Exp. Theo. NANOTECHNOLOGY 10 (2026) 13-23 https://doi.org/10.56053/10.1.13

Inhibitory effect of silver oxide nanoparticles and *Saccharomyces cerevisiae* on *Escherichia coli* and *Staphylococcus aureus* bacteria

Mais Qasem Mohammed[1,*], *Ahmed Hamed Mahde Shugran*[2]

[1]College of Health & Medical Techniques-Al-Dour, Northern Technical University, Al-Dour, 34002, Iraq
[2]College of Education for Pure Sciences, Department of Biology, Tikrit University
[*)] Email: mais.moh@ntu.edu.iq

Received 11/10/2025, *Received in revised form* 14/11/2025, *Accepted* 1/12/2025, *Published* 15/1/2026

Baker's yeast, or Saccharomyces cerevisiae, is a unicellular fungus that has been extensively studied and used as a suitable biofactory for the production of bio nanoparticles. The study aims to investigate the inhibitory effect of silver oxide nanoparticles on pathogenic bacteria. This study examines the biosynthesis, characterization, and antibacterial efficacy of silver oxide nanoparticles (AgO-NPs) that are synthesized from Saccharomyces cerevisiae extract. Pathogenic bacteria, specifically Staphylococcus aureus and Escherichia coli, are isolated and identified from diarrhoea samples and utilized as test organisms. Phytase enzyme is isolated from both commercial and locally sourced S. cerevisiae yeast using solvent extraction and precipitation techniques. The isolated enzyme functioned as a biocatalyst in the eco-friendly creation of AgO nanoparticles. Silver oxide is reduced and stabilized using the enzymatic extract, resulting in nanoparticles that are later characterized by FTIR, UV–vis spectroscopy, and scanning electron microscopy (SEM). FTIR examination verified the existence of functional groups, including hydroxyl, carbonyl, and amine groups, signifying the participation of proteins, phenols, and polysaccharides in the stabilization of nanoparticles. The UV–vis spectra exhibited a large absorption peak at 400–430 nm, indicative of surface plasmon resonance (SPR) in silver nanoparticles, whereas SEM micrographs displayed spherical, agglomerated nanoparticles with an average diameter of 53 nm. The antibacterial activity is evaluated using the well-diffusion method against Staphylococcus aureus and Escherichia coli. The AgO-NPs demonstrate concentration-dependent inhibition, achieving maximum inhibition zones of 15 mm and 16 mm, respectively, at 100 mg/dl. The results indicate the promise of yeast-derived silver oxide nanoparticles as environmentally sustainable and efficient antibacterial agents against pathogenic microorganisms.

Keywords: Saccharomyces cerevisiae; Silver oxide; Nanoparticles; Staphylococcus aureus.

1. INTRODUCTION

Over the past few decades, nanotechnology has emerged as a transformative field with substantial impact on biomedical sciences, particularly in the development of advanced drug-delivery systems [1]. Nanoparticle-based therapeutics have attracted considerable interest due to their unique physicochemical properties, which enable precise targeting of specific tissues and cells, thereby enhancing treatment efficiency while minimizing systemic toxicity [2]. Their ability to encapsulate drugs, protect them from premature degradation, and control their release profiles contributes to improved bioavailability and therapeutic outcomes. Moreover, by delivering drugs directly to the intended site of action, nanoparticles reduce the required dosage and associated side effects, addressing key limitations of conventional pharmaceutical formulations [3]. As research continues to expand the design and functional versatility of these nanocarriers, their potential in improving the management of various diseases—including cancer, infectious conditions, and neurological disorders—positions them as a critical and rapidly evolving component of modern medicine.

Baker's yeast, scientifically known as Saccharomyces cerevisiae, is a unicellular fungus that has been thoroughly researched and utilized as an effective biofactory for the synthesis of bio-nanoparticles. This organism is recognized for its major role in fermentation and its highly manipulable genome, which made it an exemplary model in studies involving cell cycle regulation, DNA repair, and protein synthesis [4,5]. Previous studies have shown that S. cerevisiae can inhibit the proliferation of various pathogenic bacteria such as Escherichia coli and Staphylococcus aureus through mechanisms involving antimicrobial metabolites, competition for nutrients, secretion of peptides, and β-glucans that compromise bacterial integrity [6]. Silver nanoparticles have also been widely investigated due to their optical, electrical, and antimicrobial properties, allowing their integration into medical and cosmetic applications [7]. Past research suggests that their antibacterial effects stem from the high affinity of silver for sulfur- and phosphorus-containing biomolecules in bacterial membranes and DNA, leading to impaired enzyme function, membrane damage, and DNA inactivation [8,9].

Based on the extensive previous research on S. cerevisiae and silver-based nanoparticles, the present study aims to investigate the inhibitory effect of silver oxide nanoparticles on pathogenic bacteria. Specifically, this work seeks to comprehensively evaluate their antimicrobial potential through assessing growth inhibition, determining minimum inhibitory concentrations (MIC), and examining their impact on bacterial morphology and viability. Additionally, the study aims to explore possible mechanisms of action, including membrane disruption, oxidative stress induction, and interference with essential cellular processes. By integrating these evaluations, the research intends to contribute to the development of effective nano-based antibacterial alternatives, highlight their potential advantages over conventional antibiotics, and support future applications in medical, industrial, and environmental fields.

2. EXPERIMENTAL

2.1 Bacterial sample collection

Staphylococcus and Escherichia coli bacteria samples are obtained by isolating and identifying them from diarrhea samples after culturing them on blood, MacConkey, and mannitol salt agar.

2.2 Extraction and Production of Phytase from S. cerevisiae 's Yeast

The method described by Ipata and Cerignani [10] is adopted as:
1 - One sample of dried S. cerevisia yeast from a well-known brand, supplied by foreign companies to the local market, is taken in one replicate to measure specific activity and protein concentration during the extraction and precipitation phase. The yeast is found to be the most efficient and effective for completing the subsequent purification steps to obtain a pure enzyme for biological applications.
2- Preparing local S. cerevisiae 's yeast: Local yeast is prepared using traditional methods using only flour and water, without any additives. A specific amount of flour, approximately 25 grams, is placed in a glass bottle with a tight lid. The same amount of distilled water (25 ml) is added to the flour and mixed well. The container is covered, leaving a small opening for air to enter for respiration. The mixture is left for 24 hours at room temperature (25°C). On the second day, 25 grams of flour and water are added, mixed, and left under the same conditions. This addition is important because the yeast needs nutrition to grow properly. This process is repeated for five days. Many bubbles are observed as a result of gas exchange, a clear indication of yeast formation in the dough. Additionally, the odor of the mixture changes to a smell resembling vinegar or acidic solutions, indicating the formation of methane gas. On the fifth day, after all the additions are complete, the container is tightly closed and placed in the refrigerator at 4°C for future use. The yeast is fed weekly to ensure its continuity.
3 - Toluene solvent
4 - Distilled water

2.3 Phytase enzyme extraction and production

100 g of prepared baker's yeast is weighed and mixed with 50 ml of organic toluene solvent. The mixture is placed in a water bath at 45°C for one hour. Leaved the mixture at room temperature at 25°C for 2-3 hours. Then, 100 ml of cold distilled water are added. The mixture is placed in a glass separating funnel and shake well for half an hour. Then, it is incubated at 4°C for 18 hours. The mixture is filtered, the separated aqueous phase is collected, and centrifuged it in a refrigerated centrifuge at 10,000 rpm at 4°C for 20 minutes. The filtrate is taken and the precipitate is discarded.

2.4 Preparation of Silver Nanoparticles (Ag-NPs)

Silver nanoparticles are prepared from the aqueous extract in the laboratories of the Scientific Research Authority, Environment and Water Center, using the method [11]. As follows:
1-A magnetic shaker is used to mix 5 ml of the previously prepared enzyme.
2- 1 g of silver oxide (AgO) is dissolved in 100 ml of deionized water, separated by dripping, at a flow rate of 0.2 ml/min, at a temperature of 60-70°C and 800 rpm for 30-60 minutes. After the color change, the solution is stored at room temperature for 24 hours to obtain a 1 mM silver nitrate solution.
3- Impurities are then separated by centrifugation (4500 rpm) for 30 minutes.
4-The precipitate is then collected, washed thoroughly twice with distilled water, and dried at 50°C in an oven to obtain silver oxide nanoparticles in powder form.
5- The formation of a precipitate and a change in the color of the material are considered the primary products of the nanomaterial.
6-Samples of the prepared and dried silver nanoparticles are sent for examinations, which included:

2.5 Characterization of silver nanoparticles

Silver oxide nanoparticles (AgO NPs) formed by the bioreduction of silver ions from the extract are detected using the following methods:

2.6 UV-vis spectroscopy

The optical properties of the silver oxide nanoparticles are determined from the previously prepared solutions. The sample solutions are transferred for examination using a UV-vis spectrophotometer to detect and record the absorbance of the biosynthesized silver AgNPs after exposure to wavelengths of 850-190 nm [12].

2.7 Scanning electron microscope (SEM)

The physical properties, such as shape and size, of the silver nanoparticles obtained from the silver oxide nanoparticle extract are studied using a scanning electron microscope. Samples are examined under different magnifications and constant voltage, and then are photographed [13].

2.8 Fourier-transform infrared spectroscopy (FTIR)

A biologically prepared silver oxide nanoparticle sample is examined. These active aggregates act as encapsulating and reducing agents for silver oxide nanoparticles. Samples are prepared by depositing them on a glass slide and drying them at 60°C in an electric oven for 30 minutes. They are then made into a paste with a highly viscous liquid such as Nujol paraffin oil. A small amount of this paste is then placed between two potassium bromide discs to form a very thin layer and examined using an infrared spectrometer [14].

2.9 Antimicrobial activity of the extract and silver-oxide nanoparticles by well-diffusion assay (WDA).

AgO_2-NP with S. cerevisiae 's Yeast extract are tested for their antibacterial activity against two dangerous bacteria, S. aureus and E. coli. We obtained the microorganisms from our studies. The microdilution method, as recommended by the Clinical and Laboratory Standards Institute (CLSI), is used to calculate the minimal inhibitory concentration (MIC) [15]. The first step is serially diluting any of the previously specified chemicals in 100 µL of Mueller-Hinton broth. A bacterial density of 0.5 McFarland standard is then attained by diluting the overnight bacterial cultures. A final volume of 200 µL is then obtained by adding 100 µL of bacterial suspension with different chemical concentrations (25, 50, 75, 100 mg/mL) to each well. Only bacterial suspension is used as the control.

3. RESULTS AND DISCUSSION

3.1 Analysis and characterization of silver oxide nanoparticles

3.1.1 Fourier transform infrared spectroscopy (FTIR)

Reversed functional groups on the particle surface indicate decreased and stabilized materials during production. O–H stretching vibrations of adsorbed water or phenolic and hydroxyl chemicals are caused broad absorption peaks at 3444–3230 cm^{-1}, indicating hydrogen bonding on the particle surface. The signal at 2931 cm^{-1} from aliphatic C–H vibrations suggests organic leftovers from the reducing chemicals or bioreactor used in the synthesis.

Peaks at 1712 and 1670 cm^{-1} indicate the C=O vibrations of carbonyl compounds, such as carboxylic acids or ketones, which stabilize particles on their surfaces. The peaks at 1593-1535 cm^{-1} are linked to amine N–H vibrations or aromatic compound C=C vibrations, indicating the role of proteins or phenols in particle encapsulation.

The range of 1388-1238 cm^{-1} is linked to C–N and C–O vibrations, indicating the presence of capping agents such sugars or natural polymers. Peaks at 1109-1038 cm^{-1}, indicating C–O–C or C–O vibrations, support the role of carbohydrates or ethers in stabilizing the particle surface. The Ag–O bond vibrations at 542 and 482 cm^{-1} are the principal spectral fingerprint of silver oxide nanoparticles (Ag_2O NPs).

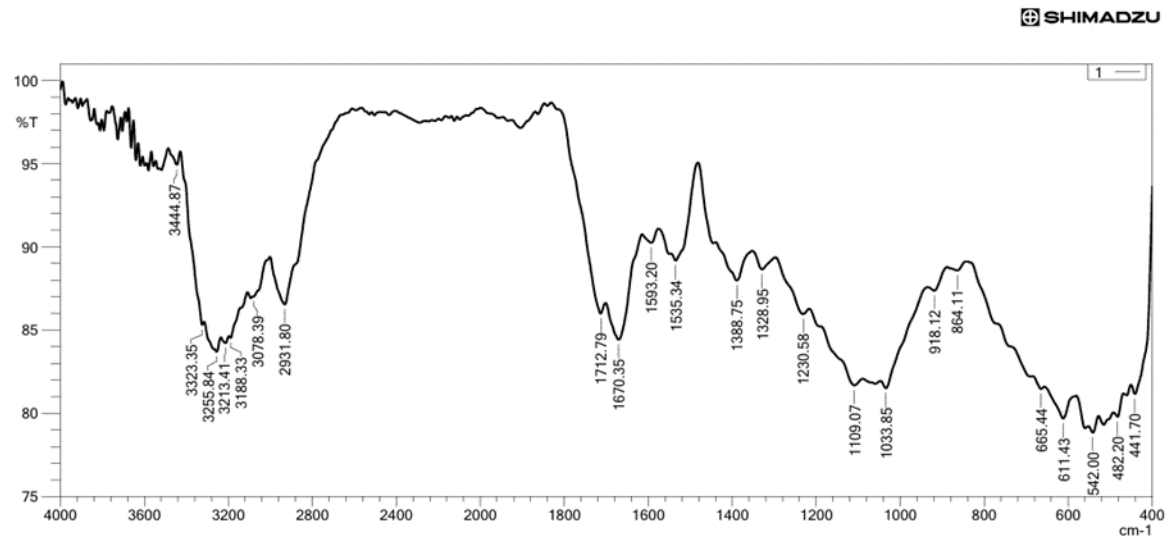

Figure 1 FTIR spectrum of silver oxide nanoparticles synthesized using S. cerevisiae extract.

3.1.2 UV-visible analysis

The absorption spectrum of the sample is recorded in the range of 230–1100 nm (Figure 2). The spectrum exhibits a broad absorption peak at approximately ≈ 400–430 nm, which is a typical feature of surface plasmon resonance (SPR) associated with silver nanoparticles or a mixture of metallic silver and silver oxide. The broadening of the peak and the high spectral background at long wavelengths indicate significant light scattering resulting from a broad particle size distribution or the presence of surface aggregates. The strong absorption at lower wavelengths (< 300 nm) also suggests inter-band transitions or the presence of organic surface compounds acting as capping agents. This indicates that the sample contains silver/silver oxide nanoparticles coated with organic compounds, which is consistent with the FTIR results, have revealed hydroxyl and carbonyl groups on the surface.

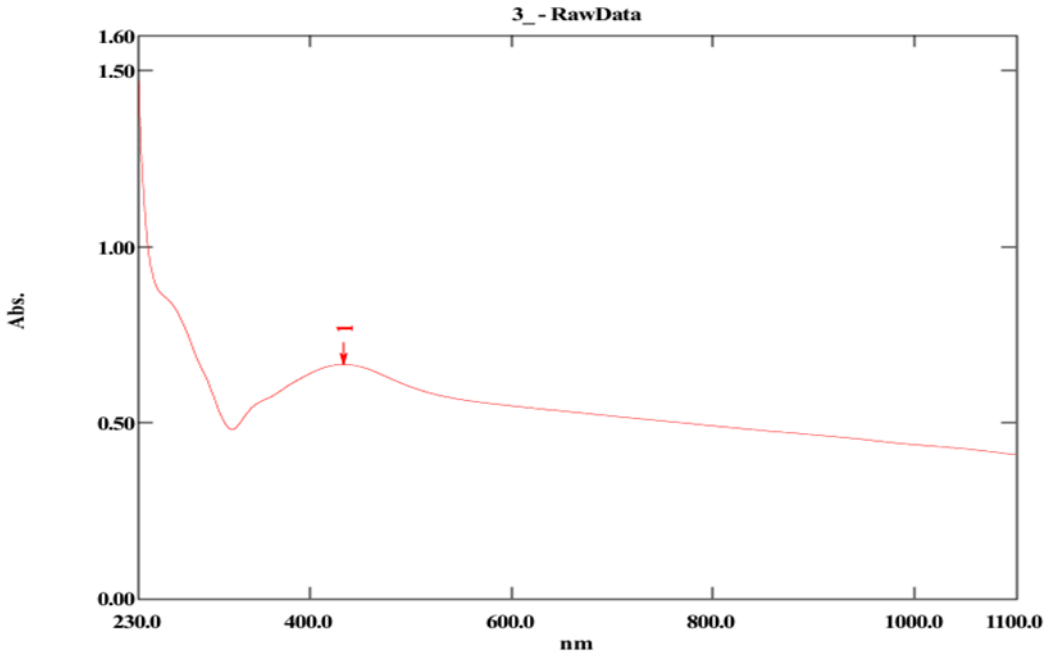

Figure 2 Characteristic surface plasmon resonance (SPR) peak at about 400-430 nm is visible in ultraviolet-visible spectra of silver oxide nanoparticles produced with S. cerevisiae extract.

3.1.3 Scanning electron microscope (SEM)

All measured values fall within a range of less than 100 nanometers, proving that the prepared particles are indeed nanosized. The measurement (53 nm) indicates that the particles are completely uniform in size, but there is some variation. This is normal when preparing using plant extracts, due to the presence of compounds in the extract (such as phenols and sugars) that affect the rate and degree of particle growth. from the image, we notice that the particles have a nearly spherical, agglomerated shape. This is also very common in the preparation of silver nanoparticles using plant extracts. The small size (53 nm) gives the particles high activity due to their large surface area. Aggregation may slightly reduce effectiveness in some applications, but the effect often remains strong, especially in antibacterial applications.

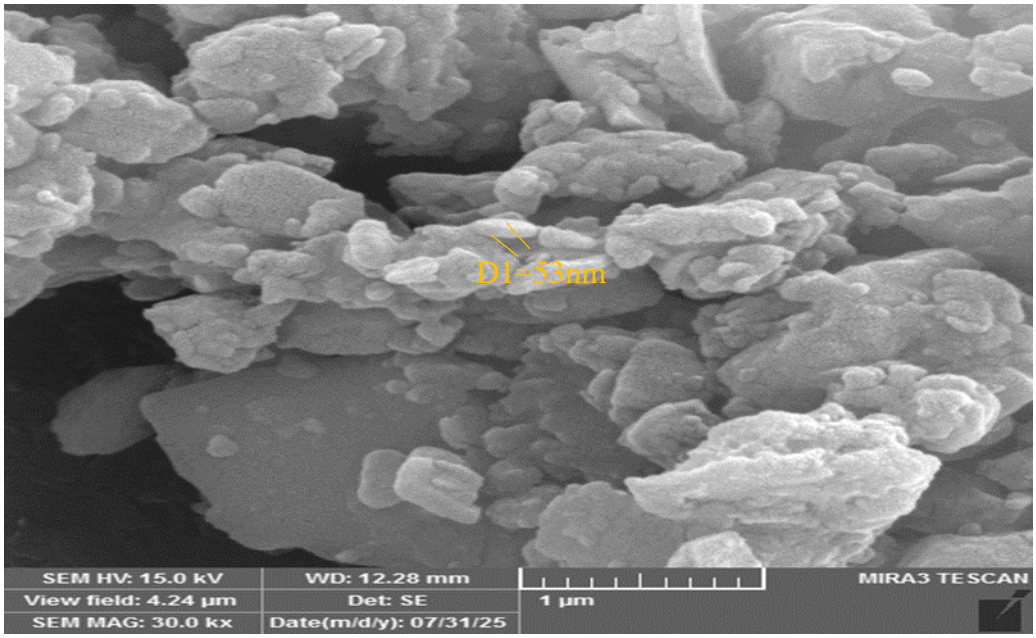

Figure 3 SEM of silver oxide nanoparticles synthesized using S. cerevisiae extract.

FTIR has showed that silver oxide nanoparticles (Ag_2O NPs) generated using Saccharomyces cerevisiae extract are surrounded by several functional groups, such as hydroxyl (O–H), carbonyl (C=O), and amine (N–H), as well as C–O and C–N bonds. Given this information, it is clear that bioactive chemicals, such as proteins, phenols, and sugars, play a crucial part in the process of stabilizing the particles and preventing them from aggregating [16], who reveals that proteins and phenolic compounds in bioactive extracts work as reducing and stabilizing agents for the particles, this result is compatible with the findings that they obtained. In addition, they have [17] demonstrated that the functional groups that are present on the surface of nanoparticles help to stability of the nanoparticles and guarantee that their biological activity is preserved.

There is a large absorption peak at around 400–430 nm, which is a characteristic peak of the surface plasmon resonance (SPR) phenomenon that occurs in silver nanoparticles, as demonstrated by the UV-Vis data [18]. Who confirms that the extended spectrum in this region reflects a wide variety in particle size and surface aggregation, this implies the creation of a mixture of metallic silver and silver oxide. The results of the Fourier transform infrared spectroscopy (FTIR) are supported by the existence of related organic molecules that act as encapsulating agents, as determined by the absorption at shorter wavelengths (< 300 nm).

As determined by scanning electron microscopy (SEM), the nanoparticles that are generated had a shape that is essentially spherical and had an average size of 53 nanometers. Due to its diminutive size, the specific surface area is increased, which in turn leads to a rise in bioactivity. It is noted that there is some agglomeration, which is a common phenomenon that occurs when utilizing plant or microbial extracts. This is because the presence of sugars and phenols, which control the growth rate of particles, is seen [19]. Research provides support for this identification. While the majority of research on the antibacterial properties of yeasts has focused on S. boulardii, numerous recent studies have investigated S. cerevisiae. Srinivas et al. investigated the antagonistic properties of S. cerevisiae OBS2 against various bacterial pathogens, including S. aureus, utilizing the agar well diffusion assay. The findings demonstrate the antibacterial efficacy of this strain against S. aureus and other pathogens [20]. Investigate the antagonistic properties of 28 strains of S. cerevisiae against several harmful

microorganisms. Fifteen examined strains exhibit antibacterial activity against S. aureus [21]. a study examining the antagonistic activity of the supernatant and lysate of the yeast S. cerevisiae against several pathogens utilizing the agar well diffusion method. Nonetheless, the supernatant and lysate extracts are not generated. The findings indicate that both the supernatant and lysate exhibited antibacterial activity against S. aureus [22].

In terms of their antibacterial activity, the nanoparticles that are synthesized showed a clear efficiency against both Staphylococcus aureus and Escherichia coli. The inhibition zones have reached 15 mm and 16 mm at the highest concentration (100 mg/dl), respectively. [23], silver nanoparticles interact with bacterial cell walls, affecting their permeability and enzymatic processes. This discovery is similar with the findings of the aforementioned researchers. In addition, the research [24] has demonstrated that silver nanoparticles have the ability to induce oxidative stress, which ultimately results in the death of bacterial cells. The buildup of a bigger number of active particles on the surface of the bacterium is the reason for the enhanced efficiency at higher concentrations, which may be explained by this particular phenomenon.

Investigated other effective combating strategies with potential anti-biofilm agents, including plant extracts, peptides, enzymes, lantibiotics, biosurfactants, metal nanoparticles, and polysaccharides such as polymer β-glucan has antibiofilm activity against gram-positive and -negative bacteria at 100 μg/ml. [25-26]. It proves that β-glucan prevented the biofilm inhibition of gram-positive and -negative bacteria at 25 μg/ml concentration.

We highlight those microbial extracts, such as those have derived from S. cerevisiae, are given the additional benefit of manufacturing nanoparticles that are both stable and ecologically friendly. This is something [27] mentioned in their review on green nanoparticle preparation techniques. In comparison to the findings of previous studies, we have found that this is advantageous. Because the results of FTIR, UV-vis, and SEM are consistent with antibacterial activity, this indicates that there is a clear correlation between the surface properties of the particles and their biological role. As a result, silver oxide nanoparticles that are prepared using microorganisms are a promising candidate for medical applications as an antimicrobial [28,29].

3.2 Antibacterial effect of silver oxide nanoparticles synthesized using S. cerevisiae extract against pathogenic bacteria

The result of the study shows that high concentrations (100 mg/dl) of silver -oxide nanoparticles synthesized using S. cerevisiae extract presents wide inhibition zones against S. aureus(15mm) and E. coli (16mm) compared with low concentrations, as shown in Table 1 and Figure 4.

Table 1 Inhibition zone of silver oxide nanoparticles synthesized using S. cerevisiae extract against pathogenic bacteria.

Nano-concentration Mg/dl	S. aureus Inhibition zone (mm)	E. coli Inhibition zone (mm)
25	11	14
50	12	14
75	12	15
100	15	16

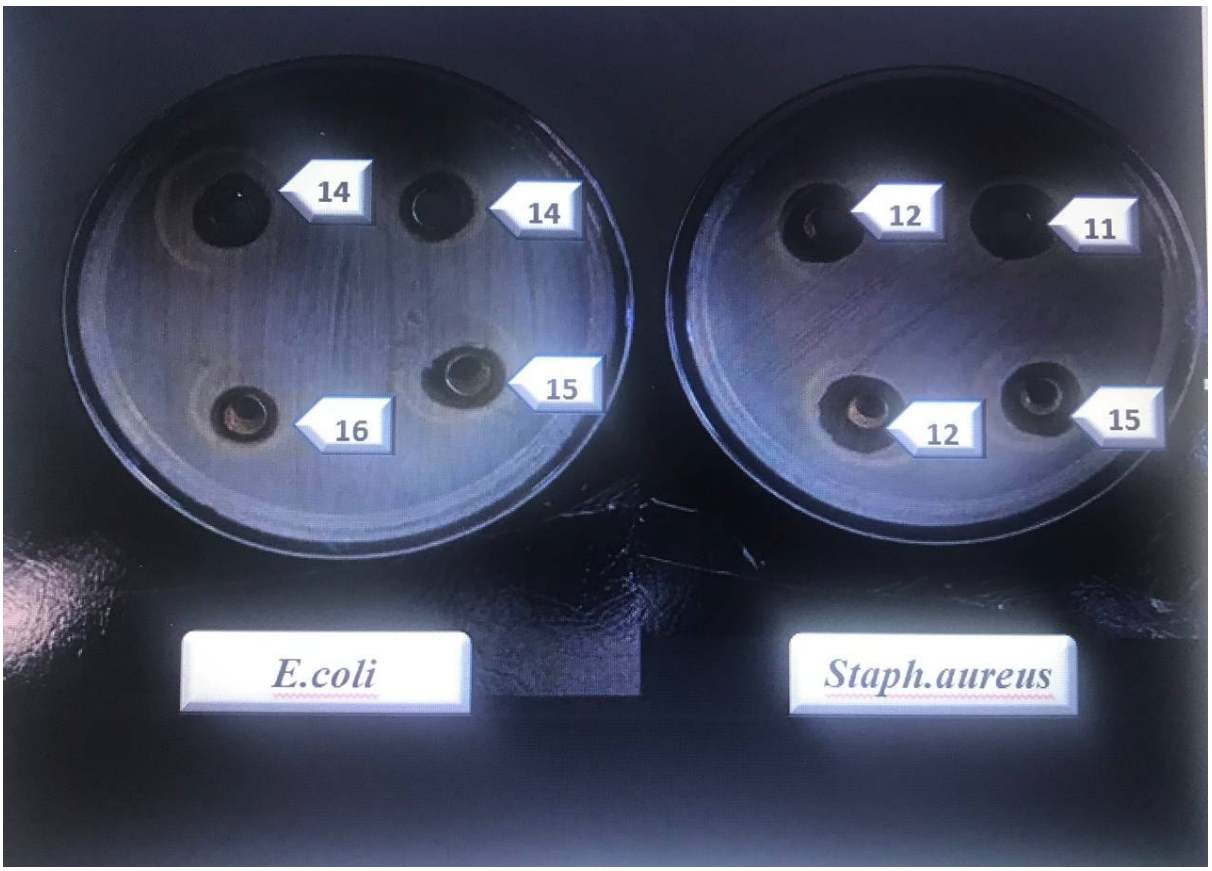

Figure 4 Inhibition zone of silver oxide nanoparticles synthesized using S. cerevisiae extract against pathogenic bacteria.

The silver oxide nanoparticles synthesized using Saccharomyces cerevisiae extract exhibit clear antibacterial activity against both Escherichia coli and Staphylococcus aureus. The inhibition zone diameters ranged from 14 to 16 mm for E. coli and from 11 to 15 mm for S. aureus, indicating a notable inhibitory effect on bacterial growth, which is consistent with previous reports highlighting the broad-spectrum antimicrobial potential of silver-based nanomaterials [30-31]. This activity is attributed to the physicochemical properties of the nanoparticles, which enable them to interact with bacterial cell walls and disrupt vital cellular processes through mechanisms such as enzyme inactivation and oxidative stress induction [32-33]. The slightly higher activity are observed against E. coli compared to S. aureus may be explained by structural differences in the cell wall architecture between Gram-negative and Gram-positive bacteria, affecting nanoparticle penetration and adhesion, as are suggested in comparative

studies [34]. These findings support the potential application of biologically synthesized silver-based nanoparticles as promising antimicrobial agents for medical or industrial use.

4. CONCLUSIONS

The findings of this study confirm that Saccharomyces cerevisiae extract can function as an effective, eco-friendly biocatalyst for the green synthesis of silver oxide nanoparticles. The produced AgO-NPs exhibited nanoscale dimensions with an average size of approximately 53 nm, along with characteristic morphological and structural features verified through FTIR, UV–vis and SEM analyses. The nanoparticles showed notable antibacterial activity against Staphylococcus aureus and Escherichia coli, demonstrating concentration-dependent inhibition and indicating their potential as sustainable antimicrobial agents. Overall, these results highlight the capability of yeast-derived extracts to serve as both reducing and stabilizing agents in nanoparticle synthesis, supporting their broader application in medical, industrial, and environmental fields.

References

[1] J. Y. Sung, Deng Z, S.W. Kim. Antibiotics 14 (2025) 301 https://doi.org/10.3390/antibiotics14030301
[2] E. Cojocaru, O. R. Petriș, C. Cojocaru, Pharmaceuticals 12 (2024) 1059 https://doi.org/10.3390/ph17081059
[3] A. A. Yetisgin, S. Cetinel, M. Zuvin, A. Kosar, O. Kutlu, Molecules 8 (2020) 2193 https://doi.org/10.3390/molecules25092193
[4] M. Parapouli, A. Vasileiadis, A. S. Afendra, AIMS Microbiol 6 (2020) 31 https://doi.org/10.3934/microbiol.2020001
[5] H. Barabadi, H. Vahidi, M. Arjmand, M. Abdorashidi, R. Jahani, S. Amidi, O. Hosseini, S. Sadeghian-Abadi, K. Jounaki, F. Ashouri. Inorganic Chemistry Communications 1 (2024) 112291 https://doi.org/10.1016/j.inoche.2024.112291
[6] Badis Bendjemil, Maram Mechi, Khaoula Safi, Mounir Ferhi, Karima Horchani Naifer, Exp. Theo. NANOTECHNOLOGY 8 (2024) 51 https://doi.org/10.56053/8.3.51
[7] A. Bouafia, S. E. Laouini, A. S. Ahmed, A. V. Soldatov, H. Algarni, K. Feng Chong, G. A. Ali, Nanomaterials 6 (2021) 2318 https://doi.org/10.3390/nano11092318
[8] I. X. Yin, J. Zhang, I. S. Zhao, M. L. Mei, Q. Li, C. H. Chu. Int. J. Nanomedicine 15 (2020) 2562
[9] B. Khalandi, N. Asadi, M. Milani, S. Davaran, A. J. Abadi, E. Abasi, A. Akbarzadeh, Drug research 11 (2017) 6 https://doi.org/10.1055/s-0042-113383
[10] P. L. Ipata, G. Cercignani. In Methods in Enzymology 51 (1978) 401 https://doi.org/10.1016/S0076-6879(78)51053-7
[11] M. Gauthami, N. Srinivasan, N. M. Goud, K. Boopalan, K. Thirumurugan, Nanoscience & Nanotechnology-Asia 1 (2015) 7 https://doi.org/10.2174/2210681205011507281032O9
[12] P. Ramesh, A. Rajendran, A. Meenakshisundaram, Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy 125 (2014) 78 https://doi.org/10.1016/j.saa.2013.12
[13] A. Gade, S. Gaikwad, N. Duran, M. Rai, Micron 1 (2014) 9 https://doi.org/10.1016/j.micron.2013.12.005
[14] S. Razavi, A. Partoazar, N. Takzaree, M. Fasihi-Ramandi, A. Bahador, M. H. Darvishi, Nanomedicine 13 (2018) 1331 https://doi.org/ 10.2217/nnm-2017-0385
[15] Y. S. Liu, Y. C. Chang, H. H. Chen, J. Food and Drug Analysis 1 (2018) 56 https://doi.org/10.1007/s40264-014-0250-z
[16] N. E. El-Naggar, N. A. Abdelwahed, W. I. Saber, A. Egyptian Journal of Biological Pest Control 26 (2016) 644 https://doi.org/10.3390/molecules30030684
[17] S. Pasieczna-Patkowska, M. Cichy, J. Flieger. Molecules 30 (2025) 684 https://doi.org/10.3390/molecules30030684

[18] S. Khairunnisa, V. Wonoputri, T. W. Samadhi, Materials Science and Engineering 1 (2021) 012006 https://doi.org/10.1088/1757-899X/1143/1/012006
[19] N. Saidi, P. Owlia, S. M. A. Marashi, H. Saderi, Iran J. Microbiol 11 (2019) 254 doi:10.4014/jmb.2008.08053
[20] M. D. S. F. Lima, K. M. S. Souza, W. W. C. Albuquerque, J. A. C. Teixeira, M. T. H. Cavalcanti, A. L. F. Porto, Microb Pathog 110 (2017) 677 https://doi.org/10.1016/j.micpath.2017.05.010
[21] M. Akruddin, M. N. Hossain, M. M. Ahmed, BMC Complement Altern Med. 110 (2017) 677 10.1159/000512494
[22] J. R. Morones, J. L. Elechiguerra, A. Camacho, K. Holt, J. B. Kouri, J. T. Ramírez, M. J. Yacaman, Nanotechnology 16 (2005) 2353 https://doi.org/ 10.1088/0957
[23] W. R. Li, X. B. Xie, Q. S. Shi, H. Y. Zeng, Y. S Ou-Yang, Y. B.Chen, Applied Microbiology and Biotechnology 85 (2011) 1122 10.1007/s00253-009-2159-5
[24] M. Rai, A. Yadav, A. Gade, Biotechnology Advances 30 (2012) 627 https://doi.org/10.2174/1573413123
[25] A. Iswarya, M. Anjugam, B. Vaseeharan, Fish Shellfish Immunol 68 (2017) 64 https://doi.org/10.1016/j.fsi.2017.07.002
[26] M. Rai, A. Yadav, A. Gade, Biotechnology Advances 27 (2009) 76 10.1016/j.biotechadv.2008.09.002
[27] H. H. Lara, N. V. Ayala-Núñez, L. Ixtepan-Turrent, C. Rodríguez-Padilla, World Journal of Microbiology and Biotechnology 26 (2010) 615 https://doi.org/10.1007/s11274-009-0211-3
[28] Asaad T. Al-Douri, Alaa A. Khaleel, Luay Mannaa ibrahim , Abeer Talib Abdulqader , Ammr Khalid Shihab , Mustafa Khaleel Ibrahim , Maksood Adil Mahmoud Al-Doori. Exp. Theo. NANOTECHNOLOGY 9 (2025) 563 https://doi.org/10.56053/9.4.563
[29] Maksood Adil Mahmoud Al-Doori , Nahedh Ayad Faris, Noor Adnan Mahmood, Asaad T. Al-Douri, Luay Mannaa ibrahim , Amna M. Al-Tikrity. Exp. Theo. NANOTECHNOLOGY 9 (2025) 555 https://doi.org/10.56053/9.4.555
[30] C. Marambio-Jones, E. M. Hoek, Journal of Nanoparticle Research 12 (2010) 1531 https://doi.org/10.1007/s11051-010-9900-y
[31] A. M. Fayaz, K. Balaji, M. Girilal, R. Yadav, P. T. Kalaichelvan, R. Venketesan, Nanomedicine: Nanotechnology, Biology and Medicine 6 (2010) 103 https://doi.org/10.1016/j.nano.2009.04.006
[32] Maksood Adil Mahmoud Al-Doori, Asaad T. Al-Douri, Nahedh Ayad Faris. Exp. Theo. NANOTECHNOLOGY 9 (2025) 503 https://doi.org/10.56053/9.3.465
[33] Ahmed Suhail Hussein,Noor Khalid Ismael, Asaad T. Al-Douri, Abbas Saeb Zaham, Ali Y.Alwan1, Mais Qasem Mohammed, Sama Amer Abbas El-Tekreti, Shaimaa Tarik Mahmood, Saeb Jasim Mohammed Alnajm,Younis W. Younis, Maksood Adil Mahmoud Al-Doori. Exp. Theo. NANOTECHNOLOGY 9 (2025) 512 https://doi.org/10.56053/9.3.505
[34] Safa Salah Salman, Asaad T. Al-Douri, Albosale Abbas Hadi,Saeb Jasim Mohammed Alnajm. Exp. Theo. NANOTECHNOLOGY 9 (2025) 372 https://doi.org/10.56053/9.2.361