

RESEARCH PAPER

Effect of Pulses Laser Nd:YAG on Functionalized (CMC – Silver) Nanoparticles: A Novel Approach to Bacterial Control

Huda Zaki Abdulrahman¹, Nada S. Ahmade^{2*}

¹ Department of physical, Collage of Science, University of Diyala, Diyala, Iraq

² Department of physical, Collage of Education for pure Science, University of Diyala, Diyala, Iraq

ARTICLE INFO

Article History:

Received 13 December 2025

Accepted 26 March 2026

Published 01 April 2026

Keywords:

CMC-AgNPs

FESEM

Nd:YAG

UV-Vis

ABSTRACT

This study investigates the effect of Nd:YAG pulsed laser irradiation on carboxymethyl cellulose (CMC) functionalized with silver nanoparticles (AgNPs) for bacterial control applications. The CMC-AgNPs nanocomposite was synthesized and exposed to varying laser fluences to enhance its structural, optical, and antibacterial properties. Characterization techniques such as UV-Vis spectroscopy, and FESEM were employed to analyze the modifications induced by laser treatment. The results indicate that laser irradiation significantly enhances the dispersion and stability of AgNPs within the polymer matrix, leading to improved antibacterial efficacy against *Escherichia coli* and *Staphylococcus aureus*. Lasers exert their antibacterial action primarily through thermal effects, which cause protein denaturation and membrane disruption, and photomechanical effects that physically rupture bacterial cells. Additionally, lasers (He: Neon, 5mW) can enhance the production of reactive oxygen species (ROS) in photodynamic therapy, leading to oxidative damage of bacterial DNA and cell walls. Recent studies also demonstrate the synergistic effects of combining laser irradiation with antimicrobial agents such as silver nanoparticles, resulting in increased bacterial membrane permeability and improved therapeutic efficacy.

How to cite this article

Zaki Abdulrahman H., S.Ahmade N. Effect of Pulses Laser Nd:YAG on Functionalized (CMC – Silver) Nanoparticles: A Novel Approach to Bacterial Control. J Nanostruct, 2026; 16(2):2060-2069. DOI: 10.22052/JNS.2026.02.052

INTRODUCTION

Laser-based techniques, such as laser ablation in liquids (LAL) and laser post-irradiation, offer precise control over nanoparticle synthesis and modification without the need for chemical reagents. By adjusting laser parameters such as wavelength, pulse duration, intensity, and exposure time researchers can tailor the size, shape, and surface characteristics of AgNPs. These changes directly influence their optical behavior, particularly their surface Plasmon resonance (SPR), a property central to their performance in

biomedical and sensing applications. Moreover, laser interactions can induce photo thermal effects, generating localized heat that enhances the antibacterial activity of AgNPs or enables their use in cancer therapy. Lasers also facilitate surface modifications and morphological transformations, enabling the development of highly functional nanomaterials [1,2]. In Table 1 when a laser beam interacts with a material, it transfers energy to the material in a controlled and localized manner. This interaction can lead to a wide variety of physical, chemical, thermal, and optical changes.

* Corresponding Author Email: nadaahmad@uodiyala.edu.iq



This work is licensed under the Creative Commons Attribution 4.0 International License.

To view a copy of this license, visit <http://creativecommons.org/licenses/by/4.0/>.

The exact effect depends on the laser parameters (wavelength, intensity, pulse duration, repetition rate) and the material properties (absorption, thermal conductivity, reflectivity) [3].

In Table 2 the interaction of laser light with silver nanoparticles opens a versatile and clean pathway for their synthesis, structural tuning, and application enhancement, making it a vital area of research in modern nanotechnology [4]. Antimicrobial Activity: Silver nanoparticles are highly effective against bacteria, fungi, and viruses, disrupting their cell membranes and interfering with vital processes. While silver nanoparticles offer numerous benefits, concerns about their environmental impact, potential toxicity to humans, and long-term stability need to be addressed. Research is ongoing to optimize their applications while minimizing risks. Silver nanoparticles represent a cutting edge material with a wide range of applications, driven by their unique properties and versatility. However, responsible use and further research are essential to fully harness their potential [5-8]. Carboxymethyl cellulose (CMC) is a water-soluble polymer derived from cellulose, the most abundant natural polymer found in plant cell walls. CMC is widely used across various industries due to its excellent thickening, stabilizing, and water-retention properties. It

is a versatile and biodegradable material that has become a key component in numerous applications. (CMC) is a chemically modified cellulose derivative, produced by the reaction of cellulose with chloroacetic acid under alkaline conditions. This process introduces carboxymethyl groups (-CH₂-COOH) into the cellulose backbone, making the polymer water-soluble and improving its functional properties. High solubility in water, forming clear or opaque solutions depending on the degree of substitution, exhibits excellent thickening and rheological control properties [9]. Table 3 laser ablation is a high-precision material removal process that uses a focused laser beam to vaporize, remove, or modify material from the surface of a solid or liquid. It is a versatile and non-contact technique used in various fields such as materials science, manufacturing, medicine, and research due to its ability to deliver precise control and minimal damage to surrounding areas. laser ablation, a high-energy laser pulse interacts with the material's surface, causing rapid heating, melting, or vaporization. Depending on the intensity and duration of the laser beam, material removal occurs through physical, thermal, or photochemical mechanisms [10]. laser ablation is a cutting-edge technology that provides unparalleled precision and control for material

Table 1. laser beam interacts with a material [3].

S	Physical Effect	Explain
1	Absorption	The material absorbs the laser energy, especially if the wavelength matches the material's electronic transitions.
2	Heating	Absorbed energy converts to heat, causing temperature rise in the material.
3	Melting and Vaporization	At high temperatures, the surface may melt or evaporate.
4	Ablation	With pulsed or intense lasers, material is ejected from the surface as atoms, ions, or plasma.
5	Plasma Formation	In high-intensity lasers, a plasma (ionized gas) may form above the surface.

Table 2. Mechanism of inhibition for bacteria [4].

S	Mechanism	Effect on bacteria
1	Cell Membrane Disruption	AgNPs attach to bacterial membranes, causing leakage and rupture.
2	Release of Silver Ions (Ag ⁺)	Silver ions penetrate the cell and bind to proteins and DNA, disrupting vital functions.
3	Generation of Reactive Oxygen Species (ROS)	Causes oxidative stress, damaging proteins, lipids, and DNA.
4	Inhibition of Enzymes and Replication	Interferes with enzymatic activity and DNA replication.

removal and modification. Its applications span from nanotechnology to medicine, making it a vital tool in advanced research and industrial processes [11]. Laser technology has gained considerable attention for its potential to inactivate bacteria through non-chemical, physical mechanisms. Lasers offer a precise, controllable, and non-invasive means of targeting bacterial cells, making them valuable tools in medical, dental, and environmental applications. When laser light interacts with bacterial cells, it can induce various effects depending on the wavelength, power, pulse duration, and exposure time. The primary antibacterial mechanisms include thermal damage, which disrupts cell membranes

and denatures proteins; photomechanical effects, which physically disrupt bacterial structures through shock waves; and photochemical reactions, which may produce reactive oxygen species (ROS) that lead to oxidative stress and cellular death. Furthermore, lasers can enhance the efficacy of antimicrobial agents such as silver nanoparticles (AgNPs) by increasing bacterial membrane permeability and facilitating agent uptake. This study investigates the antibacterial effects of laser irradiation alone and in combination with silver nanoparticles, evaluating changes in bacterial count and zones of inhibition against various strains. Understanding these interactions is crucial for developing effective, laser-based

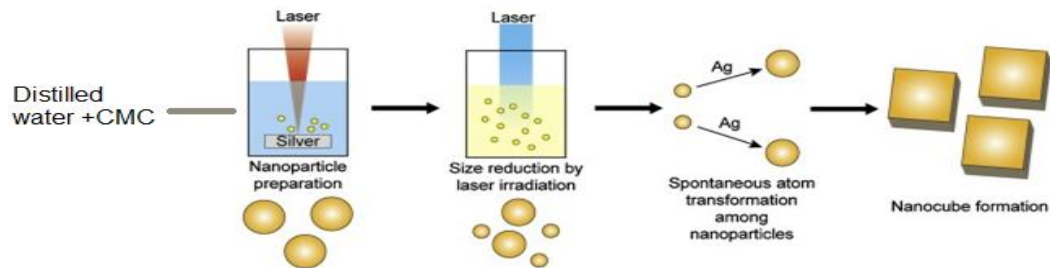


Fig. 1. Setup of laser ablation for synthesis silver Nanoparticles [12].

Table 3. Parameters of laser effect bacteria [10].

S	Parameter of Laser Ablation	Explain
1	Laser Wavelength	Determines the energy absorption efficiency based on the material's properties.
2	Pulse Duration	Can range from femtoseconds (ultrafast ablation) to nanoseconds or continuous waves, affecting precision and thermal impact.
3	Power Density	Higher power densities enable rapid material removal but may increase heat-affected zones.
4	Repetition Rate	The number of laser pulses per second influences the processing speed and material interaction. Advantages of Laser Ablation, Non-contact and precise material removal, Minimal mechanical stress on the material, Versatility in processing a wide range of materials, Ability to operate in small, complex geometrie, Challenges of Laser Ablation- Potential for thermal damage or heat-affected zones in certain materials.
5	High cost of laser systems.	Requires careful optimization of laser parameters for specific applications.

antibacterial therapies, particularly in the fight against antibiotic-resistant infections [8].

MATERIALS AND METHODS

Preparation silver Nano particles by Laser Ablation

A liquid solution consisting of a polymer (CMC) as a stabilizer was prepared to prevent aggregation and to ensure uniform particle size distribution. The CMC was dissolved in distilled water using a magnetic stirrer for 20 minutes before the silver plate was placed. A silver target (2×2 cm pellet) was placed at the bottom of a container that was filled with the prepared liquid medium. The liquid medium, containing distilled water and stabilizers (CMC), was selected to achieve the desired properties, as shown in Fig. 1.

Laser Irradiation

A high-energy pulsed laser (Nd:YAG, 1064 nm) was focused on the silver target. The laser pulses (100, 150, and 200 pulses) were applied, and the silver surface was rapidly heated, leading to material ablation. Plasma Formation and Nanoparticle Generation: A plasma plume was generated at the target–liquid interface by the laser energy, causing silver atoms and clusters to be ejected into the liquid medium. These

silver atoms were nucleated and were grown into nanoparticles due to rapid cooling in the surrounding liquid (Fig. 2).

The colloidal silver nanoparticles are collected as a dispersion in the liquid. characterization techniques like UV-Vis spectroscopy, SEM (Scan Electron Microscopy), advantages of laser ablation for AgNP synthesis. Ecofriendly Process, no chemical reducing agents or toxic precursors are required, reducing environmental impact, high purity, the nanoparticles are free of byproducts, ensuring high chemical purity [13-16].

The appropriate amount of Mueller-Hinton agar was dissolved in distilled water. It was sterilized by autoclaving at 121°C and 15 psi for 15–20 minutes. Approximately 20 mL of molten agar was poured into each sterile Petri dish. The agar was allowed to solidify at room temperature. A bacterial suspension was prepared in sterile saline or broth (0.5 McFarland standard, 1.1×10^6 CFU/mL). A sterile cotton swab was dipped into the bacterial suspension, and the bacteria were evenly spread across the agar surface using the swab to ensure a uniform lawn. Small wells (~6 mm in diameter) were made in the agar using a sterile cork borer or the wide end of a sterile pipette tip. The agar plugs were carefully removed from each well using

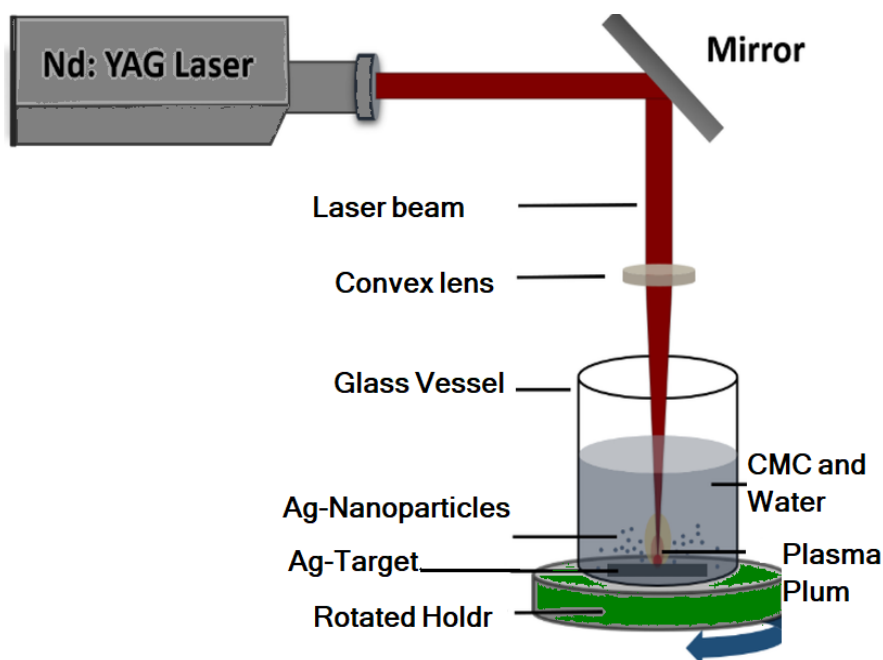


Fig. 2. Laser Irradiation.

a sterile tool. Fifty to one hundred microliters (50–100 μL) of the test substance were added to each well using a micropipette. The plates were left at room temperature for 1 hour to allow diffusion. The plates were incubated in an inverted position at 37°C for 24 hours. After incubation, clear zones around the wells were observed these were known as zones of inhibition. The diameter of these zones was measured (in mm) using a ruler or caliper.

A Helium-Neon laser with a typical wavelength of 632.8 nm was used. Common power settings were 5 mW. The laser was mounted on a fixed stand to ensure a constant distance (15 cm) from the Petri dish. The beam was fully directed toward the entire plate by using a beam expander. Exposure durations of 5, 10 minutes were selected. The distance and angle were kept constant. Optionally, control plates were covered with aluminum foil or a shield to avoid unintentional exposure.

RESULTS AND DISCUSSION

The X-ray pattern (XRD) for Silver nanoparticles (AgNPs)

Table 4 and Fig. 4 show the XRD intensity varies with the diffraction angle, reflecting the crystalline structure of the silver nanoparticles. Main diffraction peaks a sharp and intense peak appears around $2\theta \approx 38^\circ$ corresponding to the (111) crystal plane of face-centered cubic (FCC) silver. Other weaker peaks may correspond to higher-order reflections, such as (200), (220), or (311), depending on the synthesis conditions. Effect of pulse count as the number of laser pulses increases (from 100 to 200 pulses), the intensity of the (111) peak increases, indicating an increase in crystallinity or nanoparticle concentration. Curve “c” (200 pulses) has the most prominent peaks, that higher material yield and better-defined crystalline structure. Interpretation

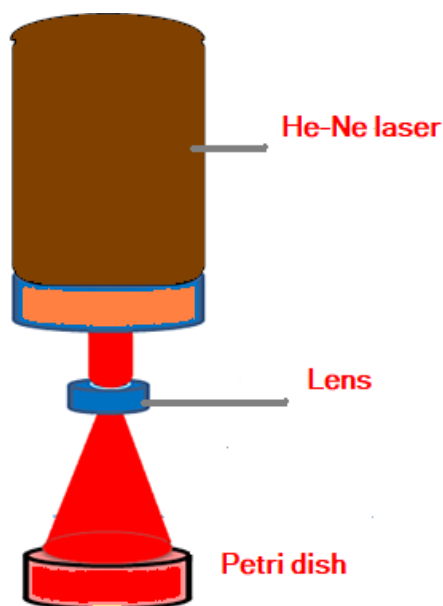


Fig. 3. Helium-Neon laser irradiation.

Table 4. Miller indices of AgNPs.

2 Theta (2θ)	Miller indices (hkl)
38.1°	111
44.3°	200
64.5°	220
77.4°	311
81.6°	222

crystallinity the prominent peaks, particularly at $2\theta \approx 38^\circ$ confirm the formation of crystalline silver nanoparticles with an FCC structure as Fig. 4. Pulse effect higher laser pulses increase the intensity and sharpness of the peaks, indicating larger or more abundant nanoparticles. Improved crystallinity due to prolonged laser exposure. Broadened peaks, slight broadening of peaks at lower pulses (curve "a") smaller nanoparticle sizes due to less ablation energy. Parameters influencing nanoparticle properties, customizable size and shape, the size and shape of nanoparticles can be controlled by adjusting laser parameters such as pulse duration, wavelength, and energy, Versatility Laser ablation can be performed in different liquid media to tailor nanoparticle properties. Like,

laser parameters, wavelength, flounce (energy per area), and pulse duration (nanoseconds, picoseconds, or femtoseconds). Liquid medium like, water solutions containing stabilizers affect particle size and stability. Target material and position, the purity and surface condition of the silver target, along with the distance between the laser beam and target, influence nanoparticle formation. And lest ablation time, longer ablation durations can produce higher concentrations of nanoparticles but may lead to larger particle sizes due to aggregation [17-20].

UV-Visible spectroscopy for Sliver nanoparticles (AgNPs)

Fig. 5 surface Plasmon resonance (SPR) peaks

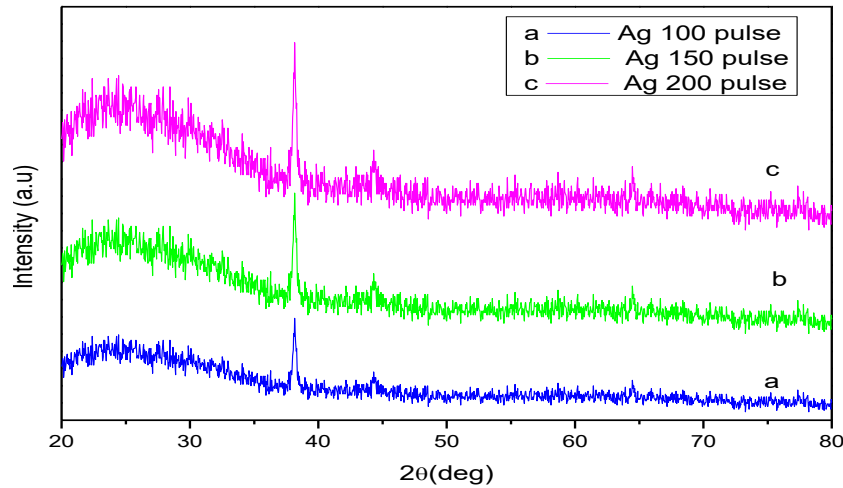


Fig. 4. XRD of (Ag-CMC) (a-100, b-150, c-200) pulse.

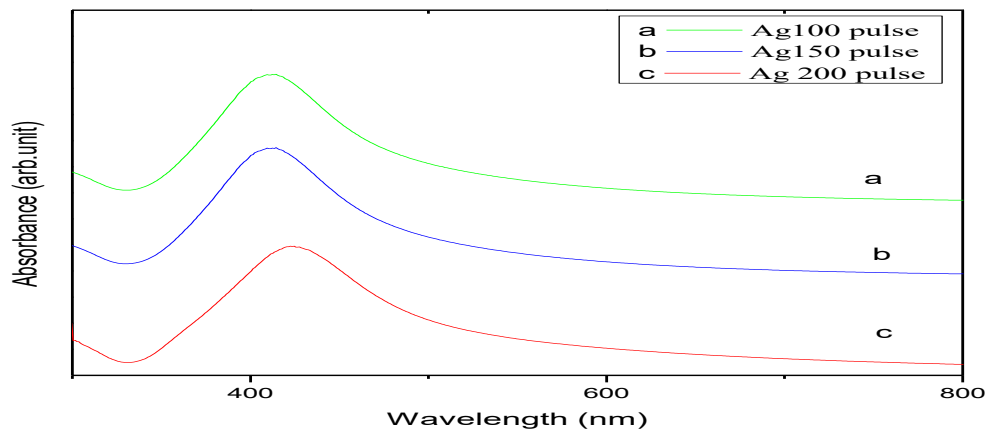
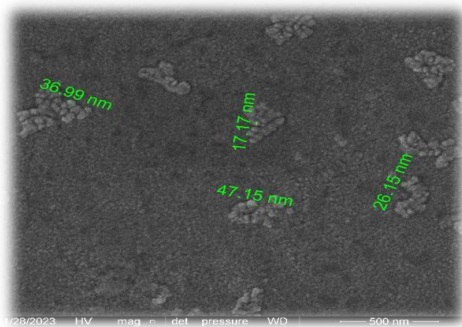


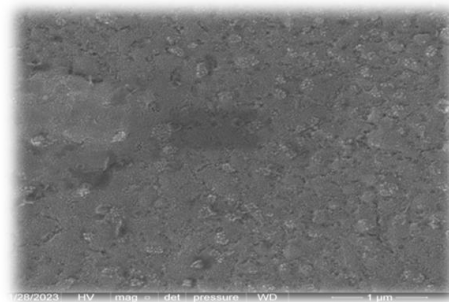
Fig. 5. UV. visible of (Ag-CMC) (a-100, b-150, c-200) pulse.

the distinct peaks in the spectrum are due to (SPR), a characteristic optical property of silver nanoparticles. SPR peaks are observed between 400–450 nm for all curves, which is typical for AgNPs. Peak intensity of the SPR were decreases from curve “a” (100 pulses) to “c” (200 pulses). This indicates that the concentration of nanoparticles and the extent of particle interaction changes

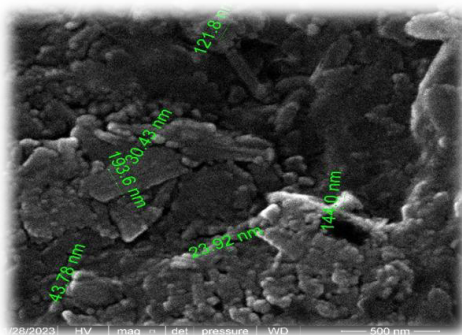
with the number of pulses. Peak shift, a slight redshift (movement to higher wavelengths) might be present as the number of pulses increases, an increase in particle size. Enhanced aggregation of nanoparticles due to prolonged laser ablation. Broadening of peaks, broader SPR peaks, particularly in curve “c”, could indicate, A wider size distribution of nanoparticles due to aggregation



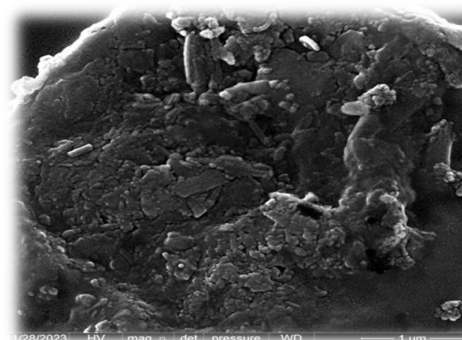
(a -500 nano-scale)



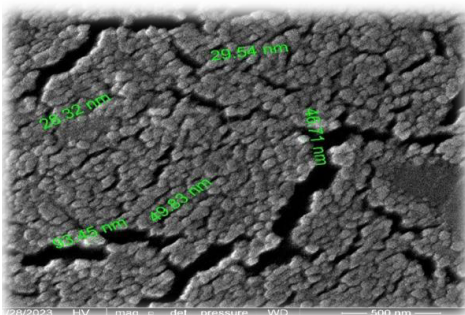
(a -1 Micro Scale)



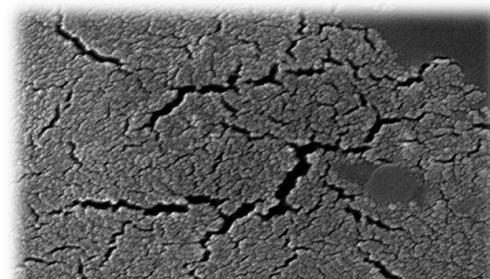
(b -500 nano-scale)



(b -1 Micro Scale)



(b-500nano-scale)



(b -1 Micro Scale)

Fig. 6. FESEM of (Ag-CMC) (a-100, b-150, c-200) pulse.

and the formation of larger clusters. Nanoparticle formation the presence of SPR peaks confirms the successful synthesis of silver nanoparticles [21].

The SPR peak position (~400–450 nm) corresponds to spherical or near-spherical nanoparticles. Effect of laser pulses 200 Pulses, peak intensity higher nanoparticle concentration, well-dispersed particles. 150 Pulse moderate intensity and sharpness indicate balanced particle size and dispersion. 200 Pulses Lower peak intensity and broadening due to particle aggregation and reduced nanoparticle yield due to possible overexposure. By controlling the number of laser pulses, the size, concentration, and optical properties of AgNPs can be tailored for specific applications. The UV-Vis spectrum validates the plasmonic behavior of silver nanoparticles and their dependence on synthesis, increasing laser pulses affects particle size, distribution, and interaction, as indicated by intensity and peak position changes [22].

Field emission scanning electron microscopy (FESEM)

Field emission scanning electron microscopy

(FESEM) for Silver nanoparticles (AgNPs) Fig. 6, the nanoparticles' sizes range between approximately 17.7 nm to 47.15 nm, indicating a variation in particle dimensions. The labeled sizes show the measurements of specific nanoparticles in the image. Nanoparticle morphology the particles appear roughly spherical, though some may exhibit slight clustering or aggregation. Aggregates are visible where multiple particles are closely packed together. due to interactions or insufficient stabilization during synthesis. Nanoparticle formation the FESEM image confirms the successful formation of silver nanoparticles with a nanoscale size range. The size variation arises from differences in energy delivery during laser ablation or varying growth conditions. Some clusters could form due to insufficient capping agents or stabilizers (CMC polymer). This aggregation might affect the optical and antibacterial properties of the nanoparticles. Homogeneity the size distribution seems moderately uniform, but smaller and larger particles coexist, the silver nanoparticles exhibit nanoscale dimensions suitable for applications like antibacterial, to achieve better dispersion and size uniformity, stabilizing agents like carboxymethyl

Table 5. Effect nanoparticles on two types of bacteria.

Sample	Concentration (µg/mL)	E. coli (mm)	S. aureus (mm)
Control (CMC only)	50	0	0
AgNPs	50	11	13
AgNPs	100	13	15
AgNPs + CMC	50	14	16
AgNPs + CMC	100	19	20

Table 6. Effect nanoparticles and laser on E. coli.

Sample	Bacterial Count (CFU/mL)	E. coli (mm)	Reduction in Bacteria%
Control	1.1 *10 ⁶	0	0%
Laser only	6.4 *10 ⁵	9	41.8%
AgNPs +CMC	2.9 *10 ⁵	13	73.6%
AgNPs + Laser (5mint)	2.6*10 ⁵	20	76.3%
AgNPs + Laser (10mint)	2.2 *10 ⁴	22	80%

Table 7. Effect nanoparticles and laser on S. aureus.

Sample	Bacterial Count (CFU/mL)	S. aureus (mm)	Reduction in Bacteria%
Control	1.1 *10 ⁶	0	0%
Laser only	6 *10 ⁵	17	45.4%
AgNPs +CMC	2.8 *10 ⁵	20	74.5%
AgNPs + Laser (5mint)	2.4*10 ⁵	24	78.2%
AgNPs + Laser (10mint)	2 *10 ⁴	27	81.8%



cellulose (CMC) can be used during synthesis. Aggregation might reduce specific properties like surface area or optical activity, so optimizing synthesis conditions is crucial [23-25].

Biology Part

Effect nanoparticles on two types of bacteria

First, the nanomaterial solution is prepared. Then used Well Diffusion Method for nanomaterials, Bacterial lawn is prepared by swab the bacterial suspension evenly across the entire Muller Hinton agar surface using a sterile cotton swab. Then, create wells in Agar by use a sterile cork borer (6 mm diameter) to punch wells into the agar. Remove the agar plug carefully. then, add nanomaterial with fill each well with a specific volume (50,100, μ L) of the nanoparticle solution. In last put the Patri Dish in incubate, at 37°C for 24 hours [1,4].

AgNPs have dose-dependent antibacterial activity increasing concentration improves the effect more effective against Gram-positive *S. aureus*, possibly due to thinner peptidoglycan layers compared to the protective outer membrane of Gram-negative bacteria. *P. aeruginosa* is least sensitive, which is typical due to its robust resistance mechanisms. Strong synergistic effect between AgNPs and CMC, at both concentrations, zones are larger than AgNPs alone. Even at 50 μ g/mL, the combo outperforms AgNPs at 100 μ g/mL (Table 5). CMC may enhance dispersion and stability of AgNPs, improving their interaction with bacterial cells [6,7].

Effect nanoparticles and Laser on Bacteria

Tables 6 and 7 laser alone shows moderate antibacterial effect that due to localized heating, photo-thermal effects, disruption of bacterial cell walls. Silver nanoparticles exhibit strong antibacterial properties likely, disrupting bacterial membranes, generating reactive oxygen species (ROS), Interacting with bacterial DNA and proteins, They're more effective than the laser alone. Combining laser and AgNPs significantly enhances antibacterial action. Laser increase AgNPs penetration and heating effect Laser also activate AgNPs lead to boosting ROS generation. Increasing laser exposure time to (10 min) slightly improves both inhibition zone and bacterial reduction antibacterial effect is reaching a saturation point. Extending the exposure from (5 to 10 minutes) yields minimal additional benefit the effect show

very activity in *S. aureus* than *E. coli*.in all case [20,21,26].

CONCLUSION

The use of silver nanoparticles (AgNPs) combined with carboxymethyl cellulose (CMC) polymer has proven to be an innovative and highly effective approach for combating bacterial infections. This synergistic combination leverages the potent antibacterial properties of AgNPs and the stabilizing, biocompatible nature of CMC, making it a promising material in various applications. Enhanced Antibacterial Effect, The AgNP-CMC composite exhibits broad-spectrum antibacterial activity by disrupting bacterial membranes, generating reactive oxygen species (ROS), and releasing silver ions. The presence of CMC enhances the dispersion and prolonged action of AgNPs. Versatility The composite material is applicable in diverse fields, including wound dressings, antimicrobial coatings, food packaging, and water purification. Its ability to be processed into films, hydrogels, or sprays makes it adaptable for different uses. Eco-Friendly and Sustainable, Green synthesis methods for AgNP-CMC composites minimize environmental impact while providing effective antibacterial solutions. Challenges Addressed: The use of CMC helps mitigate the potential risks associated with AgNP toxicity by ensuring controlled release and stability.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

REFRANCES

1. Haji SH, Ali FA, Aka STH. Synergistic antibacterial activity of silver nanoparticles biosynthesized by carbapenem-resistant Gram-negative bacilli. *Sci Rep.* 2022;12(1).
2. Anwar S, Khan RA, Ali H, Aziz U, Khanam B, Zakria M, et al. Antibacterial Efficacy of Tryptophan Coordinated Silver Nanoparticles Against *E. Coli*: Spectroscopic and Microscopic Evaluation of Bacterial Cell Death. *Elsevier BV*; 2024. <http://dx.doi.org/10.2139/ssrn.4910256>
3. Prajapati V, Luhana K, Patel B, Patel D, Sahu SK, Bagatharia S, et al. Multifunctional Silver Nanoparticles Synthesized via *Exiguobacterium aurantiacum*: Applications in Dye Remediation, Anticancer and Antibacterial Activity. *Curr Microbiol.* 2025;82(7).
4. Abbas K, Alethari I, Muslim E, Faja O. Anti-bacterial activity of green synthesized and surface modified silver nanoparticles with silica and dopamine for efficient cadmium removal from aqueous solutions. *Open Veterinary Journal.*

- 2025(0):1.
5. Aliero AS, Zawawi NA, Malek NANN, Usman BJ, Asraf MH, Matmin J, et al. Harnessing Palm Oil Mill Effluent for the Green Synthesis of Silver Nanoparticles: Optimization via Response Surface Methodology and Assessment of Antibacterial Activity. *Journal of Inorganic and Organometallic Polymers and Materials*. 2024;35(5):3580-3596.
 6. Qaeed MA, Hendi A, Obaid AS, Thahe AA, Osman AM, Ismail A, et al. The effect of different aqueous solutions ratios of *Ocimum basilicum* utilized in AgNPs synthesis on the inhibition of bacterial growth. *Sci Rep*. 2023;13(1).
 7. Fiegler-Rudol J, Skaba D, Kawczyk-Krupka A, Wiench R. Antibacterial and Bactericidal Effects of the Er: YAG Laser on Oral Bacteria: A Systematic Review of Microbiological Evidence. *Journal of Functional Biomaterials*. 2025;16(6):209.
 8. Katalinić I, Pranjić A, Budimir A, Kanižaj L, Bago I, Rajić V. Antimicrobial effect of 2.5% sodium hypochlorite irradiated with the 445 Nm diode laser against bacterial biofilms in root canal - in vitro pilot study. *Lasers Med Sci*. 2025;40(1).
 9. dos Santos GV, Moura HFS, Crugeira PJL, da Silva APLT, de Castro ICV, Costa WLR, et al. Photoinactivation of sulfate-reducing bacteria using 1,9-dimethyl-methylene blue – DMMB and laser light. *J Photochem Photobiol B: Biol*. 2025;263:113103.
 10. Siwach P, Sanan R, Nagpal A, Shetty OK, Bhardwaj A, Sharma M. Comparison of the antibacterial efficacy of 810 nm diode laser and photodynamic therapy in reducing microbial flora in patients with peri-implant mucositis – An in vivo study. *The Journal of Indian Prosthodontic Society*. 2025;25(1):40-45.
 11. Jassim NM, Diwan MH, Ahmade NS. Femtosecond Optical Nonlinearity Signal and Dark Field Scattering Microscopy of Gold Coated Zinc Oxide Nanowires. *Neuroquantology*. 2020;18(8):66-71.
 12. Ahmade NS, Abdullah HW, Abdullaha SS, Abdullah RM. Fabrication, characterization and some mechanical properties of graphene–kevlar epoxy hybrid. *AIP Conference Proceedings: AIP Publishing*; 2020.
 13. Abdullah HW, Ali ZM, Ahmade NS, Mahdi ZS. Preparation iron oxide nano powder in 20 minute. *AIP Conference Proceedings: AIP Publishing*; 2020. p. 020140.
 14. Jassim NM, Ibrahim NI. Z-Scan Study of the Non-linear Optical Properties of Silver/Curcumin Dye Nanocomposites Prepared Via Nanosecond Pulsed Laser Ablation. *Revue des composites et des matériaux avancés*. 2024;34(4):533-540.
 15. Jassim NM. Synthesis and nonlinear optical responses of Ag: ZnO core: shell nanoparticles induced by Z-scan technique. *Journal of Optics*. 2024.
 16. PLASMONIC Enhancement in Molecular Fluorescence of Natural Curcumin Dye With Silver Nanoparticles Synthesis and Biological Application. *Journal of Pharmaceutical Negative Results*. 2022;13(3).
 17. Jassim NM, Ali AH, Mohammed AJ. Experimental implementation of Raman scattering spectroscopy, photoluminescence and some optical properties of silver nanoparticles created by eco-friendly technique. *EUREKA: Physics and Engineering*. 2021(6):3-10.
 18. Jassim NM, Kareem NA, Ibrahim NI. Investigation on synthesis, structural and nonlinear optical responses of cadmium selenide coated with gold nanoparticles induced by femtosecond laser excitation. *Eastern-European Journal of Enterprise Technologies*. 2021;3(5 (111)):13-18.
 19. Jassim NM, Abed ZA, Mahdi ZS. Synthesis, Characteristics and Study the Photoluminescence of the CdSxSe1-x Nanocrystalline Thin Film. *Baghdad Science Journal*. 2020;17(1).
 20. Bishoyi AK, Mandhata CP, Sahoo CR, Samal P, Dubey D, Jali BR, et al. Biogenic Synthesis and Characterization of Silver Nanoparticles With *Cyanobacterium Oscillatoria salina* Using Against MDR Pathogenic Bacteria and Their Antiproliferative and Toxicity Study. *Cell Biochemistry and Function*. 2025;43(1).
 21. Syafiuddin A, Salmiati, Hadibarata T, Beng Hong Kueh A, Razman Salim M. Novel Weed-Extracted Silver Nanoparticles and Their Antibacterial Appraisal against a Rare Bacterium from River and Sewage Treatment Plan. *Nanomaterials*. 2017;8(1):9.
 22. Ullah H, Hefnawy M, Nawaz R, Baki ZA, Hanafiah MM, Anjum M. Green synthesis of silver nanoparticles via ionic liquid mediated ultrasonic extracted secondary metabolites from *Amaranthus viridis* and their antibacterial performance. *Chem Eng Commun*. 2025;212(9):1422-1436.
 23. Desouky E, Shalaby M, Gohar M, Gerges M. Evaluation of antibacterial activity of silver nanoparticles against multidrug-resistant Gram negative bacilli clinical isolates from Zagazig University Hospitals. *Microbes and Infectious Diseases*. 2020;1(1):15-23.
 24. Bhuyar P, Rahim MHA, Sundararaju S, Ramaraj R, Maniam GP, Govindan N. Synthesis of silver nanoparticles using marine macroalgae *Padina* sp. and its antibacterial activity towards pathogenic bacteria. *Beni-Suef University Journal of Basic and Applied Sciences*. 2020;9(1).
 25. Lubis FA, Malek NANN, Sani NS, Jemon K. Biogenic synthesis of silver nanoparticles using *Persicaria odorata* leaf extract: Antibacterial, cytocompatibility, and in vitro wound healing evaluation. *Particuology*. 2022;70:10-19.