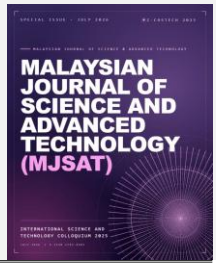
MJSAT

Malaysian Journal of Science and Advanced Technology

journal homepage: https://mjsat.com.my/



Agro-Waste-Mediated Green Synthesis of Silver Nanoparticles from Harum Manis and Sala Mango Peel Waste and Their Antimicrobial Activity

Fadhilatun Nisa Hamzah[1], Zainab Razali[1*], Nur Syafiqah Rahim[1], Muhammad Azhar Zulkffle[1], and Roejhan Md Kawi [2]

[1]*Faculty of Applied Sciences, Universiti Teknologi MARA, Perlis Branch, Arau Campus, 02600 Arau, Perlis.*
[2]*Faculty of Electrical Engineering & Technology, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia.*

KEYWORDS

Silver nanoparticles
Green synthesis
Agro-waste utilisation
Mango peel extract
Antimicrobial activity

ARTICLE HISTORY

Received 22 November 2025
Available online 21 August 2026

ABSTRACT

Green synthesis of silver nanoparticles (AgNPs) is increasingly recognised as an environmentally sustainable alternative to traditional physicochemical synthesis methods. The growing challenge of antimicrobial resistance has further intensified the search for effective and sustainable antimicrobial materials. In this study, mango peel agro-waste from the Harum Manis and Sala varieties was utilised as a natural reducing and stabilising agent for the biosynthesis of AgNPs.The formation of AgNPs was demostrated using UV–Visible spectroscopy, which showed characteristic surface plasmon resonance peaks within the range of 400–500 nm. Fourier Transform Infrared (FTIR) analysis revealed the presence of functional groups associated with biomolecules responsible for nanoparticle reduction and stabilisation. The antimicrobial activity of the synthesised AgNPs was assessed against *Escherichia coli* and *Staphylococcus aureus* using disc diffusion and minimum inhibitory concentration (MIC) assays. Both mango peel-derived AgNPs exhibited moderate antibacterial activity with inhibition zones ranging from 8–10 mm, while the MIC value for both bacterial strains was determined to be 0.1 g/mL. These findings demonstrate the potential of mango peel agro-waste as a renewable resource for AgNP synthesis and highlight its promising application as an eco-friendly antimicrobial agent.

1. INTRODUCTION

Nanoparticles refer to nanoscale materials with particle sizes generally ranging between 1 and 100 nanometres [1]. Because of their distinctive physicochemical characteristics, nanoparticles have gained significant attention and are increasingly utilised across numerous technological and biomedical applications. Among the different types of nanoparticles, silver nanoparticles (AgNPs) have been extensively investigated because of their remarkable antibacterial properties. AgNPs have demonstrated strong antibacterial activity against a wide range of pathogenic microorganisms, including multidrug-resistant bacteria [2].

Numerous approaches have been explored for the production of silver nanoparticles while aiming to achieve both economic feasibility and environmental sustainability. According to Razali et al. [3], there has been increasing interest in plant-mediated synthesis of silver nanoparticles derived from biological waste due to their antibacterial, antioxidant, and biocompatible properties. Plant-derived extracts are rich in phytochemical constituents capable of functioning as natural reducing as well as stabilising agents during nanoparticle agro-waste resource that can potentially be utilised for environmentally friendly nanoparticles synthesis.

Despite the increasing number of studies on plant-mediated nanoparticles synthesis, the utilisation of mango peel agro-waste, particularly from Harum Manis and Sala varieties, remains relatively underexplored. Mango peel contains various phytochemical compounds such as phenolics, flavonoids, and tannins, which may contribute to the reduction and stabilisation of silver nanoparticles. Therefore, the utilisation of mango peel

*Corresponding author:
E-mail address: Zainab Razali < zainab215@uitm.edu.my >.
https://doi.org/10.56532/mjsat.v6iS1.787
2785-8901/

waste not only supports sustainable nanoparticles synthesis but also promotes agro-waste valorisation.

In this study, silver nanoparticles were synthesised from peel extracts of Mangifera *indica* var. Sala and *Mangifera indica* var. Harum Manis using a green synthesis approach. The synthesised AgNPs were characterised using UV–Visible (UV–Vis) and Fourier Transform Infrared (FTIR) spectroscopy, and their antimicrobial activity was evaluated against *Escherichia coli* and *Staphylococcus aureus* using disc diffusion and minimum inhibitory concentration (MIC) assays.

The application of silver nanoparticles has become increasingly important in several industrial sectors, particularly in pharmaceutical and biomedical applications. Conventional chemical and physical synthesis methods of AgNPs often involve hazardous chemicals, high energy consumption, and complex procedures, in contrast, green synthesis offers a safer, cost-effective, and environmentally sustainable alternative for nanoparticles production. Additionally, the utilisation of fruit peel waste helps reduce solid waste accumulation in landfills. Although fruit waste can naturally decompose, the process may require a long period and depends on microbial degradation.

At the same time, antimicrobial resistance has become a growing global health concern. According to the World Health Organization (WHO), several bacterial pathogens have been categorised into critical, high, and medium priority groups due to the urgent need for new antimicrobial agents [4]. In this context, silver nanoparticles have shown promising potential as alternative antimicrobial agents due to their broad-spectrum antibacterial activity and biocompatibility. Therefore, the agro-waste-mediated green synthesis of AgNPs using mango peel waste not only contributes to environmental sustainability but also provides a promising strategy for developing alternative antimicrobial materials.

2. MATERIALS AND METHODS

2.1 Preparation of waste extracts

The peels of Harum Manis and Sala mangoes were prepared based on method by Rajeshkumar et al. [5], for the peel with slight modifications. Mango peels were carefully separated from the fruit and subsequently oven-dried at 50°C until complete dehydration was achieved. Next, the dried peel was cut into fine pieces and *grind* by mechanical grinder to produce powder. Then, the peels extract from Harum Manis and Sala were prepared using distilled water for 3 different concentration, 0.05 g/mL, 0.08 g/mL and 0.1 g/mL. After that, the breakers were put in the water bath at 60 ºC for 10 minutes and the solution was filtered through Whatman No.1 filter paper.

2.2 Preparation of bacteria culture

About 1 mL of the bacterial culture were inoculated into 10 mL of nutrient broth and incubated at 37 ºC while being agitated at 250 rpm for 18 hours. Next, 1 ml from passage one was mixed with new nutrients broth in another bottle and incubated at 37 ºC while being agitated at 250 rpm for 18 hours. After 18 hours of incubation for passage 2, 1 ml of nutrient broth was transferred into the new 10 mL of nutrients broth.

2.3 Preparation of Muller-Hilton Agar

A total of 38 grams of Mueller Hinton Agar powder was mixed properly with 1 L of distilled water. Next, the mixture was heated and sterilized using an autoclave (pressure of 15 psi for 15 minutes) at 121 ºC. Finally, the agar solution was poured into the empty petri dish in a laminar flow.

2.4 Synthesis of silver nanoparticles using Mangifera indica Var Sala and Harum Manis waste extracts

150 ml of 0.01 M aqueous silver nitrate was prepared by weighing 0.225 g of silver nitrate powder and mixing it to 150 mL of distilled water. Then, 20 mL of 0.01 M aqueous $AgNO_3$ and 2 mL of peel extracts are prepared at several concentrations which are 0.10 g/mL, 0.08 g/mL, and 0.05 g/mL. Then, it was put in different Erlenmeyer flasks and heated in the water bath or 60 minutes at 60 ºC. The reaction of the mixture was monitored every 20 minutes, and the changes of colour were recorded. The colour shifted into reddish-dark brown after heating a mixture of the peel extracts and $AgNO_3$ solution confirming the reduction of silver nanoparticles.

2.5 UV-Visible spectroscopy

This procedure was done based on Rajeshkumar et al. [5], with some modification. Before scanning, each 4 mL of sample extract was pipetted into the quartz cuvette. The sample was scanned using a UV-Vis spectrophotometer with optical absorbance in the wavelength (300 to 600 nm) and a scanning speed of 300 nm/min. The absorbance spectrums of the solution were recorded.

2.6 Fourier Transform Infrared (FTIR) spectroscopy

This method was based on Veerasamy et al. [6], with slight modifications. Before beginning the analysis, the solution of synthesized AgNPs is centrifuged, supernatant was removed, and the pellet was washed and dried to yield the powdered form. The dried nanoparticles were placed in a sample holder and analysed using FTIR in a spectrum range of 300–4000 cm^{-1}. The FTIR spectra was measured and recorded.

2.7 Disc diffusion method

This procedure follows Veerasamy et al. [6], with some modifications. The plate of Muller-Hilton agar (MHA) plate marked to four segments, positive control, negative control, the extract of peels and the synthesized silver nanoparticles. Then, *Escherichia coli* and *Staphylococcus aureus* were cultured on the MHA plate with streaking techniques.

The space that was being used was cleaned and wiped with 70% alcohol. The Bunsen burner was on, and the procedure was conducted near the Bunsen burner to avoid the spread of bacteria. First of all, the inoculating loops were sterilized by exposing the tip to the flame until it becomes bright red. Then, after cooling down the tip, the bacteria were be inoculated into the agar using the cool inoculating loops by dipping the bacteria broth and streaking it on the agar plate. The streaking techniques that used are lawn streaking techniques. Those techniques spread the bacteria evenly across the entire surface of the agar plate by streaking in multiple directions. The sterile blank disc was dip into the sample peel extract, the sample of AgNPs synthesized from the waste extracts with the different concentration (0.10 g/mL, 0.08 g/mL, and 0.05 g/mL) and distilled water as negative control. The standard antibiotic gentamycin is used as positive control. Then, the disc was placed on the agar plate according to the labelled segment.

Lastly, the plate was sealed with parafilm and stored upside down in the incubator for 18 hours at 37 °C. The zone of inhibition appears after 18 hours and the diameter of zone of inhibition was calculated and recorded.

2.8 Minimum inhibitory concentration (MIC)

The MIC of each peel extract was determined by the broth dilution method as outlined by Yahya et al. [7] but with some adjustments. Different concentrations of AgNPs samples (0.1 g/mL, 0.05 g/mL, 0.025 g/mL and 0.0125g/mL) were made through serial two-fold dilutions. In a two-fold dilution, the concentration of the extract is reduced by a factor of two. For example, if the initial concentration of the extract is 2 g/mL in the first tube, the second tube will have a dilution of 1:2, resulting in a concentration of 1 g/mL.

Next, a series of sterile test tubes was prepared and labelled according to respective AgNPs concentration (0.1 g/mL, 0.05 g/mL, 0.025 g/ml, 0.0125 g/ml), a positive control and negative control. Each test tube is filled with 1 mL of nutritional broth. Then, 0.1 mL of *E. coli* was introduced into the test tubes with nutritional broth, while in the other test tubes, 0.1 mL of *S. aureus* suspension is added. Subsequently, varying concentrations of AgNPs (0.1 g/mL, 0.05 g/mL, 0.025 g/mL, 0.0125 g/mL) derived from each extract were introduced into sterile nutritional broth test tubes containing bacteria and followed by incubation at 37°C for 24 hours. Positive control consisted of nutrient broth and bacteria without AgNPs from peel extracts, while negative control contains only nutrient broth and AgNPs from peel extracts without the bacteria. After incubation, the optical density (OD) of each test tube is measured using a spectrophotometer at a wavelength of 600 nm. The OD values for each concentration are recorded.

2.9 Data analysis

All experiments were conducted in triplicate to ensure reproducibility. Statistical analysis was performed using one-way Analysis of Variance (ANOVA) since the results involved comparisons among multiple groups.

3. RESULT AND DISCUSSION

3.1 Optical observation

In this study, silver nanoparticles (AgNPs) were successfully formed using green synthesis approaches with Harum Manis and Sala mango peels as reducing agents. Initially the mixture of peel extract and $AgNO_3$ are colourless and yellowish. Without peels extract, $AgNO_3$ solutions are colourless, but the peels extract of mangoes is yellowish resulting the yellowish colour when the extract is mix with $AgNO_3$ solution (Table 1 and Table 2).

Table 1. The color change of the Sala and $AgNO_3$ solution

Period	Color Change
0 minutes	Yellowish / Colorless
30 minutes	Brown
60 minutes	Dark Reddish Brown

Table 2. The color change of the Harum Manis and $AgNO_3$ solution

Period	Color Change
0 minutes	Yellowish / Colorless
30 minutes	Brown
60 minutes	Dark Reddish Brown

Over time, the yellowish colour changes into deep brown colour caused by surface plasmon resonance (SPR) indicating the presence of phytochemical in mango's peels extract successfully reduced Ag^+ ions into Ag^0. Silver nanoparticles are produced when Ag^+ ions, released from a dissolved silver compound, gain electrons through a redox reaction with a reducing agent [8]. The intensity and stability of the brown coloration further suggest the successful synthesis and stabilization of AgNPs over time. The quick transformation from colourless solution into brown signifies the rapid synthesis of AgNPs which eventually developed into even more dark brown colour [9].

This colour change is a typical indicator of silver nanoparticle formation and is associated with surface plasmon resonance (SPR), which occurs when silver ions are reduced into metallic nanoparticles. Similar colour transitions have been widely reported in plant-mediated AgNP synthesis, confirming the successful reduction of Ag^+ ions by phytochemical compounds present in plant extracts

3.2 UV-Visible Spectroscopy Analysis

Sala and Harum Manis show absorption peak in range of 400-500 nm indicating the success of silver nanoparticles formation (Table 3 and Table 4). Both Sala and Harum Manis wavelength increase for 0.08 g/mL and decrease for 0.05 g/mL. With this result, it shows that concentrations of extract affect the formation of AgNPs. The peak at 509.8 nm at 0.08 g/mL of Harum Manis may suggest larger particle size, greater nanoparticles formation, or more intense surface plasmon resonance (SPR) due to higher concentration of reducing agents or stabilizing compounds in the extract. The decrease again to 455.5 nm at 0.05 g/mL might indicate less efficient formation or stabilization of particles at low extract concentration. The concentration of 0.08 g/mL Sala and Harum manis show the highest wavelength for each concentration which might indicates that is the optimum concentration for synthesizing AgNPs.

Table 3. The wavelength reading of Sala AgNPs from UV-Vis spectrophotometer

Concentration (g/mL)	Wavelength (nm)
0.1	435.0
0.08	445.0
0.05	438.0

Table 4. The wavelength reading of Harum Manis AgNPs from UV-Vis spectrophotometer

Concentration (g/mL)	Wavelength (nm)

0.1	457.0
0.08	509.8
0.05	455.5

The absorption peaks observed in this study within the 400–500 nm range are characteristic of the surface plasmon resonance (SPR) of silver nanoparticles. Slight variations in peak wavelength among different extract concentrations may indicate differences in nanoparticle size distribution and particle stability. Similar absorption patterns have been reported in previous studies involving plant-mediated AgNP synthesis, further confirming the successful formation of silver nanoparticles in this study.

3.3 Fourier Transform Infrared Analysis

Fourier Transform Infrared (FTIR) analysis helps in identifying functional groups of *M. indica* in synthesizing silver nanoparticles (AgNPs). It is believed that these functional groups might contributed to the bio reduction and capping process during the AgNPs synthesis. In the study done by Flieger et al. [10], the FTIR analysis shows the presence of functional groups including carboxylic acids, alcohols, phenols, aldehydes, alkanes, esters, ethers and protein which serve and essential role in synthesizing and stabilization of AgNPs.

The broad peak observed at 3232.20 cm^{-1} for 0.1 g/mL, 3239.78 cm^{-1} for 0.08 g/mL and 3030.65 cm^{-1} for 0.05 g/mL in FTIR spectrum, indicating the presence of hydroxyl (-OH) groups and aromatic C-H stretching vibrations (Figure 1-6). The presence of hydroxyl groups suggests that there are chemicals compound like phenols, and alcohols compound in the extract which are known to serve a critical function in reduction of silver ions, Ag^{+} to Ag^{0} during green synthesis of AgNPs. The broad peak at 2918 cm^{-1} suggests the presence of C-H stretching that is related to presence of alkanes.

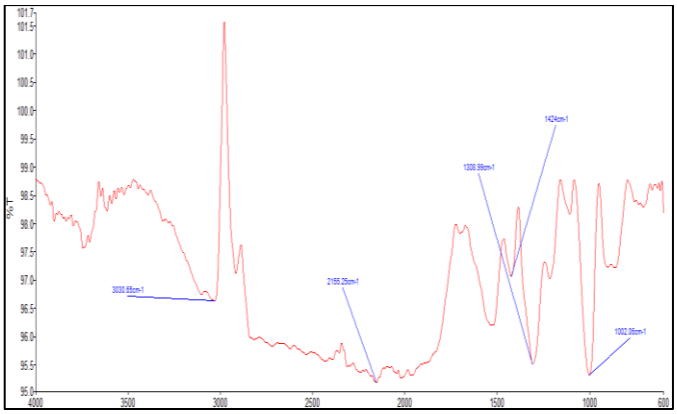


Fig. 1. The peak result of 0.05 g/mL Sala from FTIR

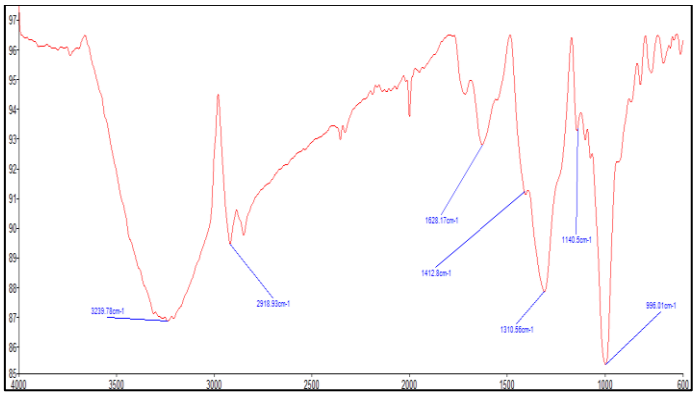


Fig. 2. The peak result of 0.08 g/mL Sala from FTIR

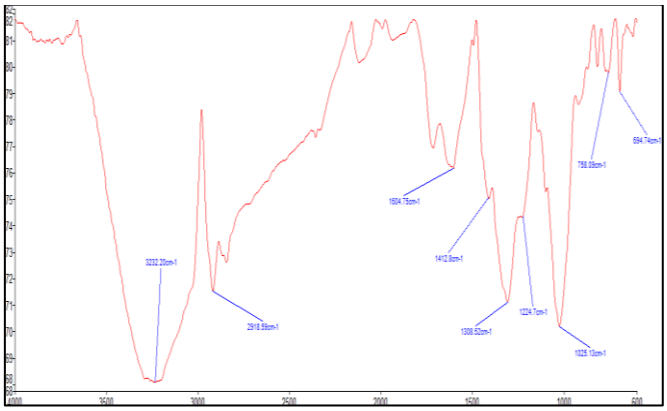


Fig. 3. The peak result of 0.10 g/mL Sala from FTIR

Alkanes group contribute significantly to stabilize silver nanoparticles. In region around 1600 cm^{-1}, peak at 1604.75 cm^{-1} and 1628.17 cm^{-1} indicated the presence of C=O stretching in aromatic rings commonly in flavonoids, esters and tannins. The observed peak at 1224.70 cm^{-1}, 1140.50 cm^{-1} and 1025.13 cm^{-1} is usually associated with C-O stretching. The wavenumber below 1000.00 cm^{-1} commonly indicates the functional groups of C-H bending and aromatic ring which typically related to mangiferin and gallic acid derivatives.

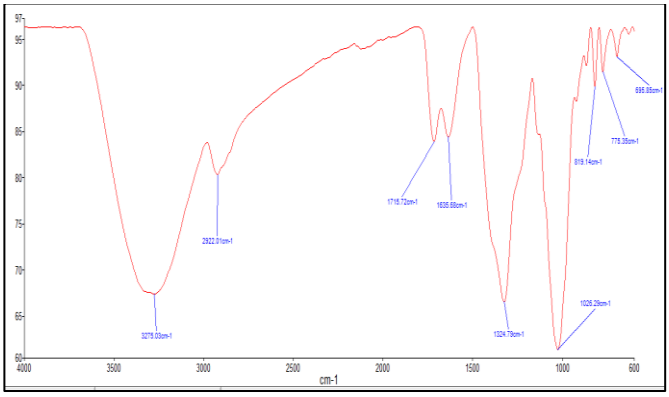


Fig. 4. The peak result of 0.05 g/mL Harum Manis from FTIR

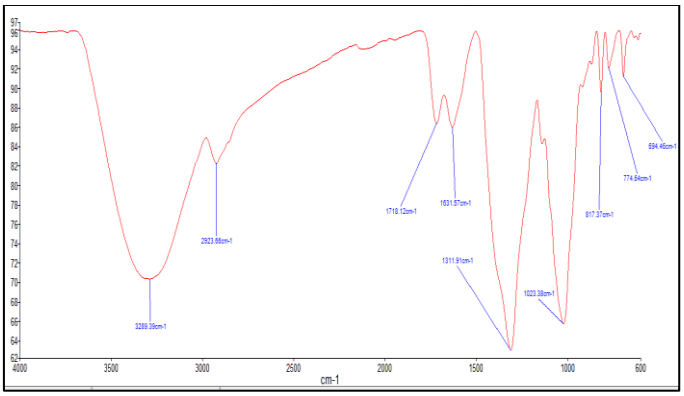


Fig. 5. The peak result of 0.08 g/mL Harum Manis from FTIR

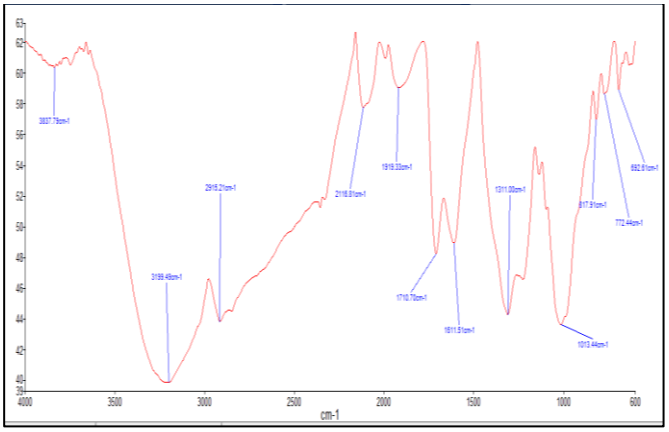


Fig. 6. The peak result of 0.10 g/mL Harum Manis from FTIR

The peak broad peak at 3289.39 cm^{-1}, 3275.03 cm^{-1}, 3837.79 cm^{-1} and 3199.49 cm^{-1} indicating the occurrence of O-H stretching that are commonly found in alcohols and phenols. The peak at 2923.66 cm^{-1}, 2922.01 cm^{-1} and 2915.21 cm^{-1} corresponds to C-H stretching of aliphatic chains (alkanes). Next, for the peak at 1718.12 cm^{-1}, 1715.72 cm^{-1}, 1919.33 cm^{-1} and 1710.70 cm^{-1} associated with C=O stretching possibly from carboxylic acids, aldehyde or esters. C=C stretching in aromatic compound or amide I groups from proteins resulting peaks at 1631.57 cm^{-1}, 1635.68 cm^{-1} and 1611.51 cm^{-1}. The peak at 1311.91 cm^{-1}, 1023.38 cm^{-1}, 1324.79 cm^{-1}, 1026.29 cm^{-1}, 1311.00 cm^{-1} and 1013.44 cm^{-1} indicated the C-O stretching found in esters, ethers and alcohols. Last but not least, the peak at fingerprint region below 1000.0 cm^{-1} is usually from the C-H bending and aromatic ring deformation [11].

Since both Sala and Harum Manis are mango varieties, the FTIR spectra reveals similar characteristics peaks. The functional groups, O-H, C=O and C-O compound suggest the presence of phytochemicals like flavonoids, tannins and proteins from the mango peel extract. These compounds are important in the reduction of silver ions to silver nanoparticles, capping and stabilizing the nanoparticles to prevent the aggregation. For example, in research made by Ahmed & Mustafa [12], tannins have been identified as significant contributors in the reduction and capping processes of silver nanoparticles (AgNPs), where they facilitate the conversion of metal ions and stabilize the nanoparticles by forming a protective layer.

3.4 Disc Diffusion

In this experiment, it appeared that the mango's peels for both Sala and Harum Manis extract, did not have any zone of inhibition (ZOI) for all of the plates. According to John et al. [13], extract using aqueous solvent did not exhibit any ZOI on several bacteria but using acetone and ethanol as solvent, the mango extract shows ZOI range from 10-27 mm. In this study, the mango peel extract was prepared using distilled water as solvent, resulting no zone of inhibition appears on the agar plate for both bacteria.

Table 5. Zone of inhibition produce by AgNPs in *E. coli*

Concentration (g/mL)	ZOI Sala (mm)	ZOI Harum manis (mm)	ZOI Gentamycin (mm)
0.1	10.00±0.00	10.00±0.58	22.0±0.58
0.08	8.67±0.58	9.00±0.00	22.0±0.58
0.05	7.67±0.58	8.67±0.58	22.0±0.58

Table 6. Zone of inhibition produce by AgNPs in *S. aureus*

Concentration (g/mL)	ZOI Sala (mm)	ZOI Harum manis (mm)	ZOI Gentamycin (mm)
0.1	9.67±0.58	10.33±0.58	22.33±0.58
0.08	9.00±0.00	9.00±0.00	22.33±0.58
0.05	8.00±0.58	8.00±0.58	22.33±0.58

The standard interpretation of zone of inhibition (ZOI) values can be categorized by size of clear zone diameter, which is above 15 mm indicate susceptibility, 10-15 mm indicate moderate sensitivity and below 10 mm suggest our sample having a low antimicrobial activity or resistance to the bacteria involved. Sala mango exhibit ZOI in range of 8 mm to 10 mm in for both *E. coli* and *S. aureus* showed a moderate inhibition of bacteria. The concentration of 0.1 g/mL revealed a slightly higher antibacterial activity that might imply that the higher concentration the higher antibacterial effect. However, there is only a small difference between the result 0.1 g/mL and 0.08 g/mL. The AgNPs from Harum Manis exhibit 7 mm to 10 mm of ZOI. The concentration of 0.1 g/mL shows the highest of ZOI (10 mm) while 0.05 g/mL shows the lowest value (7 mm) in *S. aureus*. Both Sala and Harum Manis ZOI indicated a moderate sensitivity to a low range for antibacterial properties. This result suggests that the AgNPs from both Sala and Harum Manis do have antimicrobial properties, but it is not significantly active at lower concentrations.

The reason both Sala and Harum Manis get the result in Table 3.5 and 3.6 is because they are concentration-dependent antibacterial activity. The higher extract concentration means the better nanoparticles formation which leads to a greater antibacterial activity. The lower ZOI might be because of fewer silver nanoparticles forming in the solution. At lower concentrations, there might be fewer capping agents present potentially leasing in the formation of unstable or larger silver nanoparticles[14]. The size of AgNPs is important in exhibiting the antimicrobial properties, which is the smaller the size, the greater its antimicrobial attribute. As demostrated by Wu et al. [15] reveal 2 nm of nanoparticles shows the highest efficacy in the minimum inhibition concentration (MIC), minimum bactericidal concentration (MBC) and inhibition zone diameter

test than 12 nm and 32 nm. Small nanoparticles typically enhanced antibacterial properties attributed to their larger surface area, which increases the interaction with bacterial membranes. It also allows nanoparticles to penetrate bacterial cell walls more easily, generating internal damage especially in Gram-negative bacteria such as *E. coli*.

The antibacterial effect observed in this study is likely related to the interaction between silver nanoparticles and bacterial cell membranes, which may result in membrane damage, oxidative stress, and disruption of cellular metabolic processes[10]. These mechanisms have been widely reported for AgNP-mediated antimicrobial activity and explain the moderate inhibition zones observed for both *E. coli* and *S. aureus*.

3.5 Minimum Inhibitory Concentration (MIC)

From the disc diffusion result, 0.1 g/mL AgNPs exhibit the largest ZOI. The minimum inhibitory concentration (MIC) began with a concentration of 0.1 g/mL, followed by the lower concentration of 0.05 g/mL, 0.025 g/mL and 0.0125 g/mL by two-fold serial dilution.

Table 7. Minimum inhibitory concentration of AgNPs from Sala

Concentration (g/mL)	Bacterial Growth
0.1	No bacterial growth
0.05	Bacteria grow
0.025	Bacteria grow
0.0125	Bacteria grow

Table 8. Minimum inhibitory concentration of AgNPs from Harum Manis

Concentration (g/mL)	Bacterial Growth
0.1	No bacterial growth
0.05	Bacteria grow
0.025	Bacteria grow
0.0125	Bacteria grow

The minimum concentration that completely inhibited the visible bacteria growth was 0.1 g/mL for both Sala and Harum Manis.The solution containing 0.1 g/mL AgNPs remained clear after incubation, indicating the absence of visible bacterial growth. The other lower concentrations, 0.05 g/mL, 0.025 g/mL and 0.0125 on the other hands had the sediments and the solution was cloudy, indicating the presence of bacteria. The observation was compared to the negative control that contains nutrients broth and extract. The result indicate that the particle size and the silver ion release are sufficient enough to destabilize the bacterial cell membranes and generate reactive oxygen species (ROS) to kill the bacteria. Studies on the antimicrobial mechanism of AgNPs suggest that they disrupt bacterial growth by causing dimorphic transitions, impairing DNA replication, and damaging cell membranes [16]. At lower concentration, there might be fewer nanoparticles or insufficient ion release which reduce the bactericidal activity.

According to Burange et. al. [17], to inhibit the bacterial growth, there are four mechanisms of antimicrobial properties by AgNPs. The first one is the AgNPs adhering to the surface of target bacteria cell membranes which will damage the cell membrane. Eventually the cell membrane becomes leaky and important molecules like ions and protein escape from the cell. Since the cell membrane is damage, the bacteria lose its structure and die. The mechanism is the AgNPs penetrate into the cell and interfere with important biomolecules leading to internal cellular damage. Next, AgNPs generate ROS that trigger the oxidative stress and cellular toxicity. Last but not least, AgNPs interrupt cell signal pathways which impair the vital cellular function.

4. CONCLUSION

In conclusion, silver nanoparticles (AgNPs) were successfully synthesised using peel extracts from Harum Manis and Sala mango agro-waste through a green synthesis approach. The formation of AgNPs was confirmed through UV–Vis spectroscopy with characteristic absorption peaks within the range of 400–500 nm, while FTIR analysis revealed functional groups responsible for nanoparticles reduction and stabilisation. The synthesised nanoparticles demonstrated moderate antibacterial activity against *Escherichia coli* and *Staphylococcus aureus*, with inhibition zones ranging from 8–10 mm and a minimum inhibitory concentration (MIC) value of 0.1 g/mL. These results demonstrate that mango peel agro-waste can serve as a promising sustainable resource for nanoparticles synthesis. Overall, this study demonstrates that agro-waste-mediated green synthesis of AgNPs provides a promising approach for developing alternative antimicrobial materials while supporting sustainable waste utilisation.

REFERENCES

[1] Khan, I., Saeed, K., & Khan, I. (2019). Nanoparticles: Properties, Applications and Toxicities. *Arabian Journal of Chemistry 12(7),* 908–931. doi: https://doi.org/10.1016/j.arabjc.2017.05.011

[2] Bruna, T., Maldonado-Bravo, F., Jara, P., & Caro, N. (2021). Silver Nanoparticles and Their Antibacterial Applications. *International Journal of Molecular Sciences 22*(13)*,* 7202. doi: https://doi.org/10.3390/ijms22137202

[3] Razali, Z, Jami'an, N.S.A, Sidik N.J. & Kawi, R.M (2025). Elucidation Study of Bioavailable Potential Among Plant-based Silver Nanoparticles Fabricated from Several Local Fruit Peels. *Scientific Research Journal, 22*(1), 223-241doi: https://doi.org/10.24191/srj.v22i1.17045

[4] Mancuso, G., Midiri, A., Gerace, E., & Biondo, C. (2021). Bacterial Antibiotic Resistance: The Most Critical Pathogens. *Pathogens 10*(10). 1310. doi: https://doi.org/10.3390/pathogens10101310

[5] Rajeshkumar, S., Parameswari, R. P., Sandhiya, D., Al-Ghanim, K. A., Nicoletti, M., & Govindarajan, M. (2023). Green Synthesis, Characterization and Bioactivity of *Mangifera indica* Seed-Wrapped Zinc Oxide Nanoparticles. *Molecules*, *28*(6), 2818. doi: https://doi.org/10.3390/molecules28062818

[6] Veerasamy, R., Xin, T. Z., Gunasagaran, S., Xiang, T. F. W., Yang, E. F. C., Jeyakumar, N., & Dhanaraj, S. A. (2011). Biosynthesis of Silver Nanoparticles using Mangosteen Leaf Extract and Evaluation of Their Antimicrobial Activities. *Journal of Saudi Chemical Society*, *15*(2), 113–120. doi: https://doi.org/10.1016/j.jscs.2010.06.004

[7] Yahya, S. M., Abdulmumin, Y., Abdulmumin, T. M., Sagagi, B. S., Murtala, M., Salau, A. K., & Hassan, S. A. (2021). Biological synthesis, characterization and antimicrobial effect of silver nanoparticles (Ag-NPs) using aqueous extract of mango pulp (*Mangifera indica*). *Journal of Complementary and Alternative Medical Research*, *13*(4), 39-50. doi: https://doi.org/10.9734/jocamr/2021/v13i430233

[8] Razali, Z., Md Kawi, R., & Jaafar Sidik, N. (2022). Impact of temperature and pH on antioxidant activity of green silver nanoparticles fabricated from *Ananas comosus* peel extracts. IOP Conference Series:

Earth and Environmental Science, 1019(1), 012006. doi: https://doi.org/10.1088/1755-1315/1019/1/012006

[9] Angamuthu, S., Thangaswamy, S., Raju, A., Husain, F. M., Ahmed, B., Al-Shabib, N. A., Hakeem, M. J., Shahzad, S. A., Abudujayn, S. A., & Alomar, S. Y. (2023). Biogenic Preparation and Characterization of Silver Nanoparticles from Seed Kernel of *Mangifera indica* and Their Antibacterial Potential against *Shigella* spp. *Molecules*, *28*(6). doi: https://doi.org/10.3390/molecules28062468

[10] Flieger, J., Franus, W., Panek, R., Szymańska-Chargot, M., Flieger, W., Flieger, M., & Kołodziej, P. (2021). Green Synthesis of Silver Nanoparticles Using Natural Extracts with Proven Antioxidant Activity. *Molecules*, *26*(16). doi: https://doi.org/10.3390/molecules26164986

[11] Nandiyanto, A. B. D., Oktiani, R., & Ragadhita, R. (2019). How to read and interpret FTIR spectroscope of organic material. *Indonesian Journal of Science and Technology,* 4(1), 97–118. doi: https://doi.org/10.17509/ijost.v4i1.15806

[12] Ahmed, R. H., & Mustafa, D. E. (2020). Green Synthesis of Silver Nanoparticles Mediated by Traditionally used Medicinal Plants in Sudan. *International Nano Letters 10(1).* 1-14 doi: https://doi.org/10.1007/s40089-019-00291-9

[13] John, S., Lydia, E., Iyer, P., Monica, S. J., & Thambi, P. A. (2016). Antimicrobial Efficacy of Mango Peel Powder and Formulation of Recipes using Mango Peel Powder (*Mangifera indica L.*). *International Journal of Home Science*, *2*(2), 155–161. www.homesciencejournal.com

[14] Razali, Z., Kawi, R. M., Sidik, N. J., Mohamad, S., Sarizan, N. M., Asman, N. A., & Ahmad Kamil, K. (2025). Mutual Bilateral Antibacterial and Toxicity Potentialities of Silver Nanoparticles Biosynthesized from Toxic *Dioscorea Hispida*. *Journal of Advanced Research in Micro and Nano Engineering*, *16*(1), 1–11 doi: https://doi.org/10.37934/armne.35.1.110

[15] Wu, Y., Yang, Y., Zhang, Z., Wang, Z., Zhao, Y., & Sun, L. (2018). A Facile Method to Prepare Size-tunable Silver Nanoparticles and Its Antibacterial Mechanism. *Advanced Powder Technology*, *29*(2), 407–415. doi: https://doi.org/10.1016/j.apt.2017.11.028

[16] Garibo, D., Borbón-Nuñez, H. A., de León, J. N. D., García Mendoza, E., Estrada, I., Toledano-Magaña, Y., Tiznado, H., Ovalle-Marroquin, M., Soto-Ramos, A. G., Blanco, A., Rodríguez, J. A., Romo, O. A., Chávez-Almazán, L. A., & Susarrey-Arce, A. (2020). Green Synthesis of Silver Nanoparticles using *Lysiloma acapulcensis* Exhibit High-antimicrobial Activity. *Scientific Reports*, *10*(1), 12805. doi: https://doi.org/10.1038/s41598-020-69606-7

[17] Burange, P. J., Tawar, M. G., Bairagi, R. A., Malviya, V. R., Sahu, V. K., Shewatkar, S. N., Sawarkar, R. A., & Mamurkar, R. R. (2021). Synthesis of Silver Nanoparticles by using *Aloe vera* and *Thuja orientalis* Leaves Extract and Their Biological Activity: A Comprehensive Review. *Bulletin of the National Research Centre*, *45*(1), 1-13. doi: https://doi.org/10.1186/s42269-021-00639-2