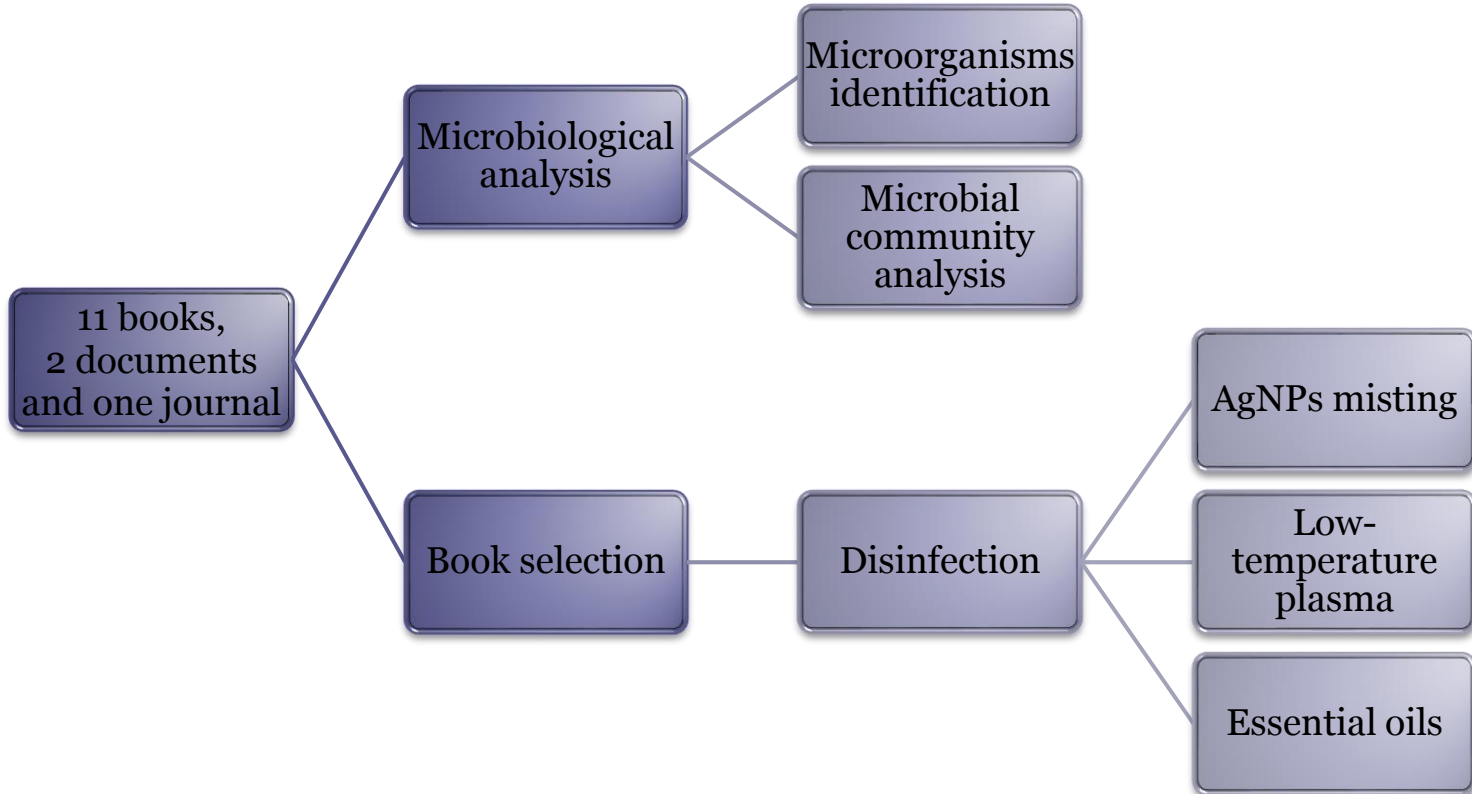
- - aged AgNPs



# Textiles optical parameters after ageing and AgNPs misting



# Disinfection of historical book collections



# Parameters of AgNPs misting

Nanosilver concentration 90 ppm

Misting cycles – 8

Airflow 30%

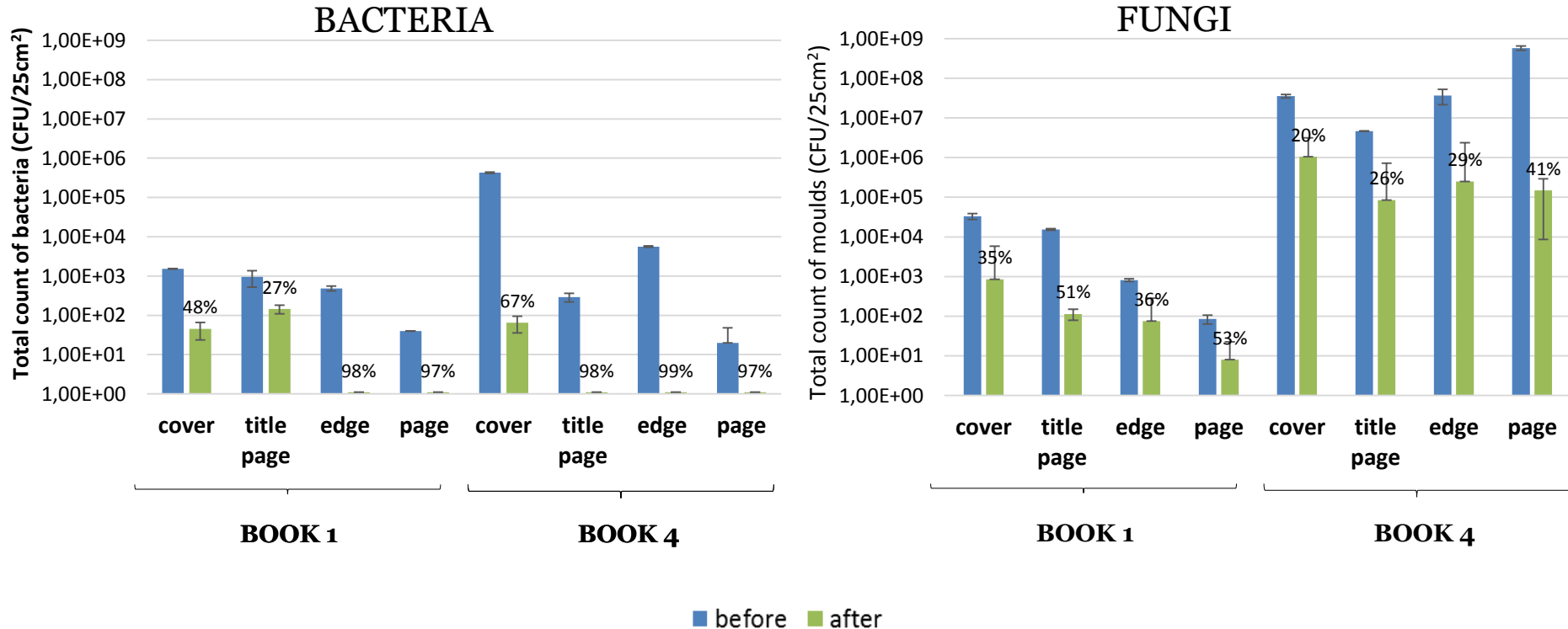
Temperature 25°C

RH 90%

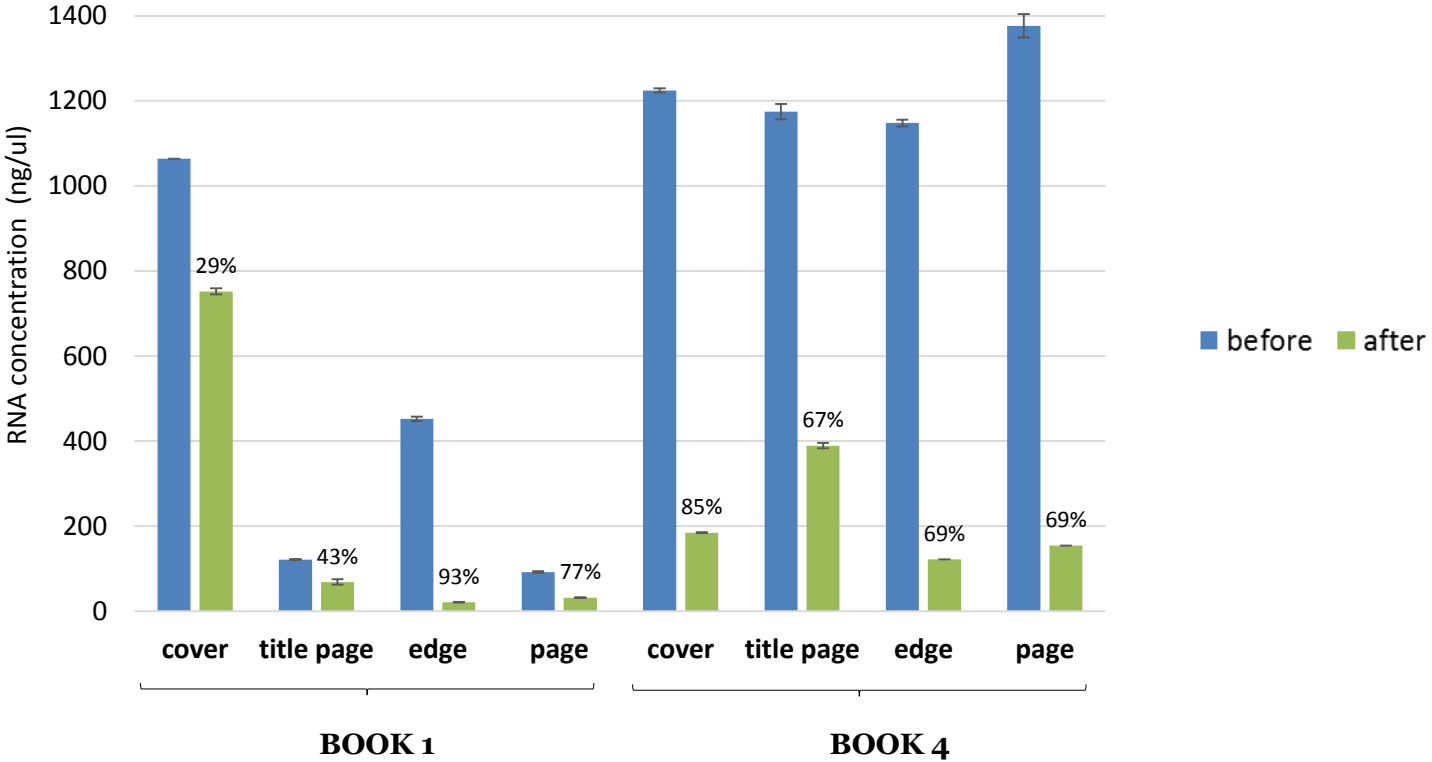
Duration – 520 min



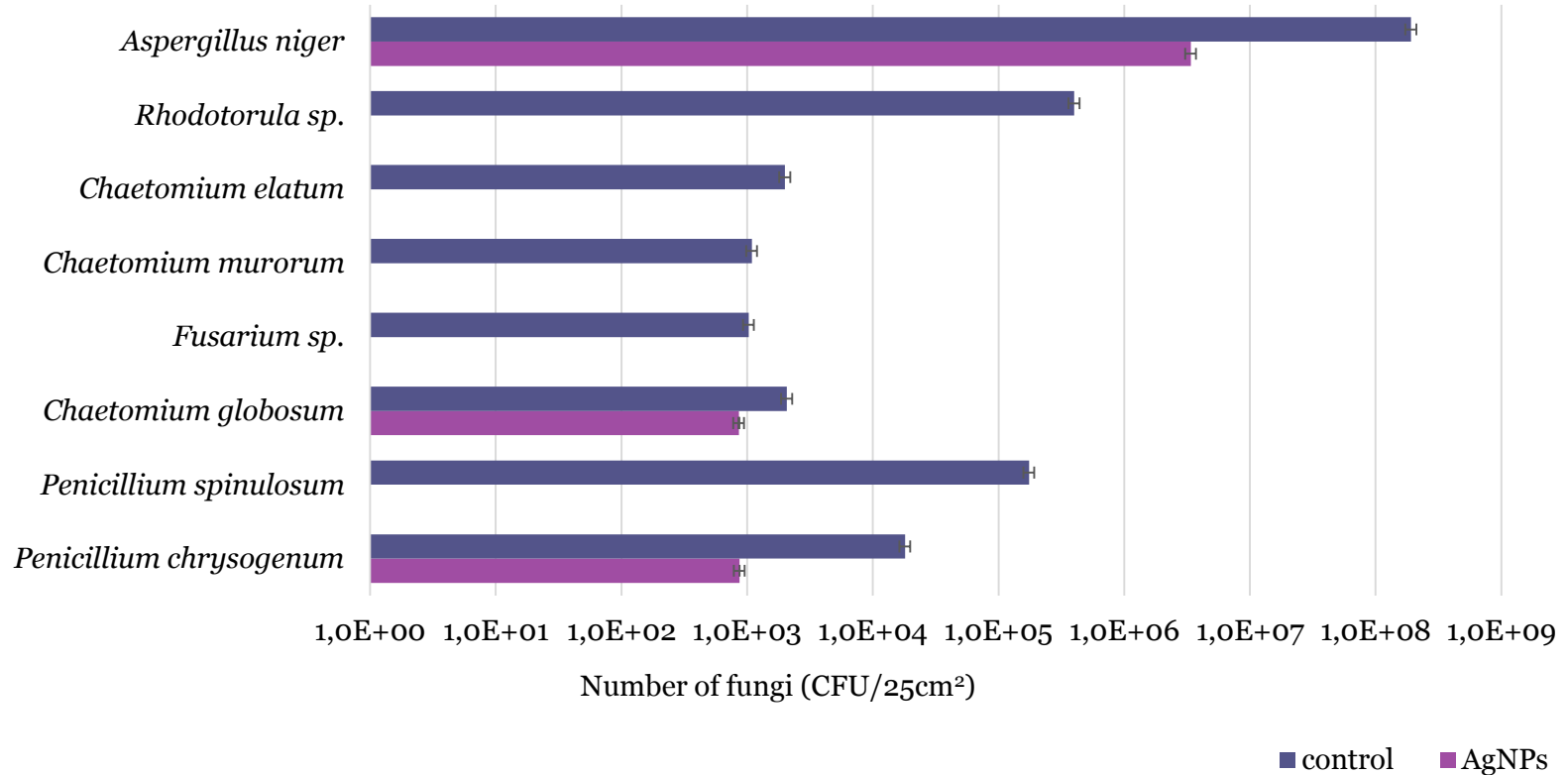
# Efficiency of AgNPs misting disinfection



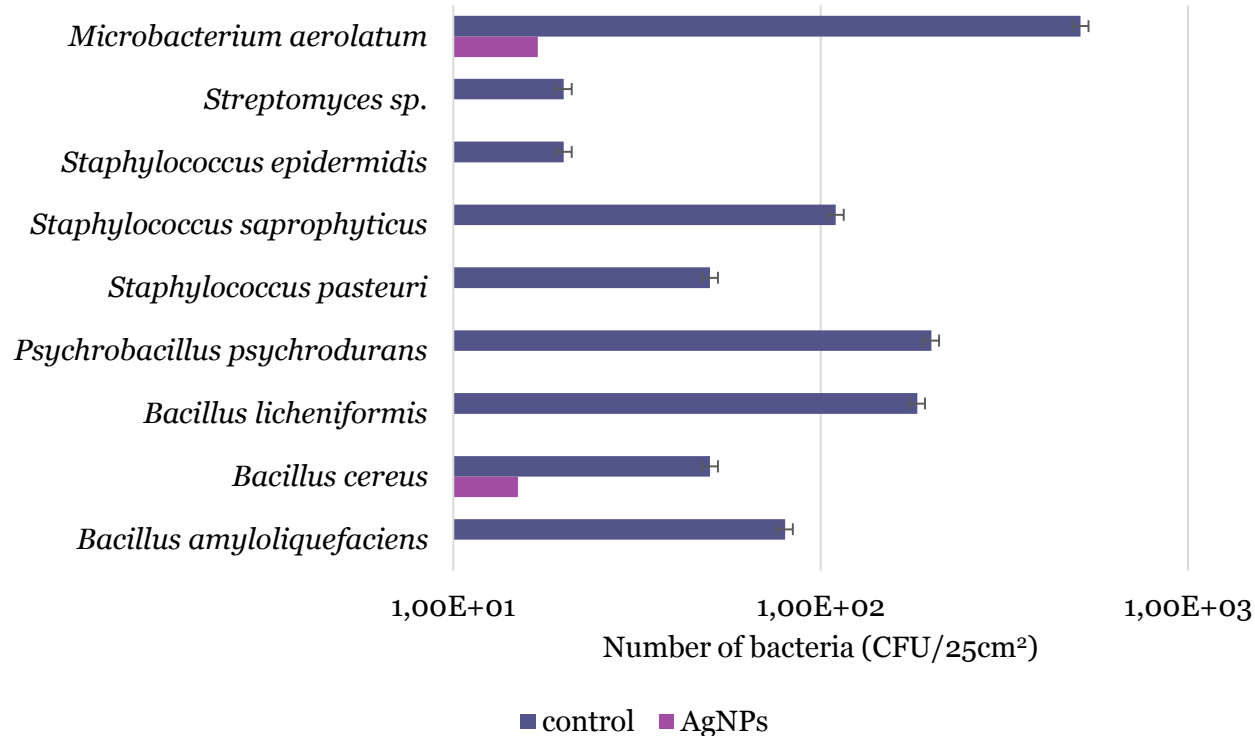
# Effect of AgNPs misting on microorganisms viability



# Fungal sensitivity to AgNPs



# Bacterial sensitivity to AgNPs



# Conclusions

1. Silver nanoparticles misting is an efficient method of growth inhibition of bacteria and fungi.
2. AgNPs misting decreases the microorganisms viability, shown as the reduction of RNA concentration.
3. AgNPs misting does not change visually the structural elements of the book.