Heliyon 10 (2024) e25580

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Enhanced antimicrobial efficacy of biogenic ZnO nanoparticles through UV-B activation: A novel approach for textile garment

David Asmat-Campos [a,c,*], Jesús Rojas-Jaimes [a,b], Marco Simbrón de la Cruz [d], Gabriela Montes de Oca-Vásquez [e]

[a] Dirección de Investigación, Innovación & Responsabilidad Social, Universidad Privada del Norte, Peru
[b] Facultad de Ciencias de la Salud, Universidad Privada del Norte, Lima, Peru
[c] Grupo de Investigación en Ciencias Aplicadas y Nuevas Tecnologías, Universidad Privada del Norte, Trujillo, Peru
[d] Escuela de Farmacia y Bioquímica, Universidad Privada Norbert Wiener, Lima, Peru
[e] National Laboratory of Nanotechnology, National Center for High Technology, Pavas, San José, 10109, Costa Rica

ARTICLE INFO

Keywords:
UV disinfection
Sanitization
ZnO nanoparticles
UV photoactivation

ABSTRACT

Zinc oxide nanoparticles (ZnO NP) are characterized by novel properties which have been attracting the attention of different lines of research due to their wide applicability. Obtaining this nanomaterial is strongly linked to biogenic synthesis methods, which have also been developed in this research, using *Coriandrum sativum* extract as a reducing agent. ZnO NPs have been properly characterized by techniques to evaluate their morphology by transmission electron microscopy (TEM) and elemental analysis by EDX. The evaluation of the antimicrobial and antifungal effects is linked to the use of a system provided by "locker sanitizer" equipment, which has been designed and built as part of this research, and is intended to treat textile garments by nebulizing the ZnO NP colloid (99.08 μg/mL) + UV-B, water + UV-B, and UV-B only, and also to evaluate the influence of the treatment time for 1, 2 and 3 min. In this sense, it is known that the nanomaterial used shows a better response to UV light because more hydroxyl radicals are produced, leading to a higher reaction rate, which results in greater efficiency in inhibitory processes. The results show that the use of the locker sanitizer is more efficient when using ZnO NP + UV-B light since it achieved 100 % growth inhibition against *E. coli*, *C. albicans*, and *A. brasiliensis*, and >99 % against *S. aureus*, after 3 min of treatment.

1. Introduction

Nanotechnology is presented as a potential alternative to face various challenges in the health sector, as well as to contribute to the fields of science and technology. There is currently a large volume of scientific literature related to methods for the synthesis of metallic nanomaterials and metal oxides. In this sense, metal oxide nanoparticles have been generating great interest in the scientific community because they are considered non-toxic and of low cost, besides being versatile to be designed in various types of nanostructures, not being alien to the zinc oxide nanoparticles (ZnO NP) [1,2], where diversity of applications are being explored due to their photocatalytic properties, in photo-electronics, photovoltaic cells and sensors [3], besides being biodegradable and having the capacity to be absorbed by the body because they can be dissolved in ions, becoming elements applied to the nutritional cycle, as well as being

* Corresponding author. Dirección de Investigación, Innovación & Responsabilidad Social, Universidad Privada del Norte, Peru.
E-mail address: david.asmat@upn.edu.pe (D. Asmat-Campos).

https://doi.org/10.1016/j.heliyon.2024.e25580
Received 12 November 2023; Received in revised form 26 January 2024; Accepted 30 January 2024
Available online 5 February 2024

applied in in-vivo bio-detection, although there are still many questions to address and investigate about biodegradability and the consequences on the nutritional cycle [4]. Thus, and considering the intrahospital contamination at the level of bacteria, fungi, and viruses, research is being carried out on the application of ZnO NPs in different formats, being textile impregnation the most developed because they would prevent the transmission of dangerous pathogens that remain on textile surfaces for long periods [5]. On the other hand, it is important to consider the method of synthesis of nanomaterials since the management of morphology, size, and colloidal mono-dispersity will depend on it, and from this, new properties will be obtained. In this sense, biogenic synthesis or green synthesis is in full swing because it promises cost-effective processes without environmental impact [6], characterized by the use of plant extracts, which act as organic reducers of the precursor metal salts due to the presence of biomolecules such as phenolic compounds, flavonoids and alkaloids [7]. Other methods use bacteria and enzymes as biological sources for the production of nanoparticles [8]. In general terms, there is a diversity of nanomaterials that contain potential antimicrobial and antifungal properties, such as silver nanoparticles (Ag NP) [9–11]; however, they are usually synthesized using chemical methods, causing environmental problems [12], copper nanoparticles (Cu NP) [13–15]. There are also composite nanoparticles, such as lactoferrin-chitosan-gellan, which have been shown to have excellent antimicrobial capacity against *S. aureus* due to their higher zeta potential and smaller size [16]. Iron oxide nanoparticles (FeO NP) have also been reported to have good antibacterial activity, inhibiting the growth of gram-negative, gram-positive bacteria and microfungi [17]; cuprous oxide nanoparticles (Cu_2O), with inhibitory potential against *S. aureus*, *E. coli*, *A. niger*, and *C. albicans* [18]; and titanium dioxide nanoparticles (TiO_2 NPs) that offer to be promising agents for the development of technologies to control infections caused by *C. parapsilosis* and *Prototheca ciferrii* [19]. In the case of ZnO NPs, antiviral effects have been demonstrated against SARS-CoV-2, Influenza A, Herpes virus, and cancer cells. This is due to their capacity to generate free radicals damaging protein molecules and nucleic acids [20–23]. It has also demonstrated antibacterial effectiveness against Gram-positive and Gram-negative bacteria with higher antagonistic activity, generating bacterial growth and inhibition [24]. Likewise, there are methods where this type of nanoparticle has been synthesized by the green route, and where excellent antibacterial activity has also been exhibited [25], besides applying it in food for similar purposes, too [26], and in animal nutrition, because good antimicrobial potency against *E. coli* and *S. aureus* has been reported [27]. In general, a positive response to a broad spectrum of pathogenic microorganisms has been obtained [28–31]. It is known that ZnO NPs show a better response in the presence of UV light, showing a better performance in photocatalytic treatments of single NPs [32] or compounds with ZnO-PVP [33] because more UV light radiation produces more hydroxyl radicals, leading to a higher reaction rate, which shows a higher efficiency in inhibitory processes. It should be noted that ZnO nanoparticles obtained with *C. sativum* extract have been widely used and investigated by the team of researchers of this manuscript as an organic reducer for the formation of ZnO nanostructures, the same ones in which their potential has been demonstrated. application in textiles [34], antiviral activity in disinfectant lockers [35], nanofertilizers [36].

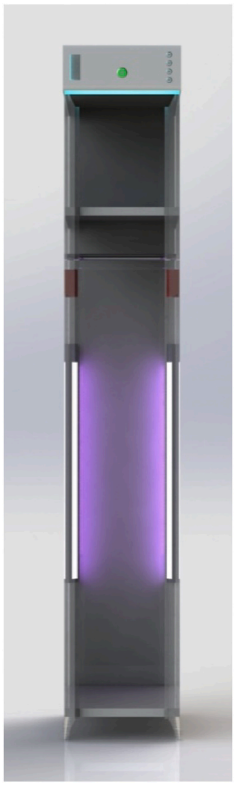

Fig. 1. Design of the locker sanitizer.

This research presents the evaluation of the antibacterial (*Escherichia coli* and *Staphylococcus aureus*) and antifungal (*Candida albicans* and *Aspergillus brasiliensis*) effects of the treatment of textiles subjected to UV-B radiation and ZnO NP exposed to a disinfectant locker system through the nebulization of the nanoparticulate colloid and its difference regarding treatment exposure times.

2. Methodology

2.1. Biogenic synthesis of ZnO nanoparticles

Zinc oxide nanoparticles (ZnO NP) were obtained by the biogenic method from the precursor zinc acetate dihydrate ($ZnC_4H_6O_4$) (Merck Millipore, Burlington, MA, USA, CAS no. 5970-45-6), and, as reducing and stabilizing agent, the aqueous extract of *Coriandrum sativum*. It is worth mentioning that the plant species in question was identified and is registered in the "Herbarium Truxillense" (HUT), of the National University of Trujillo (Trujillo, Peru). For the synthesis, a 0.21 M precursor solution was considered, which was heated in a hotplate until reaching a temperature of 70 °C with magnetic stirring (Ika Works, C-MAG HS7, Staufen, Germany) (600 RPM) for 60 min. Then, 20 mL of the aqueous extract was added, maintaining the same synthesis conditions for 90 min. In the end, the solution was removed and poured into crucibles, and taken to calcination in a muffle (Yamato, FO110CR, CA, USA) (500 °C) for 2 h, obtaining a white powder, which was ground using a mortar and washed three times with ultrapure water, and, finally, redispersed with magnetic stirring for 30 min and ultrasound (60 min), adjusting to a concentration of 99.076 ppm. Ultrapure water (Thermo Scientific, Barnstead Smart2Pure, MA, USA) was used throughout the experiment. The characterization of the nanoparticles corresponding to size and shape was analyzed by transmission electron microscopy (TEM) by adding 5 μl of the colloid placed on a carbon-coated copper grid. The NP sample was then dried in a desiccator with silica for 16 h. Measurements were carried out on a JEOL (model JEM 2011) operated at a voltage acceleration of 120 kV. EDX mediations were carried out with the TEM equipped with an OXFORD EDS 6498.

2.2. Disinfection process with locker sanitizer

The locker sanitizer (Fig. 1) was designed and built within the research framework. The main sanitization process is based on the ultrasonic nebulization of the solutions to be evaluated. In this sense, the equipment consists of a tank located at the top with a capacity of 500 mL, where the different tests were stored: the colloidal solution of ZnO NP (99.08 μg/mL) and distilled water. In addition, the equipment includes UV-B light in the cabinet. Textile treatments were performed under three conditions: UV-B only, ultrasonic nebulization of colloid ZnO NP + UV-B, and ultrasonic nebulization of distilled water + UV-B, in addition to varying the treatment times in 1, 2, and 3 min. The design of the equipment guarantees that, once the sanitization process is finished, the nanoparticles are not suspended in aerosols. For this purpose, an electrical resistor was provided to reduce the humidity in the booth, besides being constantly tested by humidity sensors with a data logger, which guarantees the pre-treatment conditions.

2.3. Bacterial and fungal inoculation on functionalized textiles

For the antibacterial challenge (*Escherichia coli* ATCC 8759 and *Staphylococcus aureus* ATCC 6538), inocula in TSB (Trypticase-Soya liquid medium) of 2.98×10^7 CFU/mL and 7.58×10^7 CFU/mL, respectively, of 200 μL, soaking sterile fabric of 1.75 cm × 2.25 cm were used. For the antifungal challenge, (*Candida albicans* ATCC 10231 and *Aspergillus brasiliensis* ATCC 16404) inocula in DSB (Dextrose-Sabouraud liquid medium) of 2.68×10^7 CFU/mL and 1.98×10^7 CFU/mL, respectively, of 200 μL, were used, soaking the sterile fabric of 1.75 cm × 2.25 cm.

A sterile fabric inoculated with the previously described concentrations without any sanitizer (ultraviolet light or ultraviolet light + ZnO NP) was used as a negative control, and the fabric without inoculation and exposed to the sanitizers (ultraviolet light and ultraviolet light + ZnO NP) was used alone as a substrate control (fabric).

2.4. Application of ultraviolet light and ultraviolet light + ZnO NP on functionalized textiles

Ultraviolet-B light (280 nm–315 nm) was applied to the fabrics with microorganisms for 1, 2, and 3 min, respectively, and the study group was simultaneously applied ultraviolet-B light + ZnO NP (99.08 μg/mL) for 1, 2, and 3 min. Three replicates per treatment were developed.

2.5. Bacterial and fungal recovery of functionalized textiles

After each treatment, the fabrics were placed in sterile flasks with 1 mL of TSB for bacteria and DSB for fungi. They were then incubated at 35 °C for 24 h. Subsequently, 4 mL of TSB or DSB medium was added as appropriate for bacteria or fungi and vortexed at 1200 RPM for 2 min to dislodge the bacteria or fungi impregnated on the fabric. Then, 1 mL was seeded by the pour plate method for colony counting. Incubation was at 35 °C for 24 h for bacteria and yeasts, and at 25 °C for up to 5 days of observation for filamentous fungi. Finally, counting was performed using a colony counter.

$$\%\ Microbial\ reduction = 100\left[\frac{(B-A)}{B}\right]$$

Where A are the Colony Forming Units (CFU) of the microorganisms, recovered after the treatments and B are the CFU (negative control) of the microorganisms recovered from the fabric without exposure to any treatment.

2.6. Statistical analysis

Analysis of variance was performed between treatments 1 (UV–B at 60, 120, and 180 s), treatment 2 (UV–B + ZnO NP at 60, 120, and 180 s), and treatment 3 (group of fabrics contaminated with the bacterial and fungal inoculums without sanitizer) with a significance of 95 % and a $p < 0.05$.

3. Results

3.1. Biogenic synthesis of ZnO NP

Fig. 2(a) shows the characterization results of ZnO NPs mediated by the biogenic synthesis, where the defined spherical structure can be evidenced, as well as some with irregular shapes with hexagonal tendency and an average size of 30 nm (Fig. 2(b)) joined in dispersed agglomerations, similar to those found by Al-Kordy et al. [37]. Likewise, an elemental analysis (Fig. 2(c)) showed the presence of peaks corresponding to zinc, which evidences the degree of purity of the synthesized colloid. The presence of the other

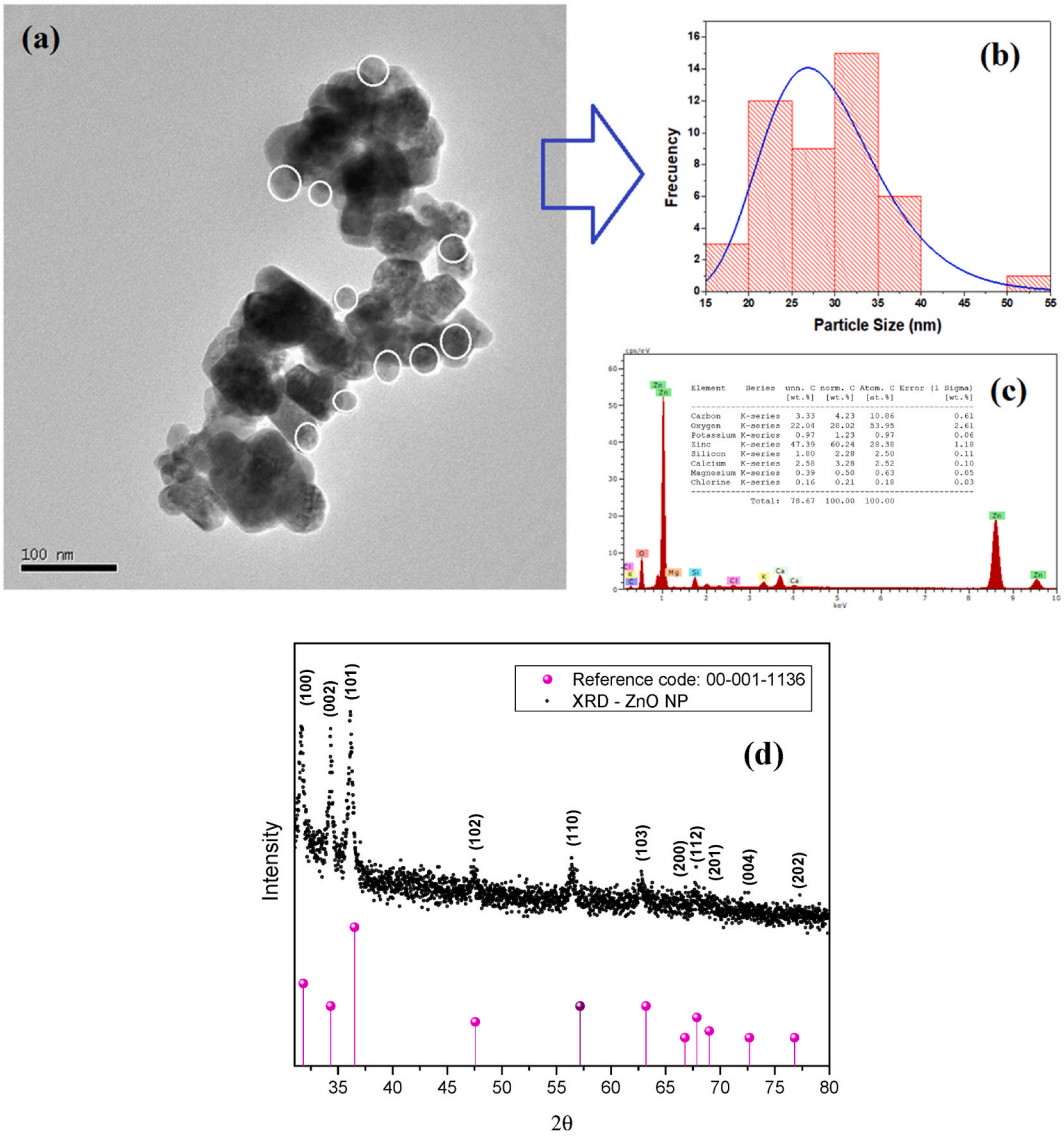

Fig. 2. Characterization of ZnO NPs by (a) Transmission electron microscopy, (b) Size histogram, (c) Elemental analysis by EDX, (d) XRD ZnO NPs.

elements is related to the treatment of the cell for analysis and some traces of the organic extract. Fig. 2(d) presents the X-ray diffraction (XRD) spectrum corresponding to the synthesized zinc oxide nanoparticles (ZnO NPs). X-ray diffraction analysis is a fundamental technique to characterize the crystal structure of the materials and provide information on the atomic arrangement and purity of the sample. In the X-ray diffraction spectrum shown in Fig. 2(d), several well-defined and intense diffraction peaks are observed, indicating high crystallinity in the ZnO NPs. The characteristic peaks correspond to the lattice planes (100), (002), (101), (102), (110), (103), and (112), with no peaks due to impurities observed. The presence of high intensity peaks suggests a periodic and regular arrangement of the zinc and oxygen atoms in the crystalline structure of the nanoparticles. Furthermore, the absence of additional peaks in the spectrum suggests that the ZnO NPs are of high purity, without significant indications of impurities or additional phases. To identify the crystalline phases present in the ZnO NPs, additional analyzes of the diffraction peaks were carried out using reference databases, such as the X'Pert HighScore software. The results of these analyzes revealed that the main peaks correspond to the dominant crystalline phases of ZnO, such as the hexagonal wurtzite structure (No. 00-001-1136). This confirms that ZnO NPs have a highly pure and well-defined crystal structure. In addition to crystallinity and purity, the analysis of the diffraction peaks also allows obtaining information about the crystallite size and the preferential orientation of the ZnO NPs. Using the Debye-Scherrer technique, the average size of the crystallites is estimated to be approximately 9.69 nm. This relatively small size indicates that ZnO NPs have a nanocrystalline morphology, which may have significant implications for their optical and electronic properties.

The mechanism of green synthesis of ZnO NPs using Coriandrum sativum extract as a reducing agent involves the utilization of reducing compounds present in cilantro, such as polyphenols and flavonoids, which interact with zinc ions in zinc acetate. These compounds donate electrons, reducing zinc ions and leading to the formation of zinc nanoparticles, which can subsequently undergo oxidation to become zinc oxide nanoparticles (ZnO).

3.2. Effect of ZnO NPs and ultraviolet light on E. coli and S. aureus

It was observed that the sanitizing treatment against *E. coli* had a 100 % growth inhibition effect expressed in CFU at 1, 2, and 3 min as shown in Table 1 and Fig. 3 (a,b). In the case of the sanitizing effect against *S. aureus*, it had a >99 % growth inhibition in all treatments, although the best one was at 3 min, as shown in Table 2 and Fig. 4 (a,b).

3.3. Effect of ZnO NPs and ultraviolet light on C. albicans and A. brasiliensis

The sanitizing effect had 100 % growth inhibition expressed in CFU against *C. albicans* at 1, 2, and 3 min as shown in Table 3 and Fig. 5 (a,b). The sanitizing effect against *A. brasiliensis* was >99 % at 1 and 2 min and 100 % at 3 min, showing the best effect (Table 4 and Fig. 6 (a, b)).

4. Discussions

ZnO NPs have a background as potential nanomaterials with antimicrobial and antifungal properties. Their mechanism is based on the mechanical alteration of the bacterial cell membrane site and increased bactericidal activity [38]. However, their efficiency improves when there is a photoactivation process of response to irradiation wavelengths in the ultraviolet region because it has a forbidden bandwidth of 3.2 eV, corresponding to the absorption threshold of 380 nm [39,40] since photocatalytic activity occurs when the ZnO NP absorbs a photon with an energy equal to or greater than the energy of the forbidden band of the material, which causes the formation of electron-hole pairs that subsequently migrate to the ZnO surface and react with the absorbed molecules, generating reactive species such as H_2O_2, superoxide (O_2^-) and hydroxyl (OH) anion radicals [41,42].

In our study, the UV-B light + ZnO NP treatment showed a 100 % bactericidal effect against *E. coli* for 1, 2, and 3 min of exposure. Similarly a previous study using *Cassia alata* plant extract as a reducing agent in the green synthesis process of Zinc oxide nanoparticles showed a dose-dependent activity of nanoparticles with an IC_{50} value of 20 μg/mL against *E. coli* [43]. Regarding the mechanism of action, ZnO NPs have been shown to cluster to negatively charged bacterial membranes due to their positive charges leading to loss of membrane integrity and protein damage at the intracellular level resulting in a bactericidal effect [44,45]. Another previous study using UV-B + ZnO NP (1 mg/mL) showed a bactericidal effect against *E. coli* at 30 s of UV-B in 3 cycles +30 min of nanoparticle exposure [46]. In contrast to our research, only 1 UV-B cycle simultaneously with the nanoparticles were used for 1, 2, and 3 min with 100 % bactericidal effect against *E. coli* at 99.18 μg/mL. The synergy between UV-B light and metal nanoparticles has been observed to generate free radicals, which would be responsible for the bactericidal power [47–49]. Another study using ZnO NPs at 12 mmol L^{-1} showed complete inhibition of *E. coli* O157:H7 growth [50]. Thus, the powerful bactericidal effect of UV-B light + ZnO NP

Table 1
Colony Forming Units of *E. coli* recovered after the treatments and percentages of elimination by UV-B light and UV-B light + ZnO NP compared to the negative control.

Negative Control	$2{,}87 \times 10^7 \pm 0{,}08$ UFC a		
Treatment	**1 min**	**2 min**	**3 min**
UV-B	0 a (100 %)	0 a (100 %)	0 a (100 %)
UV-B + ZnO NP	0 a (100 %)	0 a (100 %)	0 a (100 %)

a = A significant difference of $p < 0.05$ between treatments compared to the negative control.

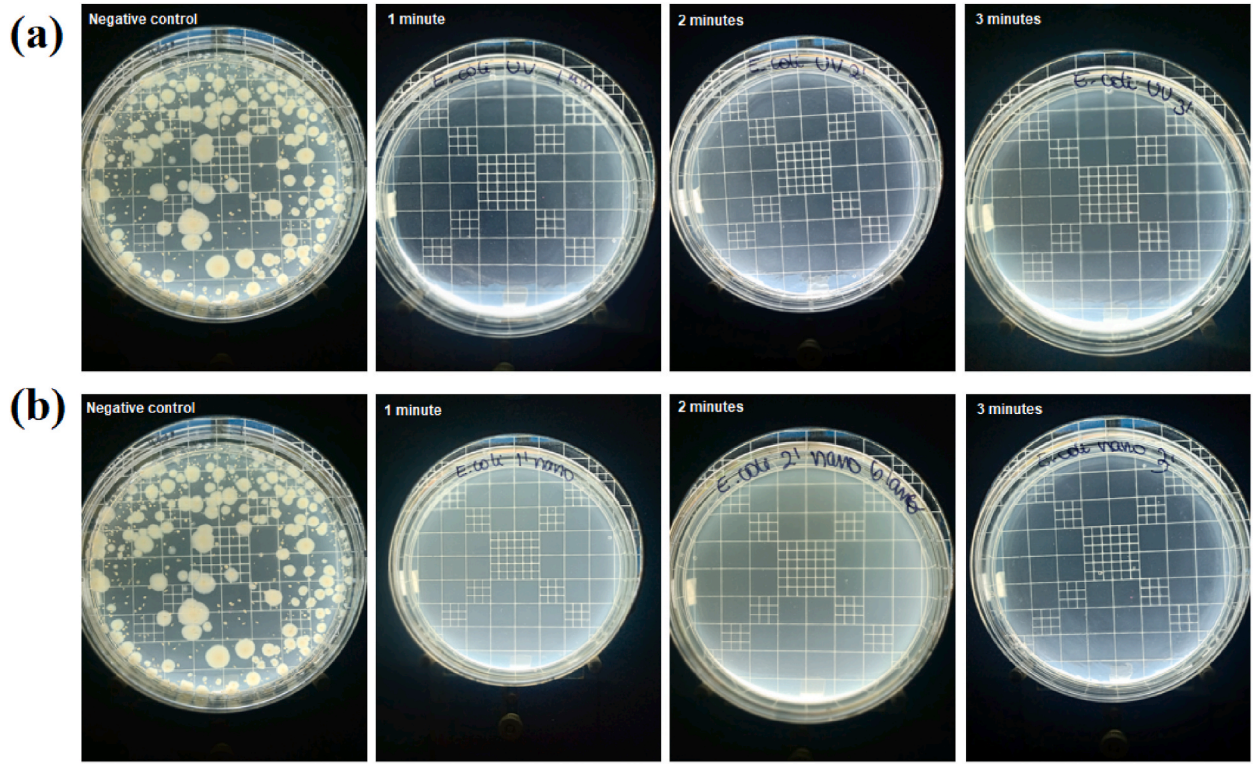

Fig. 3. Representative photos of Colony Forming Units of *E. coli* in (a) negative control and UV light treatment at 1, 2, and 3 min (top section) and (b) negative control and ZnO NP + UV light at 1, 2, 3 min.

Table 2
Colony Forming Units of *S. aureus* recovered after the treatments and percentages of elimination by UV-B light and UV-B light + ZnO NP compared to the negative control.

Negative Control	$7{,}77 \times 10^7 \pm 1{,}66$ UFC a, b		
Treatment	**1 min**	**2 min**	**3 min**
UV-B	31 ± 6 a, b (>99 %)	20 ± 2 a, b (>99 %)	23,33 ± 4,51 a, b (>99 %)
UV-B + ZnO NP	22,33 ± 4,51 a, b (>99 %)	20,33 ± 4,73 a, b (>99 %)	2,33 ± 0,58 a, b (>99 %)

a = A significant difference of $p < 0.05$ between treatments compared to the negative control.
b = A significant difference of $p < 0.05$ between ultraviolet light, ultraviolet light plus nanoparticles, and negative control treatments compared to ultraviolet light plus nanoparticles treatment at 3 min.

demonstrated in our study is corroborated.

In the case of *S. aureus*, our study showed that the UV-B light + ZnO NP treatment reduced the bacterial load by > 90 %, being the treatment with the best effect after 3 min and being statistically significant compared to the other treatments ($p < 0.05$). It has been observed that Gram-positive bacteria are less susceptible to growth inhibition when compared to Gram-negative bacteria due to the lower negative charge in their membranes [51]. A study showed growth inhibition with a minimum inhibitory concentration (MIC) of 100 μg/mL of *S. aureus* at a concentration of 100 μg/mL of positively charged ZnO NPs [52]. A study on the effect of ZnO NPs against *S. aureus* showed a reduction of the biofilm of this bacterium by 50.4 % (256 μg/mL), 37.8 % (128 μg/mL), and 29.4 % (64 μg/mL), respectively [53]. In our study was >90 %. About toxicity, a study in India on the effect of ZnO NPs on *methicillin*-resistant *S. aureus* showed a bactericidal effect at concentrations of 150 μg/mL, being non-toxic to human keratinocytes and lung epithelial cells [54]. Similarly a research study on the bactericidal effects of ZnO NPs using the green (*Ulva fasciata* extract) and chemical method for the synthesis through an In Vivo assay in rats infected with *S. aureus*, where a good recovery at concentrations of 5 mg/kg of the rats in the ZnO NPs synthesized by the green method was shown [55]. Additionally research work developed in Iran using anti-resistant ZnO NPs showed a minimum inhibitory concentration (MIC) at 393.2 μg/mL, while the use of ZnO NPs with NPAg showed a MIC of 60.8 μg/mL. Therefore, both metals would be synergistic against *S. aureus* [56]. In our study, the way of exposure to the nanoparticles was by nebulization. What also indicated the microbicidal effectiveness of ZnO nanoparticles. It is important to highlight the antibacterial functions of ZnO nanoparticles [57], so the use of these nanoparticles in a disinfectant locker is important in the prevention of microbial infections.

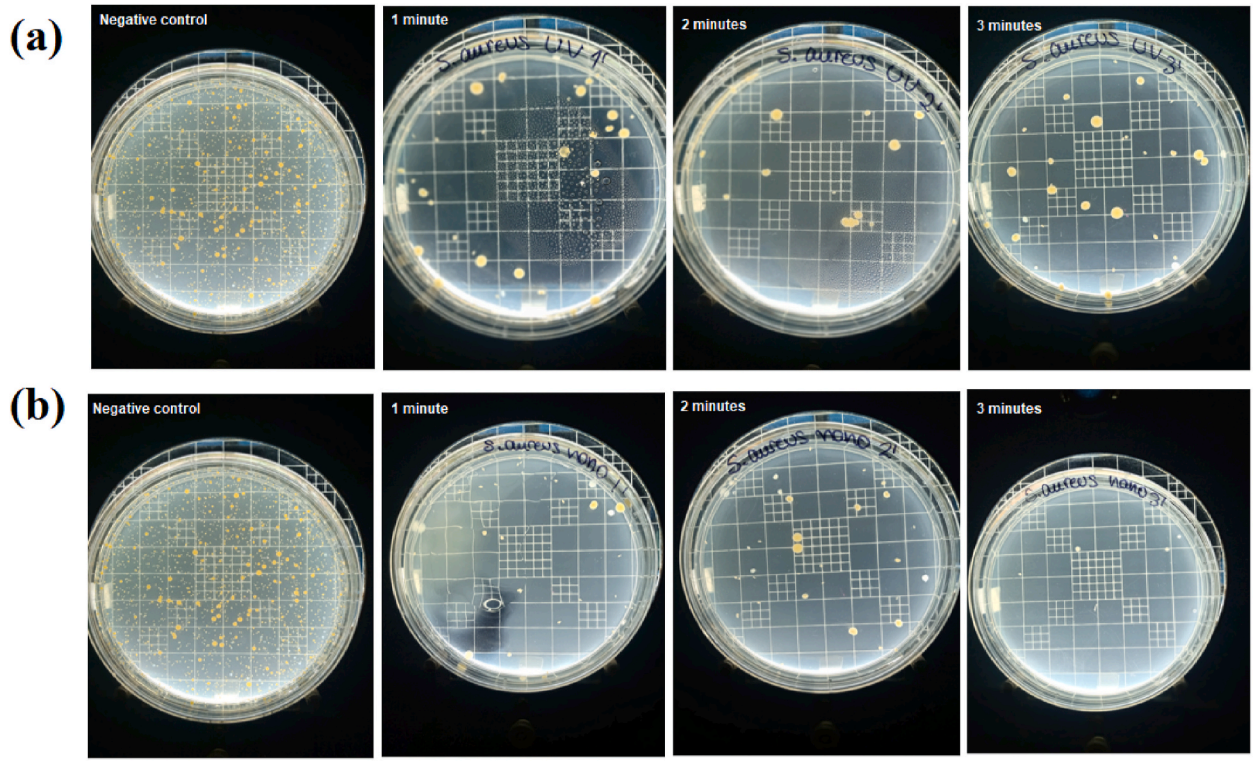

Fig. 4. Representative photos of Colony Forming Units of *S. aureus* in (a) negative control and UV light treatment at 1, 2, and 3 min and (b) negative control and ZnO NP + UV light at 1, 2, and 3 min.

Table 3
Colony Forming Units of *C. albicans* recovered after the treatments and percentages of elimination by UV-B light and UV-B light + ZnO NP compared to the negative control.

Negative Control	$2{,}54 \times 10^7 \pm 0{,}31$ UFC a		
Treatment	**1 min**	**2 min**	**3 min**
UV-B	1,33 ± 1,53 a (>99 %)	0 a (100 %)	0 a (100 %)
UV-B + ZnO NP	0 a (100 %)	0 a (100 %)	0 a (100 %)

a = A significant difference of $p < 0.05$ between treatments compared to the negative control.

In the case of *C. albicans*, the fungicidal effect of ZnO NPs + UV-B at 1, 2, and 3 min reached 100 % and was statistically significant against the negative control. A previous study using an InVivo model to determine the phagocytic response of *G. mellonella* after infection by *C. albicans* used ZnO NP at 0.2 mg/kg, reducing mortality up to 13 % compared to the negative control ($p < 0.05$), and when used at concentrations of 2 mg/kg all infected larvae survived, also demonstrating good tolerance to the concentrations tested [58]. This demonstrates the effectiveness of ZnO nanoparticles and the tolerance of eukaryotic cells to these nanoparticles. Another In Vitro study in Iran showed that using ZnO NP against *C. albicans* resulted in a minimum inhibitory concentration of 128 μg/mL and a minimum fungicidal concentration of 256 μg/mL [59]. In contrast our study, using ZnO NPs at 99.18 μg/mL + 1-min UV-B had 100 % growth inhibition. One of the additional advantages is that ZnO NPs and antifungals, such as caspofungin, have prevented cell wall-related antifungal resistance [60]. And it is also possible to use therapeutic combinations such as combination between lignin and ZnO NPs showed >90 % growth and virulence inhibition in both, at 12531.2 μg/mL and 62.5 μg/mL, respectively [61]. What makes the.use of ZnO nanoparticles flexible and multiple. *C. albicans* is an opportunistic pathogen that causes many cases of illness and death at the hospital level [61,62]. Therefore, the use of ZnO nanoparticles in the locker that eliminates *C. albicans* is of importance in Public Health.

It is important to highlight that ZnO nanoparticles exposed to ultraviolet light are excited, producing a large amount of free radicals that would be responsible for the inhibitory effect on microbial growth (Abdolalian & Taghavijeloudar, 2022).

The effect of UV-B light alone did not achieve a total inhibition (100 %) of *A. brasilienses* CFU growth, although significantly less compared to the negative control. The synergy of the treatments between UV-B + ZnO NP gave the best antifungal results, reaching 100 % growth inhibition in the UV-B + ZnO NP treatment after 3 min. *A. brasiliensis* is one of the main agents causing broncho-pulmonary aspergillosis, which can occur mostly by inhalation of contaminated air or, less frequently, by ingestion [63]. A previous

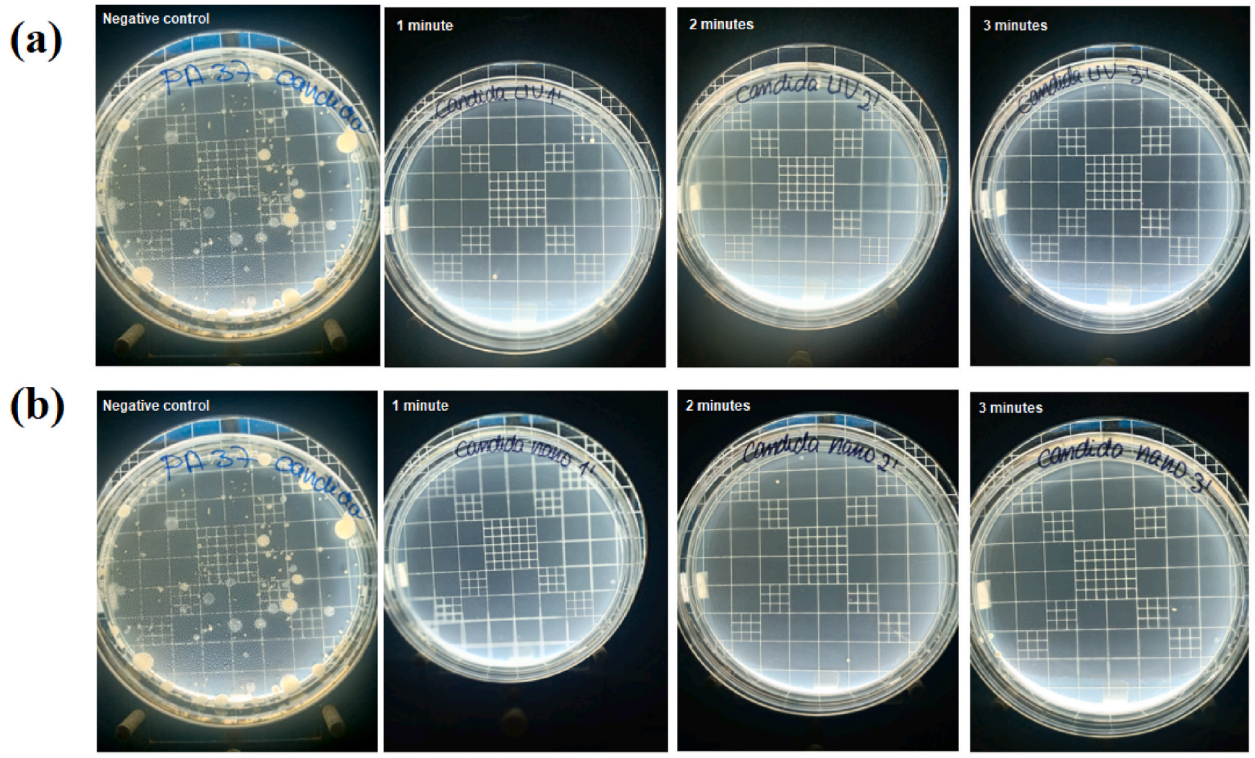

Fig. 5. Representative photos of Colony Forming Units of *C. albicans* in (a) negative control and UV light treatment at 1, 2, and 3 min and (b) negative control and ZnO NP + UV light at 1, 2, and 3 min.

Table 4
Colony Forming Units of *A. brasiliensis* recovered after the treatments and percentages of elimination by UV-B light and UV-B light + ZnO NP compared to the negative control.

Negative Control	$1{,}83 \times 10^7 \pm 4{,}04$ UFC a		
Treatment	**1 min**	**2 min**	**3 min**
UV-B	116,67 ± 1,53 a, b, c, e (>99 %)	121,33 ± 2,52 a, d, **c, e** (>99 %)	94 ± 4,58 a, b, d, c, e (>99 %)
UV-B + ZnO NP	34 ± 4,58 a, b, d, c, e (>99 %)	2,67 ± 0,58 a, b, d, e (>99 %)	0 a, b, d, c (100 %)

a = A significant difference of $p < 0.05$ between treatments compared to the negative control.
b, c, d, e = A significant difference of $p < 0.05$ between the treatments compared.

study using low-density polyethylene impregnated with ZnO NP at 500 μg/mL as a matrix against *A. brasiliensis* showed a 50 % inhibition of fungal growth [64]. Therefore, the use of nanoparticles ZnO plus ultraviolet light as used in our study would be promising as a suitable antifungal on inanimate surfaces.

5. Conclusions

Coriandrum sativum extract proved to be an excellent organic reducer of the precursor metal salt, where nanoparticles with spherical morphology and an average size of 30 nm were achieved. The locker sanitizer showed a correct performance. In this sense, it was observed that the use of UV-B light + ZnO NP (99.076 μg/mL) had an antibacterial and antifungal effect regarding growth inhibition of 100 % against *E. coli*, *C. albicans*, and *A. brasiliensis* and >99 % against *S. aureus* after 3 min of treatment on inanimate surfaces. The antimicrobial results have been very important and have a use in the elimination of infections and microbial contamination at the level of hospitals and industries.

Funding

Project UPN 20221009, UPN 20201002.

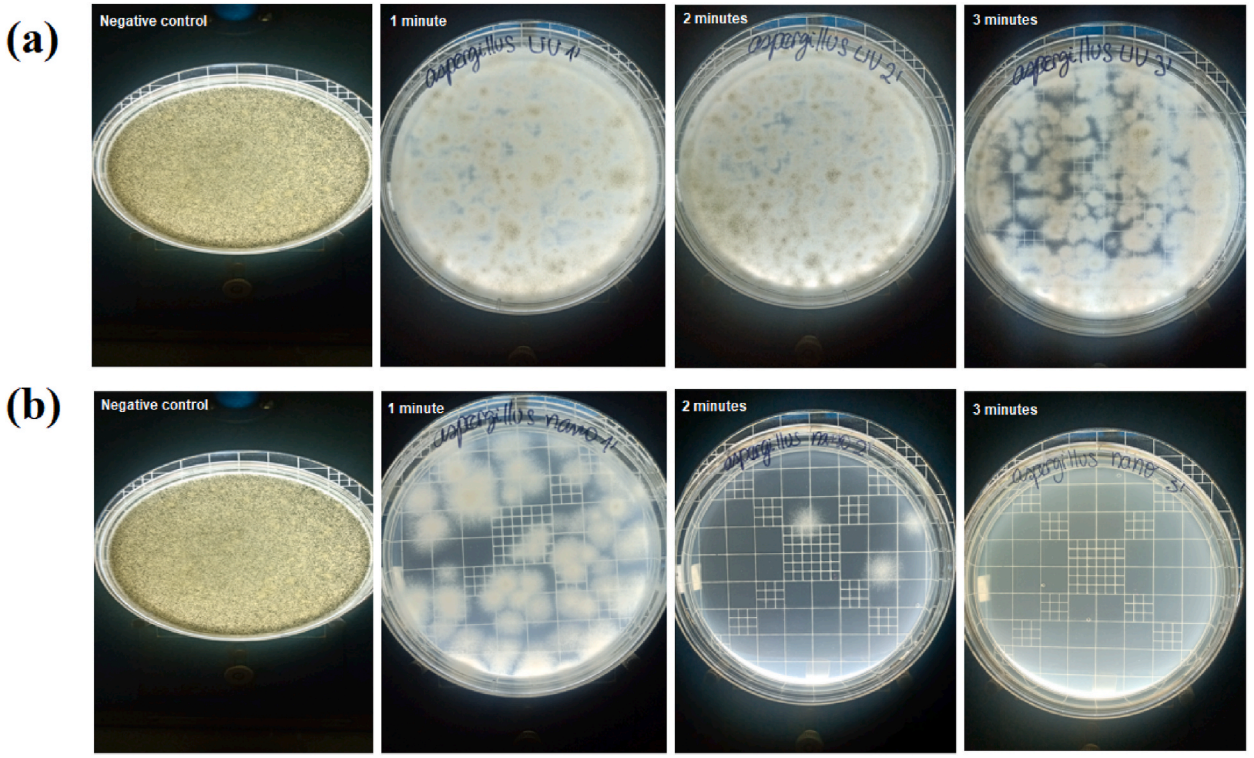

Fig. 6. Representative photos of Colony Forming Units of *A. brasilienses* in (a) negative control and UV light treatment at 1, 2, and 3 min and (b) negative control and ZnO NP + UV light at 1, 2, and 3 min.

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

David Asmat-Campos: Writing – original draft, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Jesús Rojas-Jaimes:** Writing – original draft, Investigation, Formal analysis, Data curation. **Marco Simbrón de la Cruz:** Writing – review & editing, Methodology, Investigation, Formal analysis. **Gabriela Montes de Oca-Vásquez:** Writing – review & editing, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This research is part of the project financed by the Universidad Privada del Norte (UPN) - Direction of Research, Innovation & Social Responsibility. Our special acknowledgment to the reviewers, whose suggestions will serve to improve this work.

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