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Microbicidal Activity Assessment of Polyvinyl Pyrrolidone Nanocomposite Embedded Zinc Oxide and Zingiber Officinale

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About Article

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ABSTRACT

Staphylococcus aureus (Gram-positive), *Acinetobacter baumannii* (Gram-negative), and *Candida albicans* (yeast) are significant and dangerous Urinary tract infection (UTI) isolates, due to their production of multiple virulence factors and high antibiotic resistance. Therefore, our study aimed to synthesize a nanocomposite compound, Polyvinyl Pyrrolidone (PVP) embedded with zinc oxide (ZnO) and Zingiber officinale as antimicrobial agents by using the solution-casting method. The PVP-ZnO-Zingiber officinale nanocomposites were identified through FE-SEM and XRD analyses. The nanocomposites were oval or spherical, crystalline, homogeneous, and stable, exhibiting SPR at 300 nm. The MIC of PVP-ZnO-Zingiber officinale nanocomposites was determined. *C. albicans* displays the least susceptibility to PVP pure, PVP-ZnO-Zingiber officinale (1 µg/mL), PVP-ZnO-Zingiber officinale with (2 µg/mL), and PVP-ZnO-Zingiber officinale (3 µg/mL), with an MIC value of 10, 2, 3, and 4 µg/mL, respectively. *S. aureus* exhibited moderate susceptibility, with an MIC value of 5, 2, 4, and 4 µg/mL, respectively. In contrast, *A. baumannii* showed a high susceptibility, with MIC values of 4, 2, 3, and 3 µg/mL, respectively. These investigations support the safe use of low-concentration PVP-ZnO-Zingiber officinale nanocomposites; however, further studies are needed to assess nanocomposites for clinical use.

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1. INTRODUCTION

The prevalence of multidrug-resistant (MDR) microorganisms demonstrates a significant problem and global public health attention in managing nosocomial infections, especially in vulnerable people such as UTI patients. The crisis of antibiotic resistance has become a global issue that attracts the attention of researchers through the development and use of new microbicidal methods and agents (Salam *et al.*, 2023). Recently, polymers have received fundamental attention due to their increased efficacy and biomedical use as microbicidal agents in several fields, including biology, bioremediation, biomedicine, biotechnology, water purification, and food packaging (El-Sherbiny *et al.*, 2024). PVP (Polyvinyl Pyrrolidone) is one of the polymers that has been widely studied due to its high film-forming, biocompatibility, and biodegradability. PVP is also characterized as being safe, non-toxic, water-soluble, inert, pH-stable, temperature-resistant, and having mechanical strength. This makes it suitable for coating lipophilic and hydrophilic drugs (Doan & Tran, 2023). The blending of metal zinc oxide nanoparticles (ZnO) with polymer nanocomposites has obtained significant attention due to their microbicidal effectiveness and physicochemical advantages (Radulescu *et al.*, 2023). The ZnONPs have been distinguished by their broad-spectrum efficacy against pathogen microorganisms, rendering them valuable and highly significant in therapeutic applications (Youssef *et al.*, 2024). The effect of microbicidal ZnONPs occurs through several methods, the most considerable of which are inhibition of cellular metabolic pathways, biofilm disintegration, and oxidative stress (Krishnamoorthy *et al.*, 2022). Ginger (*Zingiber officinale*) has been a distinctive medicinal value due to its various therapeutic advantages, the most significant of which are antioxidant, antimicrobial, and anti-inflammatory (Tarfaoui *et al.*, 2022). Ginger's most important mechanisms of microbicidal action involve the destruction of cellular membranes and inhibition of virulence factors, especially biofilm production (Krishna *et al.*, 2024). The synergy of ZnONPs and ginger in a polymer matrix can cause broad-spectrum microbicidal effects (Yudaev *et al.*, 2022). This study aims to synthesize and characterize PVP mixed with ZnONPs and *Zingiber officinale* to form antimicrobial agents and evaluate the effectiveness against pathogenic microorganisms.

2. LITERATURE REVIEW

UTIs are the most common microbial infections that infect millions of people globally each year (Mancuso *et al.*, 2024). Bacteria *Escherichia coli*, *A. baumannii*, *Klebsiella pneumoniae*, *S. aureus*, and *Enterococcus faecalis*. are considered among the most common causes of UTIs, which are characterized by their high antibiotic resistance (Govindarajan & Kandaswamy, 2022). A few studies have also shown that fungi such as *C. albicans* are among the causes of UTIs (Zhou *et al.*, 2023). To tackle the MDR microorganisms, polymers have recently been used. These polymers are naturally or chemically produced. They work on killing or inhibiting microorganisms. Their effectiveness in killing or inhibiting depends on the properties, mainly molecular weight, functional groups, and surface charge (Mandapalli *et al.*, 2017). PVP is considered one of the most important synthetic,

non-toxic, and hydrophilic polymers, which is why it is used as a microbicidal agent and in the pharmaceutical industry. It is also characterized by thermal stability and is highly soluble in alcohol and water (Sundaramahalingam *et al.*, 2019).

3. METHODOLOGY

3.1. Sample collection

This investigation was conducted at the Medical Biotechnology Department Laboratories, University Al-Qasim Green, Babylon, central Iraq. Collect 100 clinical mid-stream urine (MSU) specimens from March to December 2025. Collect samples from UTI patients entering Al-Qasim hospital using dry leak-proof containers.

3.2. Bacteriological analysis

MSU specimens were cultured on Sabouraud dextrose agar, blood agar, and MacConkey agar (Oxoid, UK), then incubated at 37°C for 24 hours. All microorganisms were identified phenotypically based on cultural characterization, metabolically by biochemical tests, and microscopically using Gram stain. They were also technically identified using a VETIC 2 system.

3.3. DNA extraction, PCR reactions

Cultures grown on nutrient broth were used for DNA extraction using the extraction Kit (Mo Bio Laboratories, CA, USA) according to the supplier's instructions. The primer pairs ITS1/ITS2 were used for the identification of *C. albicans*. In contrast, the 16S rRNA gene was used for the identification of *S. aureus* and *A. baumannii*. The PCR reaction and cycling parameters were carried out as described in (Khosravi *et al.*, 2015; Khodadadi *et al.*, 2017; Naveed *et al.*, 2023).

3.4. Synthesis of PVP polymer

Using the solvent casting method, the polymer was synthesized by dissolving PVP (1 g) in 40 mL of deionized water under continuous magnetic stirring for 1 hour at 60°C, to obtain a homogeneous PVP solution.

3.5. Synthesis of PVP-ZnO-Zingiber officinale nanocomposite

The nanocomposite was prepared by adding different weights of 0.5, 2, and 3 wt. % of ZnO and 3 wt. % of *Zingiber officinale* powder to the PVP solution while continuously magnetic stirring. Then the mixture was exposed to ultrasonication processing for 1 hour to ensure homogeneous spread of ZnO and *Zingiber officinale* within the polymer matrix. The process continues with continuous magnetic stirring at 37°C for 1 h to ensure the stability and steadiness of the nanocomposites within the polymer network (Alrobea *et al.*, 2024).

3.6. Characterization of PVP-ZnO-Zingiber officinale nanocomposites

Ultraviolet-visible (UV-vis) spectroscopy (JENWAY 7315, UK) was used to investigate the stability and absorption of PVP-ZnO-Zingiber officinale nanocomposites at 200–600 nm. The morphological surface images of PVP-ZnO-Zingiber officinale nanocomposites were obtained using FE-SEM (Field Emission Scanning Electron Microscopy) (JEOL JSMIT800). The



crystalline states of nanocomposites were studied using powder X-ray diffractometer (XRD) analysis (D8 Advance, Germany).

3.7. Antimicrobial efficacy evaluation of PVP-ZnO-Zingiber officinale nanocomposites

Mueller–Hinton agar (MHA) medium was prepared, and then 1 mL of the standard microbial suspension, was spread on the medium surface. After that, allow the medium surface to dry for 5 min. Then, use a sterile cork borer to make 5 wells with a diameter of 8 mm. After which, a volume of 100 μ L of the ((PVP pure (1 μ g/mL) – PVP-Zingiber officinale-ZnO (1 μ g/mL)– PVP-Zingiber officinale-ZnO (2 μ g/mL) and PVP-Zingiber officinale-ZnO (3 μ g/mL)). Incubated the agar plates for 24 h at 37°C. The antimicrobial efficacy was determined by measuring the IZD in millimeters (mm) surrounding the wells (Ojaimi & Shliouh, 2025).

The minimum inhibitory concentration (MIC) of PVP-ZnO-Zingiber officinale nanocomposites was determined for the tested microorganisms by 96-well microtiter plates according to the method described by Kowalska-Krochmal & Dudek-Wicher (Kowalska-Krochmal & Dudek-Wicher, 2021). The concentrations of nanocomposites were adjusted from 0.5 to 10 μ g/mL. I used the resazurin dye to determine the value of MIC.

3.8. Data analysis

We analyzed the results of this study using SPSS (Chi-square test) version 23 (IBM Corp., Armonk, USA) to find the relationship between categorical variables at P-value of 0.05.

4. RESULTS AND DISCUSSION

4.1. Microbes identification

Based on phenotypic, microscopic, metabolic, and genotypic identification results, we obtained 30 microbial isolates, distributed as follows: 10 *S. aureus*, 10 *A. baumannii*, and 10 *C. albicans*.

4.2. UV-vis analysis

Figure 1 shows the results of UV-visible spectroscopy, which shows an increase in absorption in the PVP-ZnO-Zingiber officinale nanocomposites and formation of a surface Plasmon resonance (SPR) peak at wavelengths of 200-300 nm. At 600 nm, the absorbability in the PVP-ZnO-Zingiber officinale nanocomposites began to decrease gradually. It was observed that the increase in absorbability is associated with an increase in the nanocomposites concentration from 1 to 3%.

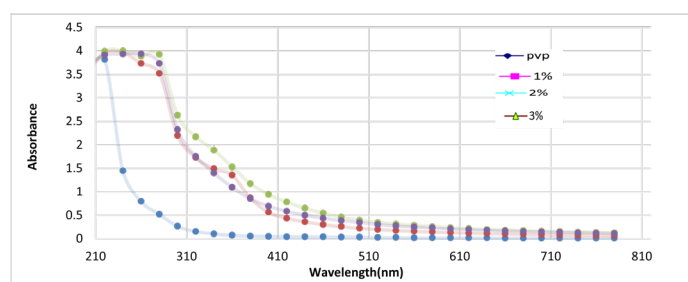


Figure 1. UV-visible spectroscopy analysis of PVP pure and PVP-ZnO-Zingiber officinale nanocomposites.

4.3. FE-SEM analysis

Figure 2 shows FE-SEM images of the PVP-ZnO-Zingiber officinale nanocomposites; Figure 2A shows a separate mass with a high rough surface for the PVP. The average particle size of the PVP pure sample is 31.10–58.70 nm. Figures 2B, C, and D show that upon incorporation of Zingiber officinale and ZnO nanoparticles, the nanocomposites show a spherical or oval homogeneous, compact appearance, gradually becoming less textured with increasing nanoparticle average size from 27 to 44 nm.

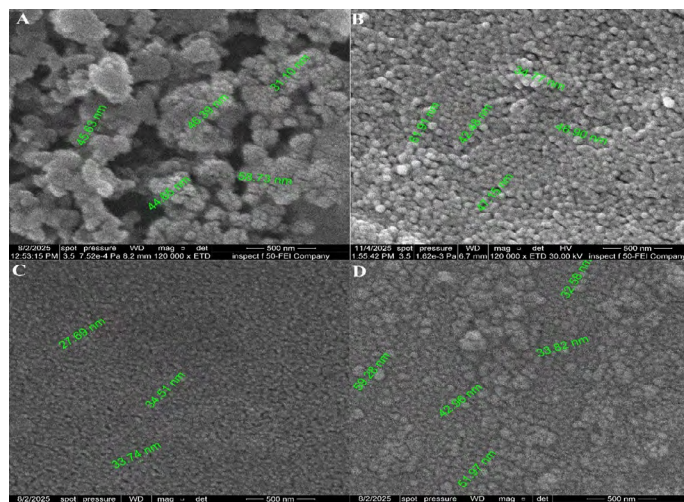


Figure 2. FE-SEM analysis images A-PVP pure, B-PVP-Zingiber officinale-ZnO (1 μ g/mL), C-PVP-Zingiber officinale-ZnO (2 μ g/mL), D-PVP-Zingiber officinale-ZnO (3 μ g/mL).

4.4. XRD analysis

Figure 3A-D. illustrates XRD patterns of the nanocomposites, a large diffraction peak centered at 20° for the PVP pure Figure 3A, indicating their amorphous nature. After the combination of ZnO and Zingiber officinale, multiple distinct peaks at 20 values of 26°, 30°, 37.3°, 47.6°, 55.6°, 63.5°, and 69.0° Figure 3C, which refer to different planes in the ZnO and Zingiber officinale structures. An increase in the intensity of ZnO and Zingiber officinale was observed as its concentration increased from 1

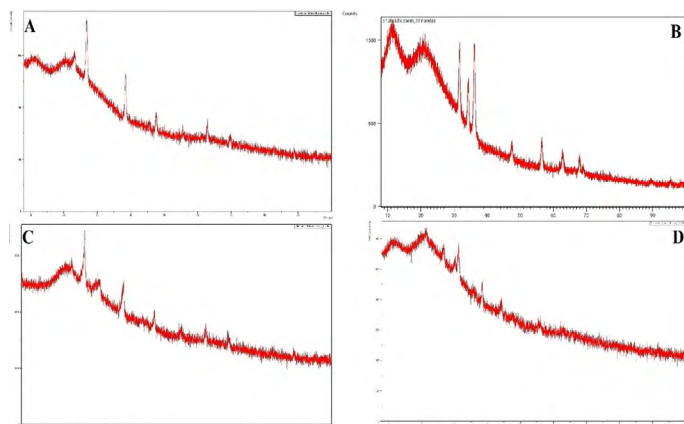


Figure 3. XRD analysis images A- PVP pure, B- PVP-Zingiber officinale-ZnO (1%), C- PVP-Zingiber officinale-ZnO (2%), D- PVP-Zingiber officinale-ZnO (3%).



to 3%. Indicating an increase in crystalline ZnO and Zingiber officinale content within the PVP polymer. The average size of the nanocomposites integrated with the PVP also increased.

4.5. Microbicidal activity of PVP-ZnO-Zingiber officinale nanocomposites

The microbicidal efficiency of PVP-ZnO-Zingiber officinale nanocomposites was evaluated against MDR bacteria and yeast isolates (Figure 4; Table 1). The findings showed varying degrees of microbicidal activity among the nanocomposites. Our findings showed that purified PVP and PVP-ZnO-Zingiber officinale (1 µg/mL) did not display any microbicidal efficacy against *S. aureus*, *A. baumannii*, and *C. albicans*, as confirmed by the absence of inhibition zones around wells. Our findings agree with previous studies, which reported that purified PVP exhibited no microbicidal activity compared to other nanocomposites against microorganisms. In contrast, PVP-ZnO-Zingiber officinale (2 µg/mL) and PVP-ZnO-Zingiber officinale (3%) displayed microbicidal activity against *S. aureus*, *A. baumannii*, and *C. albicans*, through the formation of inhibition zones around wells. The PVP-ZnO-Zingiber officinale (3 µg/mL) displays the highest antimicrobial efficacy, with inhibition zones of 18 ± 0.3 mm against *S. aureus*, 17 ± 0.1 mm against *A. baumannii*, and 16 mm against *C. albicans*. This PVP-ZnO-Zingiber officinale (3 µg/mL) proved superior antimicrobial efficiency compared to the other nanocomposites used in the research.



Figure 4. Microbicidal activities of 1. PVP-ZnO-Zingiber officinale (2 µg/mL), 2. PVP-ZnO-Zingiber officinale (3 µg/mL), 3. PVP-ZnO-Zingiber officinale (1 µg/mL), 4. PVP pure, (C) Control against *S. aureus*, *A. baumannii*, and *C. albicans*.

The MIC of PVP-ZnO-Zingiber officinale nanocomposites was determined for the tested microorganisms as detailed in Figure 5. *C. albicans* (yeast) showed the least susceptibility to PVP pure, PVP-ZnO-Zingiber officinale (1 µg/mL), PVP-ZnO-Zingiber officinale with (2 µg/mL), and PVP-ZnO-Zingiber officinale (3 µg/mL), with an MIC value of 10, 2, 3, and 4 µg/mL, respectively. *S. aureus* (Gram-positive) exhibited moderate susceptibility, with an MIC value of 5, 2, 4, and 4 µg/mL, respectively. In contrast, *A. baumannii* (Gram-negative) exhibited a high susceptibility, with MIC values of 4, 2, 3, and 3 µg/mL, respectively.

4.6. Discussion

Uropathogenic microbial infections are a major problem facing the healthcare sector globally, and they are a substantial economic burden on healthcare within the hospital setting.

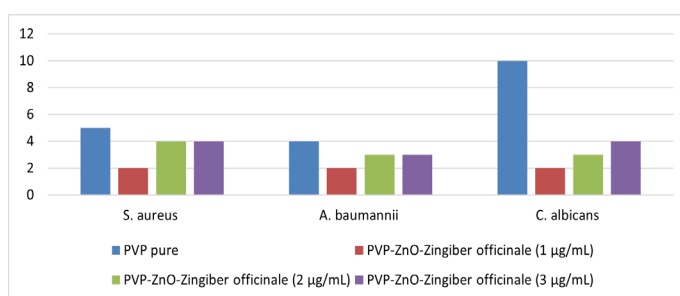


Figure 5. The MIC values of PVP-ZnO-Zingiber officinale nanocomposites against pathogenic microbes.

Gram-negative (such as *A. baumannii*), Gram-positive (*S. aureus*), and yeast (*C. albicans*) are among the most important causes of UTIs in pregnant women. Multidrug resistance in uropathogenic microbial infections has become a major health hazard. To address this challenge, nanocomposites have emerged as promising antimicrobial agents. Multidrug resistance in uropathogenic microbial infections has become a major health hazard. To address this challenge, nanocomposites have emerged as promising antimicrobial agents. Therefore, we have used in our research physical, biological, and nanoparticle alternatives represented by the use of components PVP, Zingiber officinale, and ZnO, whose properties have been studied. Our results showed that when measuring the UV-visible absorption spectra of PVP-ZnO-Zingiber officinale nanocomposites, an increase in the SPR was observed with an increase in the concentration of nanocomposites at the wavelengths of 200-300 nm. This indicates higher symmetry and uniform distribution of the nanocomposites. However, the SPR for nanocomposites begins to decrease at a peak of 600 nm. This may be due to the effect of the nanocomposites' structures and activity loss, which causes the nanocomposites to aggregate. The FE-SEM images reveal oval nanocomposites with straight boundaries. The nanocomposites appear to be isolated and non-clumped, suggesting good colloidal stability and indicating also, exceptionally good homogeneity and ideal synthesis conditions. XRD analysis results of the nanocomposites revealed the presence of several distinctive peaks of different morphology crystalline levels. The widening of XRD peaks indicates the nanoscale of the nanocomposites, and the widening of the XRD lines at half their intensity results from flattening, micro-strains inside the diffracting domains, and crystallite size.

Medical polymers have emerged as antimicrobial agents due to their properties, including molecular weight, the functional groups present on their surface, and surface charge. The effect of the polymer on microorganisms occurs in two mechanisms: the first is the polymer attaching to the bacterial wall and then penetrating it, and the second is the polymer acting to disable the cell membrane, causing the release of internal bacterial contents, leading to cell death (Karpuraranjith & Thambidurai, 2017). However, our findings showed that purified PVP is ineffective in inhibiting or killing test microorganisms, which is consistent with the findings of (Alrobea *et al.* 2024) and, at the same time, contradicts those of (Doan & Tran, 2023). However, when Zingiber officinale and ZnO were mixed with



the polymer at concentrations of 2% and 3%, they showed high effectiveness against *S. aureus*, *A. baumannii*, and *C. albicans*. As shown in Table 1. Our findings were consistent with several previous investigations that proved the effectiveness of nanocomposites against various microorganisms [Mallakpour & Mansourzadeh, 2018; Alawi & Al-Bermay 2023; Khaleel *et al.*, 2024a; Khaleel *et al.*, 2024b). ZnO is considered one of the most important metal oxides used in many biomedical and biological fields. Among the most prominent and well-known applications is their use as antimicrobial agents due to their high efficacy in inhibiting or killing microbes. This is because of their properties, the most important being their small size—the smaller the nanoparticle, the greater its effect against microorganisms (Kaushik *et al.*, 2019). In addition,

these ZnO are characterized by high stability, as well as a long shelf life, especially when mixed with other antimicrobial agents such as polymers (Radzimska & Jesionowski, 2014). Zingiber officinale is considered one of the more commonly used medicinal herbs for treating several diseases caused by microbes, due to its antimicrobial properties. Its high efficacy against microorganisms is attributed to phenolic compounds such as gingerols, zengenols, shogaols, and eugenols; these act as components in the natural alteration of proteins, which changes microbial cell permeability, thereby causing swelling and death. Additionally, these components effectively bind to the active sites of proteins or metabolic enzymes, which decreases their functional efficacy and consequently microbial cell activity and division (El-Baroty *et al.*, 2010).

Table 1. The efficacy of PVP-ZnO-Zingiber officinale nanocomposites in inhibiting pathogenic microbes.

Nanocomposites	Inhibition zone diameter in mm		
	<i>S. aureus</i>	<i>A. baumannii</i>	<i>C. albicans</i>
PVP pure	0	0	0
PVP-ZnO-Zingiber officinale (1µg/mL)	0	0	0
PVP-ZnO-Zingiber officinale (2µg/mL)	16	15	14
PVP-ZnO-Zingiber officinale (3µg/mL)	18	17	16
χ^2	.001a		
P	0		

5. CONCLUSION

In this investigation, a PVP-based nanocomposite mixed ZnO and Zingiber officinale. The PVP-ZnO-Zingiber officinale nanocomposites were oval or spherical crystalline, stable, and homogeneous, exhibiting SPR at 200-300 nm. FE-SEM and XRD results analyses confirmed its crystalline nature. Our study proved that the PVP-ZnO-Zingiber officinale nanocomposites have possess high effectiveness as antimicrobials due to the synergistic impact of ZnO nanoparticles, Zingiber officinale, and the PVP against *S. aureus*, *A. baumannii*, and *C. albicans*. PVP-ZnO-Zingiber officinale (3%) was the most efficient nanocomposite due to the activities it demonstrated against the test microorganisms. Future investigations must focus on evaluating the efficiency of these nanocomposites in medical studies to understand their potential therapeutic fields against microbes that cause diseases and are highly resistant to antibiotics. This is crucial for assessing their efficiency as successful alternatives to antibiotics, which could help reduce the problems associated with antibiotic resistance of microorganisms.

REFERENCE

- Alawi, A. I., & Al-Bermay, E. (2023). Newly fabricated ternary PAAm-PVA-PVP blend polymer doped by SiO₂: absorption and dielectric characteristics for solar cell applications and antibacterial activity. *Silicon*, 15(13), 5773-5789. <https://doi.org/10.1007/s12633-023-02477-5>
- Alrobea, H., Khan, A., Alamry, K. A., & Hussein, M. A. (2024). Antibacterial evaluation of polyvinyl alcohol/polyvinyl pyrrolidone/chitosan nanocomposite embedded curcumin@ zinc oxide. *Results in Chemistry*, 10, 101729. <https://doi.org/10.1016/j.rechem.2024.101729>
- Doan, L., & Tran, K. (2023). Relationship between the Polymer Blend Using Chitosan, Polyethylene Glycol, Polyvinyl Alcohol, Polyvinylpyrrolidone, and Antimicrobial Activities against *Staphylococcus aureus*. *Pharmaceutics*, 15(10), 2453. <https://doi.org/10.3390/pharmaceutics15102453>
- El-Baroty, G. S., Abd El-Baky, H. H., Farag, R. S., & Saleh, M. A. (2010). Characterization of antioxidant and antimicrobial compounds of cinnamon and ginger essential oils. *African journal of biochemistry research*, 4(6), 167-174.
- El-Sherbiny, H. R., Samir, H., Youssef, F. S., Mohamed, G. G., Ismail, S. H., El-Shahat, K. H., Aboelmaaty, A. M., Mahrous, K. F., Al Syaad, K. M., Ahmed, A. E., Al-Saeed, F. A., Abdualah, A. M., & Abdelnaby, E. A. (2024). Maternal supplementation of curcumin-olive oil nanocomposite improves uteroplacental blood flow, placental growth and antioxidant capacity in goats. *Journal of animal physiology and animal nutrition*, 108(3), 839-853. <https://doi.org/10.1111/jpn.13933>
- Govindarajan, D. K., & Kandaswamy, K. (2022). Virulence factors of uropathogens and their role in host pathogen interactions. *Cell surface (Amsterdam, Netherlands)*, 8, 100075. <https://doi.org/10.1016/j.tcs.2022.100075>
- Karpuraranjith, M., & Thambidurai, S. (2017). Chitosan/zinc oxide-polyvinylpyrrolidone (CS/ZnO-PVP) nanocomposite for better thermal and antibacterial activity. *International journal of biological macromolecules*, 104(Pt B), 1753-1761. <https://doi.org/10.1016/j.ijbiomac.2017.02.079>
- Kaushik, M., Niranjana, R., Thangam, R., Madhan, B.,



- Pandiyarasan, V., Ramachandran, C., ..., & Venkatasubbu, G. D. (2019). Investigations on the antimicrobial activity and wound healing potential of ZnO nanoparticles. *Applied Surface Science*, 479, 1169-1177. <https://doi.org/10.1016/j.apsusc.2019.02.189>
- Khaleel, M. R., Hashim, F. S., & Alkhayatt, A. H. O. (2024). Impact of pH and ZnO NPs on the fabricated PVA-PVP/ZnO nanofibers: Morphology, absorption behavior, anticancer, and antibacterial activity. *Ceramics International*, 50(20), 40161-40170. <https://doi.org/10.1016/j.ceramint.2024.07.283>
- Khaleel, M. R., Hashim, F. S., & Alkhayatt, A. H. O. (2024). Preparation, characterization, and the antimicrobial activity of PVA-PVP/ZnO nanofiber films via indigenous electrospinning setup. *Journal of Molecular Structure*, 1310, 138325. <https://doi.org/10.1016/j.molstruc.2024.138325>
- Khodadadi, H., Karimi, L., Jalalizand, N., Adin, H., & Mirhendi, H. (2017). Utilization of size polymorphism in ITS1 and ITS2 regions for identification of pathogenic yeast species. *Journal of medical microbiology*, 66(2), 126-133. <https://doi.org/10.1099/jmm.0.000426>
- Khosravi, A. D., Sadeghi, P., Shahraki, A. H., Heidarieh, P., & Sheikhi, N. (2015). Molecular Methods for Identification of Acinetobacter Species by Partial Sequencing of the rpoB and 16S rRNA Genes. *Journal of clinical and diagnostic research : JCDR*, 9(7), DC09-DC13. <https://doi.org/10.7860/JCDR/2015/13867.6188>
- Kowalska-Krochmal, B., & Dudek-Wicher, R. (2021). The Minimum Inhibitory Concentration of Antibiotics: Methods, Interpretation, Clinical Relevance. *Pathogens*, 10(2), 165. <https://doi.org/10.3390/pathogens10020165>
- Kołodziejczak-Radzimska, A., & Jesionowski, T. (2014). Zinc Oxide-From Synthesis to Application: A Review. *Materials*, 7(4), 2833-2881. <https://doi.org/10.3390/ma7042833>
- Krishna, G., Sivalingam, A. M., Brahma, N., & Alex, A. (2024). Phytochemical Analysis of Silver Nanoparticles of Zingiber officinale and Evaluation for Its Antibacterial Property. *Journal of pharmacy & bioallied sciences*, 16(Suppl 2), S1226-S1232. https://doi.org/10.4103/jpbs.jpbs_547_23
- Krishnamoorthy, R., Athinarayanan, J., Periyasamy, V. S., Alshuniaber, M. A., Alshammari, G., Hakeem, M. J., Ahmed, M. A., & Alshatwi, A. A. (2022). Antibacterial Mechanisms of Zinc Oxide Nanoparticle against Bacterial Food Pathogens Resistant to Beta-Lactam Antibiotics. *Molecules*, 27(8), 2489. <https://doi.org/10.3390/molecules27082489>
- Mallakpour, S., & Mansourzadeh, S. (2018). Sonochemical synthesis of PVA/PVP blend nanocomposite containing modified CuO nanoparticles with vitamin B1 and their antibacterial activity against *Staphylococcus aureus* and *Escherichia coli*. *Ultrasonics sonochemistry*, 43, 91-100. <https://doi.org/10.1016/j.ultsonch.2017.12.052>
- Mancuso, G., Trinchera, M., Midiri, A., Zummo, S., Vitale, G., & Biondo, C. (2024). Novel Antimicrobial Approaches to Combat Bacterial Biofilms Associated with Urinary Tract Infections. *Antibiotics*, 13(2), 154. <https://doi.org/10.3390/antibiotics13020154>
- Mandapalli, P. K., Labala, S., Chawla, S., Janupally, R., Sriram, D., & Venuganti, V. V. K. (2017). Polymer-gold nanoparticle composite films for topical application: Evaluation of physical properties and antibacterial activity. *Polymer Composites*, 38(12), 2829-2840. <https://doi.org/10.1002/pc.23885>
- Naveed, M., Waseem, M., Aziz, T., Hassan, J. U., Makhdoom, S. I., Ali, U., Alharbi, M., & Alsahammari, A. (2023). Identification of Bacterial Strains and Development of an mRNA-Based Vaccine to Combat Antibiotic Resistance in *Staphylococcus aureus* via In Vitro and In Silico Approaches. *Biomedicine*, 11(4), 1039. <https://doi.org/10.3390/biomedicine11041039>
- Ojaimi, R. R., & Shliouh, N. H. (2025). Chemical Synthesis, Characterization, and Antibacterial Activity of Copper Oxide Nanoparticles: In vitro Study on Uropathogenic Bacteria. *Biomedical and Biotechnology Research Journal (BBRJ)*, 9(3), 264-268. DOI: 10.4103/bbrj.bbrj_198_25.
- Radulescu, D. M., Surdu, V. A., Ficai, A., Ficai, D., Grumezescu, A. M., & Andronescu, E. (2023). Green Synthesis of Metal and Metal Oxide Nanoparticles: A Review of the Principles and Biomedical Applications. *International journal of molecular sciences*, 24(20), 15397. <https://doi.org/10.3390/ijms242015397>
- Salam, M. A., Al-Amin, M. Y., Salam, M. T., Pawar, J. S., Akhter, N., Rabaan, A. A., & Alqumber, M. A. A. (2023). Antimicrobial Resistance: A Growing Serious Threat for Global Public Health. *Healthcare*, 11(13), 1946. <https://doi.org/10.3390/healthcare11131946>
- Sundaramahalingam, K., Muthuvinayagam, M., & Nallamuthu, N. (2019). AC impedance analysis of lithium ion based PEO: PVP solid polymer blend electrolytes. *Polymer Science, Series A*, 61(5), 565-576. <https://doi.org/10.1134/S0965545X19050171>
- Tarfaoui, K., Brhadda, N., Ziri, R., Oubihi, A., Imtara, H., Haida, S., Al Kamaly, O. M., Saleh, A., Parvez, M. K., Fettach, S., & Ouhssine, M. (2022). Chemical Profile, Antibacterial and Antioxidant Potential of Zingiber officinale Roscoe and Elettaria cardamomum (L.) Maton Essential Oils and Extracts. *Plants*, 11(11), 1487. <https://doi.org/10.3390/plants11111487>
- Youssef, F. S., Ismail, S. H., Fouad, O. A., & Mohamed, G. G. (2024). Green synthesis and biomedical applications of zinc oxide nanoparticles. Review. *Egyptian Journal of Veterinary Sciences*, 55(1), 287-311. <https://doi.org/10.21608/EJVS.2023.225862.1576>
- Yudaev, P., Mezhev, Y., & Chistyakov, E. (2022). Nanoparticle-Containing Wound Dressing: Antimicrobial and Healing Effects. *Gels*, 8(6), 329. <https://doi.org/10.3390/gels8060329>
- Zhou, Y., Zhou, Z., Zheng, L., Gong, Z., Li, Y., Jin, Y., Huang, Y., & Chi, M. (2023). Urinary Tract Infections Caused by Uropathogenic *Escherichia coli*: Mechanisms of Infection and Treatment Options. *International journal of molecular sciences*, 24(13), 10537. <https://doi.org/10.3390/ijms241310537>

