OPEN ACCESS

Kashf Journal of Multidisciplinary Research
Vol: 02 - Issue 05 (2025)
P-ISSN: 3007-1992 E-ISSN: 3007-200X
https://kjmr.com.pk

GREEN SYNTHESIS OF SILVER NANOPARTICLES USING MORUS ALBA EXTRACT AND THEIR ANTIBACTERIAL PROPERTIES

Mah Noor*
Department of Microbiology and Molecular Genetics, The Women University Multan, Pakistan.
Musarrat Bibi
Department of Microbiology and Molecular Genetics, The Women University Multan, Pakistan.
Syed Muhammad Ali Shah
Faculty of Veterinary and Animal Sciences, University of Poonch Rawlakot, Pakistan.
Muhammad Talha Saeed
Department of Pathobiology & Biomedical Sciences, MNS University of Agriculture, Multan, Pakistan.
Ahmad Ramzan Noor
Department of Public Health and Epidemiology, University of Agriculture, Faisalabad.
Ahsan Anjum
Department of Pathobiology & Biomedical Sciences, MNS University of Agriculture, Multan, Pakistan.
Saira Saeed
Department of Microbiology and Molecular Genetics, The Women University Multan, Pakistan.
Hamna Sharif
Department of Microbiology and Molecular Genetics, The Women University Multan, Pakistan.

****Corresponding author: Mah Noor (namalnoor333@gmail.com)***

Article Info

This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license https://creativecommons.org/licenses/by/4.0

Abstract

Background: Metal nanoparticles can be used to control a range of resistant and pathogenic microorganisms. Nanoparticles are used in many different fields, including medicine, diagnostics, drug and gene delivery, electronics, cosmetics, coatings, biosensors, imaging, and environmental remediation. Of the many metal nanoparticles, silver nanoparticles have been the focus of much investigation because of their distinct optical properties, conductivity, chemical stability, and catalytic activity. This method allowed the synthesis of silver nanoparticles in an environmentally friendly way, which was confirmed by (UV-Vis) spectrophotometry and FTIR. Morus alba leaf extract was utilized as the reducing, stabilizing, and capping agent in the aqueous phase.

Aim: This work presents an investigation on the biosynthesis of silver nanoparticles (AgNPs) using an aqueous extract of Morus alba (mulberry) leaves and an evaluation of its antibacterial qualities.

Method: The antibacterial properties of synthesized AgNP are evaluated using agar disk and agar well diffusion. The production of silver nanoparticles is verified by the development of a characteristic color (yellow brown), which stands for the reduction of Ag+ ions.

Results: The produced AgNPs shown antibacterial efficacy against Pseudomonas aeruginosa and Escherichia coli. The biosynthesized silver nanoparticles had better antibacterial capabilities against the studied microbes, as evidenced by the formation of zones of inhibition.

Conclusion: In order to fight human pathogens (Escherichia coli and Pseudomonas aeruginosa), Morus alba and AgNPs may be employed as safe, efficient, and environmentally friendly antibacterial agents.

Keywords:
Silver Nanoparticles, Morus Alba, Green Synthesis, Ethnopharmacology, Antibacterial properties.

1. Introduction

Because of their non-toxic, optical, catalytic, bio-sensing, drug transport, antioxidant, cytotoxic, and antibacterial properties, silver nanoparticles are becoming more and more popular and are in high demand, with an annual demand of 500 tons [1, 2]. Silver nitrate was bio-reduced in the presence of plant extract to create AgNPs [3]. There are several benefits of bio-reducing AgNO3 with plant extract for the synthesis of AgNPs, including reduced waste generation, quick crystallization, economic effectiveness, and environmental friendliness [4, 5]. In order to defend themselves against various diseases, plants generate a vast diversity of secondary metabolites. Secondary metabolites are helpful in the green synthesis of AgNPs by acting as stabilizing agents. Flavonoids convert silver ions into AgNPs also control its size. For the stabilization of AgNPs tannins play an important role [6, 7] [6,7]. Polyphenols increase the antibacterial activity of AgNPs by increasing the membrane permeability of P.aeruginosa and E.coli [8-10].

We have chosen a leaf extract from the plant Morus alba, generally known as mulberry, which has both medical and commercial value. Morus alba is widely available and reducing synthesis cost. The biological activities of these leaves are believed to be influenced by the high concentration of bioactive compounds e.g. flavonoids, polyphenols and tannins which have potent antioxidant and natural stabilizing properties. Additionally, mulberry don't require hydrazine which is a hazardous reducing agent [11, 12].

The anti-diabetic, antibacterial, antioxidant, neuroprotective, anti-cancerous, and hepatoprotective properties of mulberry are also utilized. The present work aimed to assess the antibacterial activity of mulberry aqueous leaf extract against human pathogens and to employ it for the environmentally friendly production of AgNPs. By examining the zone of inhibition, the antibacterial activity of the produced nanoparticles will be evaluated [11-13].

2. Materials and methods

Table 1.1 Materials

Material	**Quantity**
Broth	20ml for each organism
Distilled water	150ml
Muller Hinton Agar	80ml
AgNO3(Rapped in Aluminum Foil)	10mg (0.01g)
Plant Leaves	10g
Test organism	2 Bacterial culture plates (Escherichia coli and Pseudomonas aeruginosa isolated from wound swabs)

2.2 Methods

2.2.1 Plant material collection and extract preparation

In February, sterile polythene bags were used to gather Morus alba leaves from MNSAUM Multan, Pakistan. After being cleaned with tap water, the leaves were thinly cut. The sliced leaves were boiled in 100 milliliters of double-distilled water for one hour, maintaining the water bath's temperature at 80 degrees Celsius, to create an extract. Whatman filter paper No. 1 in a funnel was used to filter the extract (Fig 1.1A) [14].

2.2.2 Biosynthesis of AgNPs and optimization

In the biosynthesis of AgNPs, about 20 g leaves in 100 ml dis.H2O were boiled (800C) at water bath for half an hour. Whatman filter paper No. 1 in a funnel was used to filter the extract. One mM aqueous AgNO3 solution is prepared at room temperature. Sodium hydroxide used to adjust the pH at 10 for good nanoparticle formation. AgNO3 solution was titrated against Morus alba extract for green synthesis, maintaining the water bath's temperature at 80°C. In the titration process, 5 milliliters of extract were employed until a yellow colour appeared. After 2 hours, a yellowish-brown solution emerged, confirming the green production of AgNPs. Stir the solution continuously for better synthesis of AgNPs. Fuhrer, (UV-Vis) spectroscopy used to analyse the solution which show peaks at 400 nm [15, 16].

3. Biological and catalytic activity of AgNPs

3.1 Antibacterial assay by disc diffusion and Well Diffusion Method

The disc diffusion and well diffusion assays were used to evaluate the antibacterial activity of silver nanoparticles. Two separate test tubes were used to create the nutrient broth solution, which was then autoclaved. The test tubes holding the nutrient broth were filled with the strains of P. aeruginosa and E. coli. Overnight, the injected bacterial cultures were maintained at 37°C in an incubator. Eighty milliliters of Mueller Hinton medium were produced and autoclaved to investigate the antibacterial activity of silver nanoparticles. After that, it was transferred into four Petri dishes, two of which were employed to investigate the antibacterial activity of silver nanoparticles (AgNPs) against P. aeruginosa and the other against E. coli (Fig 1.1 A). Using sterile cotton swabs, 50 µl of fresh overnight cultures of P. aeruginosa and E. coli were applied to the medium on four separate plates. Two Petri dishes were filled with sterile Whatman filter paper discs, each 4 mm in diameter, and dipped in a sample solution of nanoparticles. The remaining two Petri dishes were utilized for the Well Diffusion Method (Fig I.1C).

A sterile Pasteur pipette was used to prepare the wells on Mueller Hinton agar plate (Fig 1.1D). 50µl of biosynthesized AgNPs were added to each well (Fig 1.1 E).For twenty-four hours, the plates were incubated at 37°C. The zone of inhibition (measured in millimeters) was used to assess the antibacterial activity [17, 18].

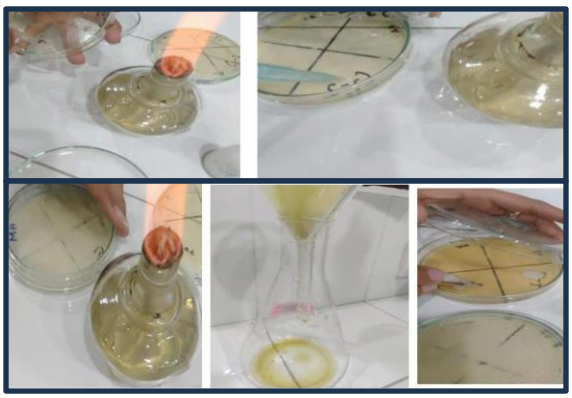


Figure 1.1 (A) Illustrating Agar Plate Solidification (B) Whatman filter paper No. 1 was used to filter the boiling leaf extract of Morus Alba (C). A sterile paper disc was set on the agar surface (D). Using a sterile Pasteur pipette to make a well (E). Fifty microliters of biosynthesized AgNPs were added to wells.

4. Results:

Zones of inhibition showed that the biosynthesized silver nanoparticles were more effective against the studied bacteria in terms of their antimicrobial capabilities. Silver nanoparticles (AgNP) at 50µL demonstrated the highest zone of inhibition (2.2 cm) against Pseudomonas aeruginosa in the well diffusion assay, whereas the lowest zone of inhibition (1.2 cm) was demonstrated against Pseudomonas aeruginosa in the disk diffusion assay. The findings show that, in comparison to the comparable disc diffusion experiment, the biosynthesized AgNPs utilized in the well diffusion assay had greater antibacterial activity.

Table I.2: Zones of inhibition diameters (cm) for 50 µL of silver nanoparticle reaction mixture following incubation with different microbes

Test organisms	**Sr.no**	**Zone of Inhibition(cm)** **Reaction Mixture (AgNP) 50µL**	
		Well Diffusion method .	**Disc Diffusion method**
Escherichia coli	**1**	1.1	1.5
	2	1.7	1.7
	3	1.2	1.4
	4	1.2	1.5
Average		1.3	1.5
Pseudomonas aeruginosa	**1**	2	1.2
	2	2.1	1.5
	3	2.2	1.3
	4	2.1	1.1
Average		8.4	1.2

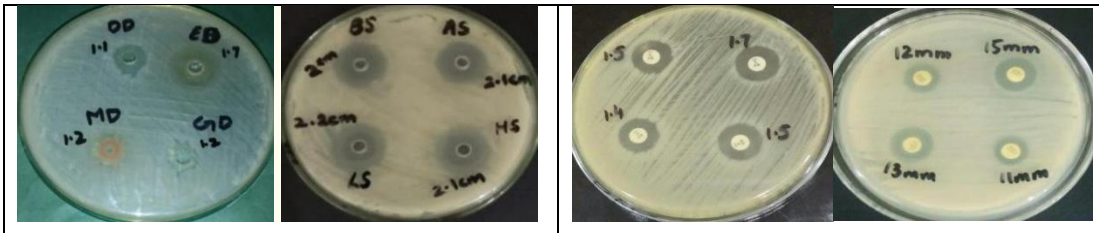
Escherichia coli			
Well diffusion method		**Disc Diffusion method**	
Mean	1.3	Mean	1.525
Standard Error	0.135401	Standard Error	0.062915
Median	1.2	Median	1.5
Mode	1.2	Mode	1.5
Standard Deviation	0.270801	Standard Deviation	0.125831
Sample Variance	0.073333	Sample Variance	0.015833
Kurtosis	3.483471	Kurtosis	2.227147
Skewness	1.812802	Skewness	1.129338
Range	0.6	Range	0.3
Minimum	1.1	Minimum	1.4
Maximum	1.7	Maximum	1.7
Sum	5.2	Sum	6.1
Count	4	Count	4
Confidence Level(95.0%)	0.430905	Confidence Level(95.0%)	0.200225
Lower Ci	0.869095	Lower Ci	1.324775
Upper Ci	1.730905	Upper Ci	1.725225

Pseudomonas aeruginosa			
Well diffusion method		**Disc Diffusion method**	
Mean	2.1	Mean	1.275
Standard Error	0.040825	Standard Error	0.085391

Median	2.1	Median	1.25
Mode	2.1	Mode	#N/A
Standard Deviation	0.08165	Standard Deviation	0.170783
Sample Variance	0.006667	Sample Variance	0.029167
Kurtosis	1.5	Kurtosis	0.342857
Skewness	0	Skewness	0.752837
Range	0.2	Range	0.4
Minimum	2	Minimum	1.1
Maximum	2.2	Maximum	1.5
Sum	8.4	Sum	5.1
Count	4	Count	4
Confidence Level(95.0%)	0.129923	Confidence Level(95.0%)	0.271753
Lower Ci	1.970077	Lower Ci	1.003247
Upper Ci	2.229923	Upper Ci	1.546753

t-Test: Two-Sample Assuming Equal Variances		
Escherichia coli		
	Variable 1	**Variable 2**
Mean	1.3	1.525
Variance	0.073333	0.015833
Observations	4	4
Pooled Variance	0.044583	
Hypothesized Mean Difference	0	
Df	6	
t Stat	-1.50699	

P(T<=t) one-tail	0.091266	
t Critical one-tail	1.94318	
P(T<=t) two-tail	0.182533	
t Critical two-tail	2.446912	
Pseudomonas aeruginosa		
	Variable 1	**Variable 2**
Mean	2.5	2.1
Variance	1.666667	0.006667
Observations	4	4
Pooled Variance	0.836667	
Hypothesized Mean Difference	0	
Df	6	
t Stat	0.618442	
P(T<=t) one-tail	0.279507	
t Critical one-tail	1.94318	
P(T<=t) two-tail	0.559015	
t Critical two-tail	2.446912	



Well Diffusion Assay **Disk Diffusion Assay**

Figure 1.2: A zone where synthetic AgNPs inhibit P. aeruginosa. B AgNPs' inhibition zones against E. coli. C AgNP-induced inhibition zones against E. coli D AgNP-induced inhibition zones against P. aeruginosa

4.1: UV-visible spectroscopy

The mulberry leaves extracts that were made in different solvents were analysed by UV-Visible spectroscopy. This was done to determine the peaks characteristics of prepared extracts. The mulberry extract was analysed in the range of 200-800nm wavelength. Two distinct peaks were found in the mulberry leaf ethanolic extract's absorbance. The first absorbance peak of aqueous leaves extract was 3.5 at 280 nm, second was 3.9 at 300nm and third was 3.6 at 320 nm. The first absorbance peak at 280 nm shows that Morus alba contains polyphenols which is responsible for its medicinal properties. Morus alba leaves extract absorbance gradually decreases from 350 to 740 nm and in the visible region absorbs less light (Figure 1.3) [19-23].

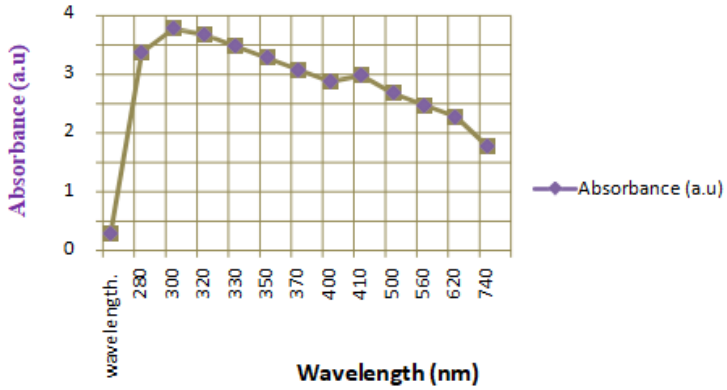


Figure 1.3: UV-visible absorbance spectrum of Morus alba leaves ethanolic extract: The absorbance of plant extract was 3.8 at 300 nm, and 3.6 at 320 nm.

4.2: FTIR Analysis:

FTIR analysis provides information about phenolic compounds of plant extracts. For RTIR analysis supernatant was discarded and pellet was dried to make it powder. The FTIR spectrum was recorded in the range of 600-4000cm-1 for extracts of Morus alba.

The result of FTIR analysis of ethanolic plant extracts recorded showed prominent peaks at wavelength between 1084-1009, 1646 and between 2929-2975 which indicated the presence of saturated primary alcohol, aromatic rings and C-H stretching of aromatic aldehyde and these compounds are responsible for its anti-inflammatory and antibacterial properties(Figure 1.4) [22, 23].

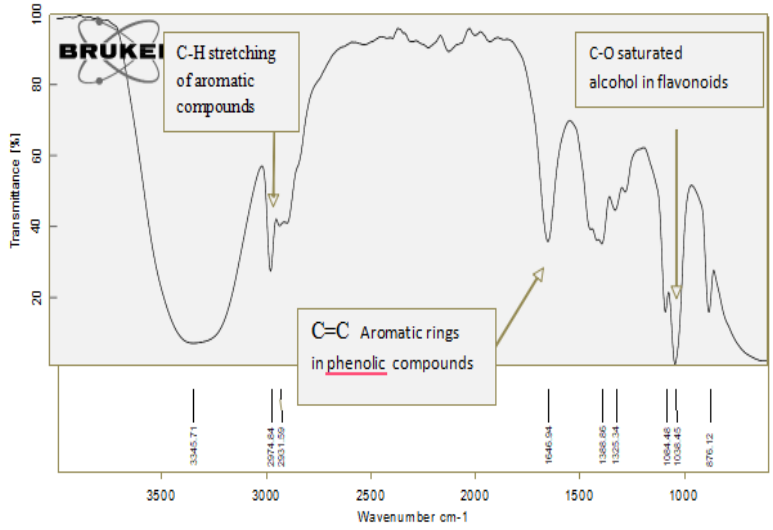


Figure 1.4: FTIR spectrum of Morus alba leaves ethanolic extract from 600-4000cm-1

5. Discussion

Recent years have seen a rise in antibiotic resistance, which has become a serious global health concern. Silver nanoparticles have recently been implicated in antibacterial properties in a different way. AgNP production typically calls for hazardous chemicals and a lot of energy, which can have serious negative effects on the environment. These days, we use biological resources, such as plant extracts of various herbs, microbes, and different enzymes, to create these silver nanoparticles in an environmentally friendly manner. A variety of photochemical, such as flavonoids and polyphenol, are crucial for stabilizing the nanoparticles [6, 7].

The development of a distinctive color (yellow brown), which represents the reduction of Ag+ ions, verifies the creation of silver nanoparticles. The antibacterial activity of manufactured AgNPs can be shown in two ways: the well diffusion method and the agar disk approach. A distinct zone of inhibition against the tested microorganism forms during the course of treatment. Our findings showed that AgNPs' zone of inhibition against P. aeruginosa (2.2 cm) in the Well diffusion experiment was larger than that of the disk diffusion assay [8-10]. In previous studies AgNPs are synthesized chemically that is toxic for environment. In this research, we synthesized NPs by using Morus alba that is ecofriendly and inhibit the bacterial growth [11].

Our research on the antibacterial activity of silver nanoparticles at least suggests that the antimicrobial activity against test organisms was influenced by the concentration and amount of AgNPs. As anticipated, a larger amount of AgNPs solution was used in the well diffusion test than in the disk diffusion assay. In this AgNPs synthesized from Morus alba shows larger zone of inhibition (2.2cm) at the concentration of only 50 ul which shows that Morus alba contains more polyphenols compounds which make them more antibacterial [24].

AgNPs' synthesized from Morus alba bactericidal activity can be attributed to a number of variables when discussing their mode of action as an antimicrobial agent. AgNPs causes the bacterial cell lysis by destroying the cell membrane. They may result in the development of an electron-light zone in the cell's core, where DNA molecules condense. It is thought to be a defense mechanism of the bacterial cell to shield the DNA from AgNP damage. However, the bacterial cell loses its capacity to replicate as a result of DNA condensation, which inhibits or suppresses growth. AgNPs' synthesized from Morus alba generate Reactive oxygen species that cause the bacterial cell death by damaging their DNA. Gram negative bacteria use defense mechanism to remove harmful compounds from body surfaces but AgNPs disable these defense mechanism and these harmful compounds accumulate in body and cause its cell death [25, 26].

Various studies have also reported a similar mechanism in which oxygen and zero valent silver (Ag0) combined to form hydrogen peroxide (H2O2), which has the potential to harm bacterial cell walls. Depending on whether the bacteria are gram-positive or gram-negative, the antibacterial activity can change. Because of their strong peptidoglycan layer, which protects them from AgNPs, gram-positive bacteria, for example, exhibit fewer alterations. It demonstrates that whereas a small amount of AgNPs (25µg/ml) is sufficient for the optimum performance against gram positive bacteria, a high concentration (50µg/ml) of AgNPs provides the strongest activity against gram-negative bacteria.

According to our findings, silver nanoparticles synthesized from Morus alba have antibacterial efficacy against a wide range of pathogenic and multidrug-resistant microbes, which is consistent with earlier research. Flavonoids, alkaloids, and polyphenols are among the phytochemicals it contains [27]. These compounds have reducing and stabilizing properties that prevent aggregation and ensure uniform sample size distribution in the production of silver nanoparticles as well as in the reduction of inflammation and

oxidative stress in medical conditions. Consequently, the generation of harmful substances is decreased. Because mulberries are inexpensive, this approach of synthesizing NPs is also cost-effective because it lowers the total cost of production. Additionally, the antibacterial efficacy of commercial medications against harmful microbes was improved by the silver nanoparticles [25, 26].

Optimize the concentration of mulberry extract by lowering reaction time, temperature, and pH in order to standardize or create a transparent, sequential manufacturing process that will increase the efficiency of sliver nanoparticle production. To confirm the stable synthesis of AgNPs, advanced techniques such as FTIR, and (UV-Vis) spectroscopy are employed [1, 3, 7, 28].

In future examine the advantages of AgNPs in a number of additional domains, such as manufacturing antimicrobial creams, patches, and sprays for consumer convenience, biomedical applications, agriculture, and the environment. Assess the toxicity of AgNPs generated by the mulberry plant to human cells to guarantee safe biomedical applications and environmental impact, including NPs' biodegradability and potential future consequence [1, 4, 6, 13, 21, 25].

We acknowledge that there may be two limitations to our research. Initially, we examined antibacterial activity while maintaining the same level of silver nitrate (AgNO3) in each well. The second is that we haven't used control. These restrictions demonstrate how challenging it is to gather information on antibacterial action.

6. Conclusion

Biosynthesized silver nanoparticles from Morus alba demonstrated strong antimicrobial activities against gram negative bacteria isolated from wound sample. Advanced techniques such as FTIR and (UV-Vis) spectroscopy are used to characterize and determine the mechanism of action of AgNPs. This study confirms that AgNPS synthesized from Morus alba were more effective against Pseudomonas aeruginosa by showing larger zones of inhibition .In future examine the advantages of AgNPs by using metagenomics and apply as an antimicrobial creams, and further study on Multidrug resistant bacteria..

Reference

1. Abbas, R., et al., Silver nanoparticles: Synthesis, structure, properties and applications. Nanomaterials, 2024. 14(17): p. 1425.
2. Koutamehr, M.E., et al., Sour whey-derived carbon dots; synthesis, characterization, antioxidant activity and antimicrobial performance on foodborne pathogens. LWT, 2023. 184: p. 114978.
3. Sadia, S.I., et al., Green synthesis of crystalline silver nanoparticle by bio-mediated plant extract: A critical perspective analysis. Nano-Structures & Nano-Objects, 2024. 39: p. 101272.
4. Singh, H., et al., Revisiting the green synthesis of nanoparticles: uncovering influences of plant extracts as reducing agents for enhanced synthesis efficiency and its biomedical applications. International journal of nanomedicine, 2023: p. 4727-4750.
5. Gavilán, H., M.B. Serrano, and J.C. Cabanelas, Nanomaterials and their synthesis for a sustainable future. Vol. 149. 2023: Materials Research Forum LLC.
6. Bachheti, R.K. and A. Bachheti, Secondary metabolites from medicinal plants: Nanoparticles synthesis and their applications. 2023: CRC Press.
7. Nagar, R., et al., Secondary Metabolites in Green Synthesis of Nanoparticles, in Microbial Approaches for Sustainable Green Technologies. 2024, CRC Press. P. 287-303.
8. Maniah, K., et al., Synergistic antibacterial activity of biogenic agnps with antibiotics against multidrug resistant bacterial strains. Journal of King Saud University-Science, 2024. 36(10): p. 103461.
9. Saleh, M., et al., Fabrication of Ag nanoparticles coated leonardite basalt ceramic membrane with improved antimicrobial properties for DNA cleavage, E. Coli removal and antibiofilm effects. Journal of Industrial and Engineering Chemistry, 2023. 128: p. 532-541.
10. Abdel-Fatah, S.S., et al., Impeding microbial biofilm formation and Pseudomonas aeruginosa virulence genes using biologically synthesized silver Carthamus nanoparticles. Microbial Cell Factories, 2024. 23(1): p. 240.
11. Kumkoon, T., M. Srisaisap, and P. Boonserm, Biosynthesized silver nanoparticles using Morus alba (white mulberry) leaf extract as potential antibacterial and anticancer agents. Molecules, 2023. 28(3): p. 1213.
12. Batiha, G.E.-S., et al., Morus alba: a comprehensive phytochemical and pharmacological review. Naunyn-schmiedeberg's Archives of Pharmacology, 2023. 396(7): p. 1399-1413.
13. Ren, Y., Y. Zhang, and X. Li, Application of agnps in biomedicine: An overview and current trends. Nanotechnology Reviews, 2024. 13(1): p. 20240030.

14. Chinnathambi, A., et al., Synthesis of agnps from leaf extract of Naringi crenulata and evaluation of its antibacterial activity against multidrug resistant bacteria. Environmental Research, 2023. 216: p. 114455.

15. Solís-Sandí, I., et al., Optimization of the biosynthesis of silver nanoparticles using bacterial extracts and their antimicrobial potential. Biotechnology Reports, 2023. 40: p. E00816.

16. Trak, D. And Y. Arslan, Synthesis of silver nanoparticles using dried black mulberry (Morus nigra L.) Fruit extract and their antibacterial and effective dye degradation activities. Inorganic and nano-metal chemistry, 2023. 53(10): p. 1124-1136.

17. Wirwis, A. And Z. Sadowski, Guide for Optimization of Olive Leaf Extraction and Silver Nanoparticles Biosynthesis as an Initial Step for Pilot Plant Design. ACS omega, 2024. 9(26): p. 29053-29068.

18. Constantin, M., et al., Synthesis, biological and catalytic activity of silver nanoparticles generated and covered by oxidized pullulan. Materials Chemistry and Physics, 2023. 295: p. 127141.

19. Nurkhaliza, F., et al. Comparative study of well diffusion and disc diffusion method to investigate the antibacterial properties of silver nanoparticles synthesized from Curcuma longa extracts. In E3S Web of Conferences. 2024. EDP Sciences.

20. Zaman, Y., et al., Tamed synthesis of agnps for photodegradation and anti-bacterial activity: effect of size and morphology. Inorganic Chemistry Communications, 2023. 150: p. 110523.

21. Ateeb, M., et al., Photocatalytic and Antibacterial activities of bio-synthesised silver nanoparticles (agnps) using Grewia asiatica leaves extract. International Journal of Environmental Analytical Chemistry, 2024. 104(18): p. 6928-6946.

22. Subhani, A.A., et al., UV-spectrophotometric optimization of temperature, ph, concentration and time for eucalyptus globulus capped silver nanoparticles synthesis, their characterization and evaluation of biological applications. Journal of Fluorescence, 2024. 34(2): p. 655-666.

23. Mughal, T.A., et al., Evaluating the biological (antidiabetic) potential of TEM, FTIR, XRD, and UV-spectra observed berberis lyceum conjugated silver nanoparticles. Microscopy Research and Technique, 2024. 87(6): p. 1286-1305.

24. Nie, P., Y. Zhao, and H. Xu, Synthesis, applications, toxicity and toxicity mechanisms of silver nanoparticles: A review. Ecotoxicology and Environmental Safety, 2023. 253: p. 114636.

25. Akhtar, M.F., et al., Evaluation of biological potential of UV-spectrophotometric, SEM, FTIR, and EDS observed Punica granatum and Plectranthus rugosus extract-coated silver nanoparticles: A comparative study. Microscopy Research and Technique, 2024. 87(3): p. 616-627.

26. Baran, M.F., A. Meşe, and A. Eftekhari, Morus alba L. Leaves-Based Silver Nanoparticles for Aging-Related Infectious Diseases. International Journal of Aging, 2023. 1(1): p. E23-e23.

27. Jeon, Y.-N., et al., Green synthesis of silver nanoparticle using black mulberry and characterization, phytochemical, and bioactivity. Antibiotics, 2024. 13(8): p. 686.

28. Qi, M., et al., Transformation, absorption and toxicological mechanisms of silver nanoparticles in the gastrointestinal tract following oral exposure. ACS nano, 2023. 17(10): p. 8851-8865.