New antimicrobial surfaces based on silica mesoporus nanoparticles functionalized with bioactive compounds

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Abstract

The RELIANCE Project aims to design and develop smart-responsive antimicrobial and self-disinfecting nanocoatings based on a new type of silica mesoporous nanoparticles (SMIN) containing metallic copper (Cu) within their structure, and subsequently modified with the addition of bioactive compounds of biological origin. These compounds, which include essential oils (EO) and antimicrobial peptides (AMP), act synergistically with Cu to improve the overall antibacterial and antiviral efficiency of the materials. The nanocoatings will be characterized by hydrophobicity and surface roughness, and they will be specifically designed not only for antimicrobial action, but also to adhere to various substrates commonly used in everyday life, such as plastic, metals, and textiles.

Overview

SMINs will be complexed with EOs or AMPs from waste streams, in order to enhance the antimicrobial action of the materials, allowing for significant efficacy against a wide range of pathogenic bacteria and viruses. The incorporation of EOs into the porous substrate enables controlled release of the bioactive compound, regulated by variations in pH or temperature. Additionally, the inclusion of AMPs, along with Cu chosen for its well-documented antimicrobial properties, ensures long-term action of the compound. Upon contact with bacteria, Cu releases ions that interfere with various cellular processes essential for microbial survival, including cellular metabolism and DNA synthesis. This synergic action leads to growth inhibition or bacterial death. Regarding the viruses, Cu ion binding and cross-linking between the strands of genome will result in the damage of viral genomes. Moreover the Cu toxicity caused by the generation of reactive oxygen species (ROS), represent a second mechanism for destroying viruses. Hence an effective viral inactivation, results from the synergistic action of Cu ion attack and ROS generation.

SMINs' antibacterial activity

SMIN: no coated silica mesoporous nanoparticles
Cu-SMIN-1: silica mesoporous nanoparticles with Cu hydroxide
Cu-SMIN-2: silica mesoporous nanoparticles with Cu oxide, calcination step at high temperature

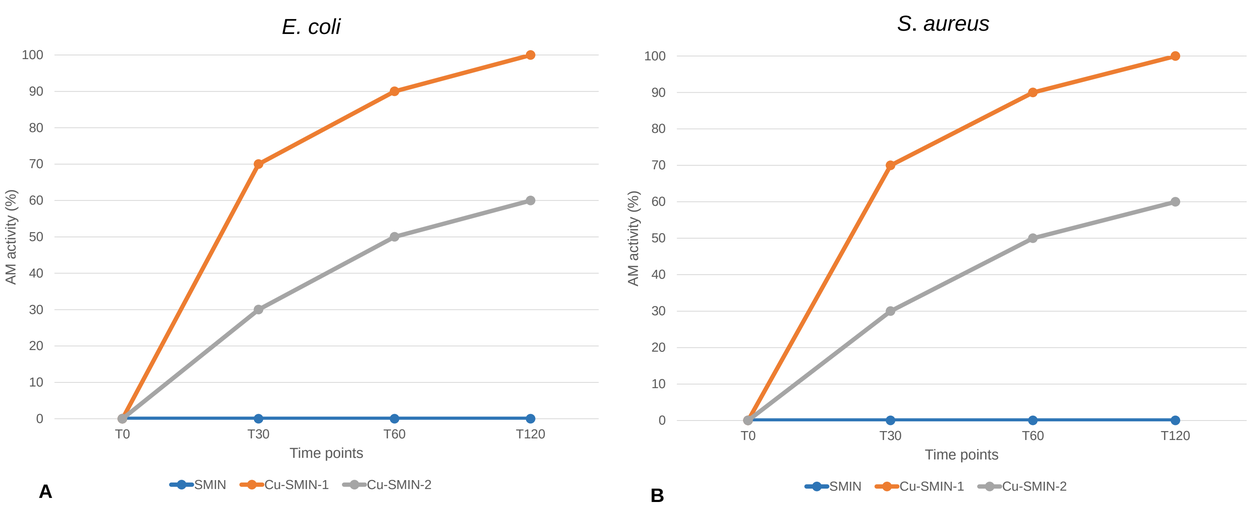

Figure 1. Antimicrobial activity (AM) Cu-SMIN-1 and Cu-SMIN-2 over time (0, 30, 60, 120 minutes) on *E. coli* (**A**) and on *S. aureus* (**B**).

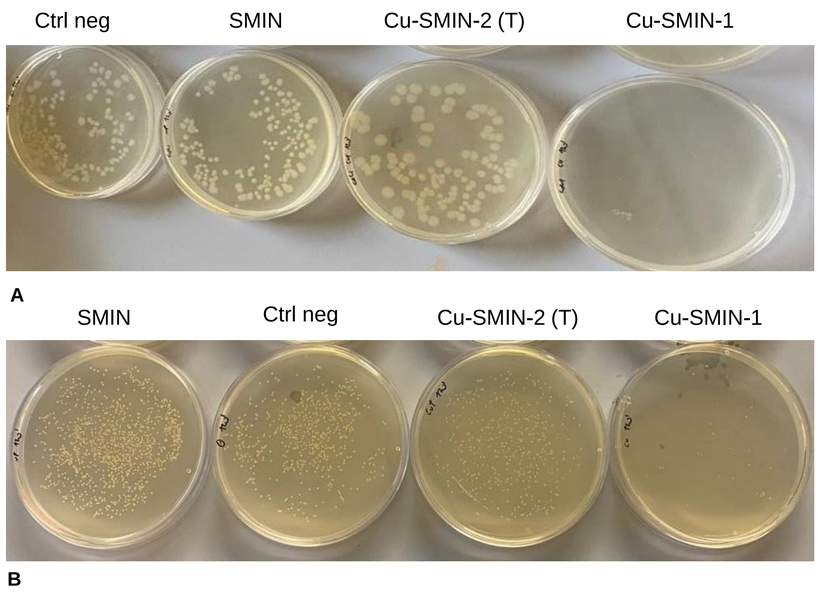

Figure 2. Decrease in the number of colonies from the negative control (ctrl neg) to Cu-SMIN-1 and Cu-SMIN-2 at 120 minutes on *E. coli* (**A**) and on *S. aureus* (**B**).

SMINs' virucidal activity

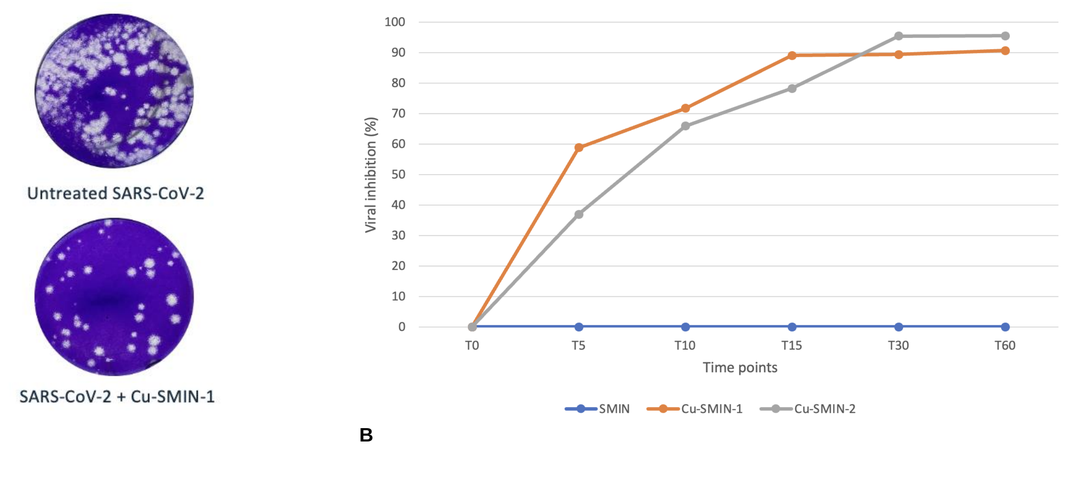

Figure 3. Virucidal activity of SMIN, CuSMIN-1 and CuSMIN-2 against SARS-CoV-2. **A**: Plaque Forming Unit (PFU) generated by untreated (control) and treated SARS-CoV-2 with Cu-SMIN-1. **B**: SARS-CoV-2 inhibition (expressed in %) after incubation with SMINs at different time points (0, 5, 10, 15, 30, 60 minutes).

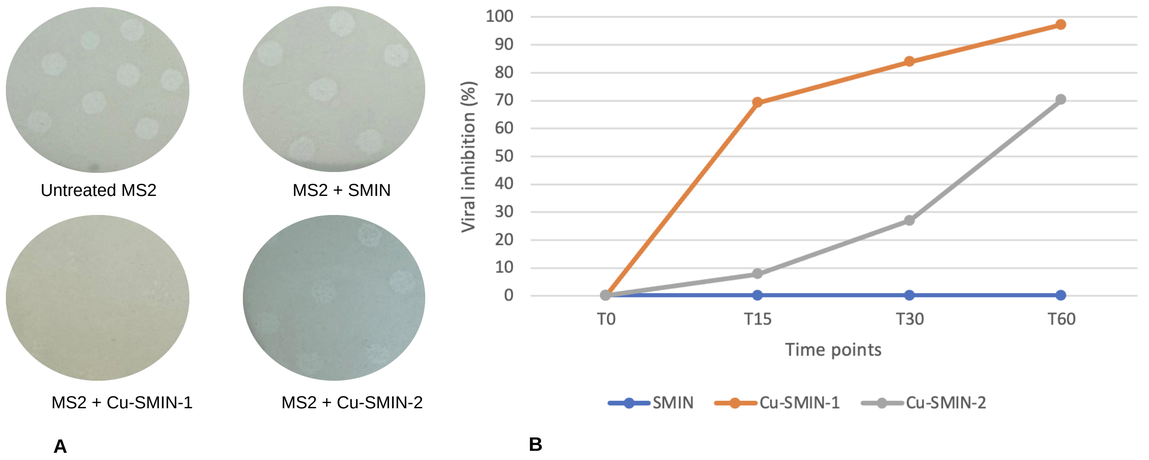

Figure 4. Virucidal activity of SMIN, CuSMIN-1 and CuSMIN-2 against MS2 Bacteriophage. **A**: Plaque Forming Unit (PFU) generated by untreated (control) and treated MS2 with the different SMINs. **B**: MS2 inhibition (expressed in %) after incubation with SMINs at different time points (0, 15, 30, 60 minutes).

Summary & outlook

Preliminary tests demonstrated the antimicrobial activity of SMINs complexed with Cu against both Gram + and Gram – bacteria. In particular, Cu-SMIN-1 exhibited a significant 90% bactericidal activity after 60 minutes of exposure, reaching 100% after 120 minutes.
Subsequent experiments, conducted to evaluate the antimicrobial efficacy of various EOs, focused on carvacrol, eugenol, thymol, and menthol. Carvacrol in particular, showed higher antimicrobial power compared to the other oils.
In the next experimental phase, Cu nanoparticles will be functionalized with different concentrations of carvacrol using various techniques to determine the formulation with the optimal antibacterial and antiviral properties.

Mesoporous nanoparticles SMINs complexed with Cu have a strong virucidal activity against both enveloped (SARS-CoV-2) and not enveloped (MS2 bacteriophage). Experiments with Cu-SMIN-1 showed that viral inactivation reached more than 90% reduction after 60 minutes of exposure, whereas with Cu-SMIN-2 an inhibition of SARS-CoV-2 and MS2 of 95.5% and 70% respectively, was observed. SMIN without Cu, could not inhibit the viruses at any incubation time points.
The obtained results, confirmed the data published yet, proving the virucidal activity of Cu.

Acknowledgements

The RELIANCE consortium consists of 15 partners spanning 8 EU and 2 non-countries. Partners include research institutions, universities, SMEs, and large industries.

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Health and Digital Executive Agency (HADEA). Neither the European Union nor the granting authority can be held responsible for them.

This project has received funding from the European Union's Horizon Europe research and innovation program, grant agreement No 101058570 (RELIANCE).