HYDROGEN
JURNAL KEPENDIDIKAN KIMIA
https://e-journal.undikma.ac.id/index.php/hydrogen/index

October 2025. 13(5)
e-ISSN: 2656-3061
p-ISSN: 2338-6487
pp. 951-961

Eco-Friendly Ultrasound-Assisted Synthesis of Silver Nanoparticles Mediated by Tea Leaf Extracts and Their Potential Applications

Nindya Tri Muliawati, Malik Fajar, Novia Amalia Sholeha*, Mohamad Alief Ramdhan, Farida Laila, Tekad Urip Pambudi Sujarnoko, Wina Yulianti, Atep Dian Supardan, Faranita Ratih Listiasari, Ika Resmeiliana

IPB University, Indonesia

* Corresponding Author: noviaamaliasholeha@apps.ipb.ac.id

Article History
Received: 29-10-2025
Revised: 14-11-2025
Published: 22-11-2025

Keywords: Green synthesis, Silver Nanoparticles (AgNPs), Ultrasonic Assisted Synthesis, Green tea Extract, Iron detection.

Abstract
The green synthesis of silver nanoparticles (AgNP) presents notable benefits, such as environmental sustainability, simplicity, cost-effectiveness, and scalability for industrial applications. This study utilized green tea leaves (Camellia sinensis), which are abundant in catechins and polyphenols, as natural reducing and stabilizing agents. Ultrasonic-assisted synthesis was utilized to improve extraction and reduction processes, as acoustic cavitation induced by ultrasonic waves facilitates efficient mass transfer, accelerates nucleation, and enhances nanoparticle dispersion. This method provides an environmentally sustainable and economically viable alternative to conventional AgNP synthesis, enhancing the sustainability of nanoparticle production. The successful synthesis of AgNP was evidenced by the distinct color change of the tea extract from green to brown, accompanied by the formation of a brown colloidal suspension, in accordance with the Surface Plasmon Resonance (SPR) phenomenon. The UV-Vis spectrophotometric analysis confirmed AgNP formation, evidenced by a characteristic absorption peak at approximately 430 nm. The synthesized AgNPs were utilized as a colorimetric sensor for Fe^{3+} ions in aqueous solutions, demonstrating distinct color changes and SPR band shifts upon interaction with the metal. This illustrates their capability as environmentally friendly nanomaterials for the swift and precise detection of heavy metals, aiding in sustainable environmental monitoring. This research integrates ultrasonic-assisted synthesis with green tea extract, presenting a viable approach for the large-scale, environmentally sustainable production of nanoparticles.

How to Cite: Muliawati, N. T., Fajar, M., Sholeha, N. A., Ramdhan, M. A., Laila, F., Sujarnoko, T. U. P., … Resmeiliana, I. (2025). Eco-Friendly Ultrasound-Assisted Synthesis of Silver Nanoparticles Mediated by Tea Leaf Extracts and Their Potential Applications. *Hydrogen: Jurnal Kependidikan Kimia*, *13*(5), 951–961. https://doi.org/10.33394/hjkk.v13i5.18213

https://doi.org/10.33394/hjkk.v13i5.18213

INTRODUCTION

Iron (Fe) is a micronutrient that is essential for many biological systems, but high levels of Fe—especially Fe^{3+}—in aquatic environments can cause a decline in water quality, increase the growth of harmful microbes, and pose a risk of oxidative damage to human health. High levels of iron in water—especially concentrations above these limits—can lead to adverse health effects, including gastrointestinal distress, oxidative damage, and in extreme cases, organ dysfunction or death (Suryati & Maksuk, 2024). Therefore, continuous monitoring of iron levels in water is essential to protect public health.

Traditional detection methods such as atomic absorption spectroscopy (AAS) and inductively coupled plasma mass spectrometry (ICP-MS) are indeed accurate and sensitive, but they often have drawbacks such as high costs, the need for trained personnel, complex sample preparation, and limited portability. Nanotechnology offers promising alternatives, especially through the development of optical nanosensors. Silver nanoparticles (AgNPs), owing to their localized surface plasmon resonance (LSPR), can produce visible color changes or spectral shifts in response to the presence of metal ions (e.g., Fe^{3+}), allowing for rapid, visual, and cost-effective detection. Silver nanoparticles (AgNPs) synthesized using sodium citrate as a reducing agent and formaldehyde cross-linked chitosan as a stabilizer demonstrated effective analytical performance for the detection of Fe(III), achieving a linearity coefficient of $R^2 = 0.924$ (Sulistyani et al., 2022). However, the dependence on synthetic reagents for reduction and stabilization complicates the synthesis process and diminishes its environmental sustainability. The synthesis method necessitates elevated temperatures, leading to increased energy consumption and potential impacts on particle stability and size distribution, thereby constraining its feasibility for large-scale or environmentally sustainable applications.

In line with the principles of green chemistry—which emphasizes the reduction of hazardous substances, energy efficiency, and the use of renewable resources—green AgNP synthesis has gained attention. The use of plant extracts as bioreductors and stabilizers avoids many toxic reagents used in conventional nanoparticle synthesis, thereby reducing environmental impact. Green tea extract (Camellia sinensis) is particularly attractive because it is rich in polyphenols, flavonoids, and other biomolecules that can reduce silver ions and stabilize the resulting nanoparticles (Widatalla et al., 2022). Moreover, integrating ultrasonic-assisted methods in green synthesis can improve particle uniformity, accelerate nucleation, reduce synthesis time, and produce smaller, less aggregated AgNPs—features that strongly influence sensitivity and selectivity in sensing applications (Manjamadha & Muthukumar, 2016; Jasmin et al., 2025). Although there is increasing interest in green synthesis, limited research has investigated the efficacy of ultrasonic-assisted green tea-based AgNPs for the detection of Fe^{3+}. This study investigates the synthesis of green silver nanoparticles (AgNPs) utilizing ultrasound and green tea extract and evaluates their efficacy as sustainable colorimetric sensors for Fe^{3+} ions in aquatic environments.

METHOD

Materials and Tools

Tea leaves was collected from local suppliers, the chemicals used ethanol 96%, distilled water, $FeCl_3$, $AgNO_3$, concentrated HCl, follin reagent, Liebermann-Burchard reagent, H_2SO_4 2 M, diethyl ether, Mg powder, Dragendorff reagent, Mayer reagent, Wagner reagent, amyl alcohol, Na_2CO_3, beaker glass, analytical balance, spatula, stirring rod, measuring glass, volumetric flask. funnel glass, hotplate, magnetic stirrer, test tube, graduated pipette, bulb, centrifuged tube, centrifuge, burette, Ultrasonic cell crusher noise isolating chamber, cuvette, Spectrophotometer UV-Vis.

Preparation of tea leaves extract with ultrasonic method

Fresh green tea leaves were washed, air-dried, and cut into small pieces to increase the surface area. A 10 g portion of the sample was placed in a glass vessel, followed by the addition of 100 mL of ethanol as the extraction solvent. Ultrasonic-assisted extraction (UAE) was then carried out at 40 °C for 30 minutes using a controlled ultrasonic chamber, where ultrasonic waves facilitated acoustic cavitation to enhance the release of bioactive compounds. The resulting extract was filtered and collected for subsequent nanoparticle synthesis.

Biosynthesis of AgNPs

A stock solution of $AgNO_3$ (0.010 M) was prepared and subsequently diluted to obtain a 0.001 M working solution in a 100 mL volumetric flask. For nanoparticle synthesis, 10 mL of green tea leaf extract was transferred into a 100 mL beaker and stirred using a magnetic stirrer. While stirring, 90 mL of the 0.001 M $AgNO_3$ solution was added dropwise from a burette to ensure controlled mixing and reduction. The mixture was then ultrasonically treated at 60 °C for 1 hour using an ultrasonic chamber operating at a frequency of 50 Hz to promote the formation of silver nanoparticles (AgNPs). The successful synthesis of AgNPs was confirmed by UV–Vis spectrophotometry, with absorbance spectra recorded in the range of 325–700 nm to identify the characteristic surface plasmon resonance (SPR) peak.

Phytochemical Screening

Alkaloid Test

Three milliliters of extract were mixed with 10 mL of chloroform–ammonia solution (3:1, v/v) and filtered. A few drops of 2 M H_2SO_4 were added to the filtrate and the mixture was homogenized until two distinct layers were formed: an organic layer and a colorless acidic layer. The acidic layer was divided into three separate test tubes. Mayer's reagent was added to tube 1, Dragendorff's reagent to tube 2, and Wagner's reagent to tube 3. The presence of alkaloids was indicated by a white precipitate (Mayer's), an orange precipitate (Dragendorff's), and a brown precipitate (Wagner's).

Flavonoid Test

One gram of tea leaf extract was dissolved in 25 mL of hot distilled water, boiled for 5 minutes, and filtered. Five milliliters of the filtrate were placed in a test tube, followed by the addition of 1 mL concentrated HCl, 0.1 mg Mg powder, and 1 mL amyl alcohol. The mixture was vigorously shaken, and the development of a red or pink coloration indicated the presence of flavonoids.

Steroid Test

Three milliliters of extract were dissolved in 25 mL of diethyl ether and mixed thoroughly. The solution separated into two phases, with the diethyl ether layer filtered for steroid testing and the residue reserved for saponin testing. To the diethyl ether layer, Liebermann–Burchard reagent was added. A green to blue coloration indicated the presence of steroids.

Saponin Test

The residue obtained from the steroid test was dissolved in 5 mL of distilled water and heated for 5 minutes. After cooling, the solution was shaken vigorously. The formation of a stable foam persisting for at least 15 minutes indicated the presence of saponins.

Tannin Test

Three milliliters of extract were dissolved in 1 mL of methanol and filtered. The filtrate was treated with a few drops of 1% $FeCl_3$ solution. The development of a green, blue, or purple coloration indicated the presence of tannins.

Detection of Fe(III) ion with AgNPs

A stock solution of $FeCl_3$ (10 mM) was prepared by dissolving 0.162 g of $FeCl_3 \cdot 6H_2O$ in a 100 mL volumetric flask with distilled water. From this stock, a series of Fe(III) standard solutions were prepared at concentrations of 17.9, 35.8, 71.6, 107.5, 143.3, and 179.1 mM by appropriate dilution in 25 mL volumetric flasks. For the test sample, 7 mL of $FeCl_3$ solution was transferred into a 25 mL volumetric flask and diluted to the mark with distilled water.

For colorimetric analysis, 1 mL of each Fe(III) standard solution or sample solution was placed into a test tube, followed by the addition of 1 mL of the synthesized AgNPs and 8 mL of distilled water. The mixtures were homogenized using a vortex mixer and filtered to remove particulates. The absorbance spectra were then recorded using a UV–Vis spectrophotometer within the maximum wavelength range of AgNPs surface plasmon resonance (SPR).

RESULTS AND DISCUSSION

Biosynthesis of AgNPs Mediated by Tea Leaf Extracts

The green synthesis of silver nanoparticles (AgNPs) offers distinct advantages over conventional chemical and physical approaches, including environmental sustainability, cost-effectiveness, procedural simplicity, and scalability for industrial applications. Green tea leaves are rich in catechins, a class of flavonoid derivatives bearing hydroxyl (–OH) groups, which act as natural reducing agents by converting Ag^+ ions into elemental silver nanoparticles (Ag^0) (Rahim et al., 2020). Catechins are readily oxidized, and together with polyphenols—present in concentrations of 30–40% in green tea, which is higher than in black tea—they serve as efficient bioreductors by donating protons in the silver reduction process (Windarti et al, 2022). The reduction of Ag^+ to Ag^0 mediated by hydroxyl-containing compounds is visually evidenced by a color change in the tea extract from green to brown, corresponding to the appearance of a characteristic Surface Plasmon Resonance (SPR) band (Handoko et al., 2022).

The extraction of catechins and polyphenols from green tea leaves is strongly influenced by the choice of solvent. In this study, ethanol was selected due to its polarity, which is compatible with phenolic and flavonoid compounds, in accordance with the "like dissolves like" principle. Ethanol has been widely reported as an effective solvent for recovering phenolic compounds from plant matrices, including tea leaves (Putri et al., 2023).

Ultrasonic-assisted extraction (UAE) was employed to enhance the recovery of bioactive compounds. UAE is based on acoustic cavitation, whereby ultrasonic waves generate microbubbles that collapse violently, disrupting plant cell walls and facilitating solvent penetration. This mechanism significantly improves extraction efficiency while minimizing energy use compared to conventional techniques such as maceration and Soxhlet extraction (Kristina et al., 2022); (Haryono et al., 2018). Furthermore, UAE is regarded as an environmentally friendly, rapid, and non-destructive technology that preserves the structural integrity of extracted compounds (Adhiksana, 2017). However, the extraction temperature and duration are critical factors. Elevated temperatures can accelerate antioxidant oxidation, resulting in extract degradation, whereas excessive duration may cause the breakdown of heat-sensitive bioactive compounds such as flavonoids (Ibrahim et al., 2015). Bioactive compounds are particularly unstable above 50 °C, which can lead to structural alterations and a decline in extract quality. Conversely, insufficient heating or short extraction times may yield suboptimal recovery of target phytochemicals (Sekarsari et al., 2019). In this work, UAE was conducted at 40 °C to balance efficiency and compound stability.

Phytochemical screening of the ethanol extract confirmed the presence of several classes of secondary metabolites, including alkaloids, flavonoids, steroids, saponins, and tannins (Rumagit et al., 2015). These metabolites not only serve as markers of extract composition but also contribute to the reduction and stabilization of AgNPs during synthesis. The observed positive reactions to specific reagents provided qualitative evidence of compounds with potential bioreductive activity. The results of the phytochemical analysis of green tea leaf extracts obtained at different extraction conditions are summarized in Table 1.

The ethanol extract of green tea leaves tested positive for the presence of alkaloids, flavonoids, steroids, saponins, and tannins. These findings are consistent with the results reported by (Wulandari et al., 2020), who also confirmed that green tea leaf extracts contain the same classes of secondary metabolites. The thermal stability of these compounds further supports the extraction results obtained in this study. Alkaloids remain stable up to 138 °C, flavonoids are not degraded below 90 °C, saponins are stable up to 70 °C, while tannins begin to decompose within the range of 98.89–101.67 °C. Therefore, the extraction temperature applied in this study (40 °C) did not adversely affect the integrity of the secondary metabolites obtained from the ethanol extract of green tea leaves.

Table 1. Test results of secondary metabolites of green tea leaves extract through phytochemicals

Phytochemical Parameters	Indicator	Color if the result is positive	Result
Alkaloids	Mayer	White sediment	+
	Dragendorf	Orange	+
	Wagner	Brown	+
Flavonoids	Amyl alcohol	Orange	+
Steroids	Lieberman-Buchard	Green	+
Saponins	-	Foam	+
Tannins	$FeCl_3$ 1%	Blackish green	+

Secondary metabolites play a critical role in the green synthesis of silver nanoparticles. The hydroxyl (–OH) and carbonyl groups in polyphenolic compounds, including flavonoids and tannins, function as electron donors in the reduction of Ag^+ ions to Ag^0 (Purnamasari, 2021).

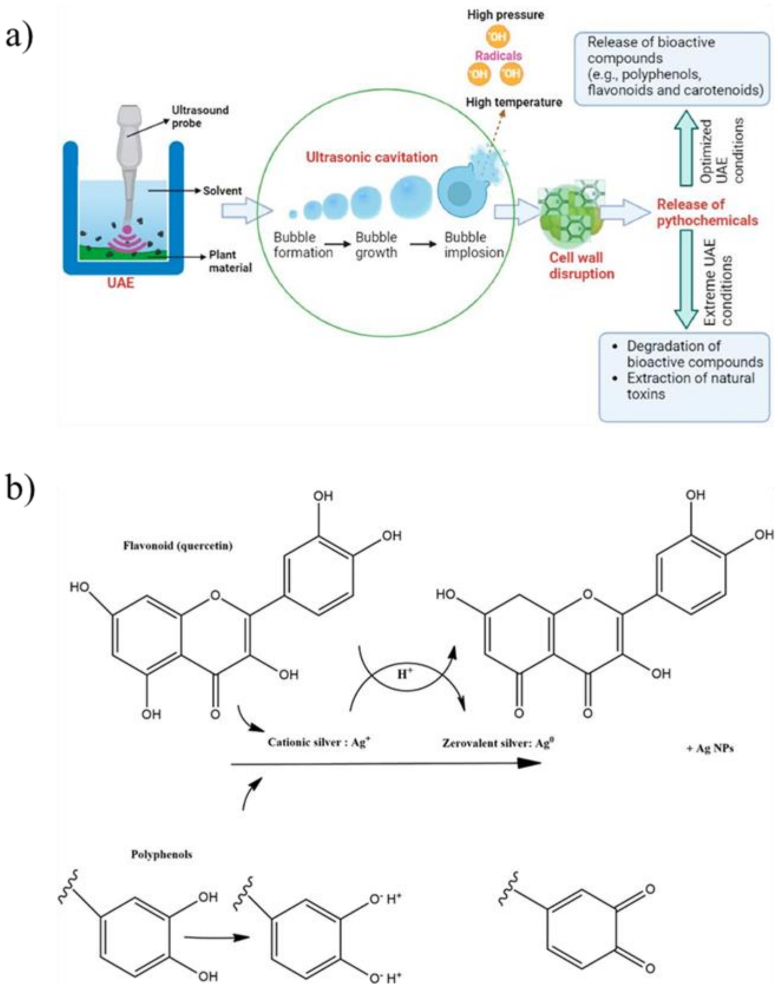

Figure 1. (a) Mechanism of the ultrasound-assisted extraction of bioactive compounds from plant materials (Demesa et al., 2024), (b) Synthesis reaction of silver nanoparticles by polyphenols and flavonoid (Omidi et al., 2018)

Figure 1 demonstrates that polyphenolic compounds experience deprotonation, resulting in the formation of reactive R–O⁻ groups that readily interact with Ag^+ ions in solution. This interaction results in the formation of RO–Ag complexes, which then participate in redox reactions that break the polyphenol chain and release metallic silver (Ag^0) (Lestari, 2019). Besides acting as reducing agents, these biomolecules contribute to stabilization, preventing aggregation and ensuring the colloidal stability of the synthesized AgNPs.

The synthesis of AgNPs using green tea leaf extract was evidenced by a distinct color change of the reaction mixture from green to blackish gray. This observation is consistent with the findings of (Lestari et al., 2019), who reported that the development of a characteristic color is one of the key indicators of AgNPs formation. The intensity of the resulting color correlates with the extent of reduction, where a darker coloration reflects a higher degree of oxidation of organic compounds and, consequently, a greater reduction of Ag^+ ions to Ag^0. This process enhances the nucleation and growth of nanoparticles, thereby increasing the overall yield and surface area of the synthesized AgNPs (Haryani et al., 2016).

Characterization of AgNPs

The biosynthesized silver nanoparticles were characterized using UV–Vis spectrophotometry to confirm their formation and optical properties (Sugito et al., 2022). The absorption spectrum of the AgNPs exhibited a distinct Surface Plasmon Resonance (SPR) band with a maximum wavelength at approximately 430 nm, which is consistent with the typical SPR range of silver nanoparticles (400–450 nm) reported in the literature (Shameli et al., 2015); (Ahmed et al., 2016). The presence of this characteristic absorption peak strongly indicates the successful reduction of Ag^+ ions to Ag^0 nanoparticles mediated by the phytochemicals present in green tea extract. The observed λmax at 430 nm suggests the formation of well-dispersed, spherical AgNPs of small size, as variations in the SPR peak position are generally associated with particle size, morphology, and degree of aggregation (Kumar et al., 2019).

The findings of this study align with earlier investigations into the green synthesis of silver nanoparticles (AgNPs) utilizing Curcuma longa extract, which indicated a surface plasmon resonance (SPR) peak for AgNPs at around 426–427 nm (Sapkota et al., 2024). The results corroborate the efficacy of ultrasonic-assisted green synthesis in generating stable AgNPs with advantageous optical properties appropriate for metal ion sensing applications (Figure 2). Compared to earlier research that synthesized AgNPs using Camellia sinensis (green tea) extracts—resulting in nanoparticles with an average size of approximately 52 nm and significant antibacterial activity (MIC 31.25–62.5 $\mu g \cdot mL^{-1}$) with distinct SPR bands between 450–500 nm (Ali et al., 2022), as well as other studies producing smaller particles (~26.9 nm) with SPR peaks around 410–420 nm under ambient conditions (Mohamed et al., 2021).

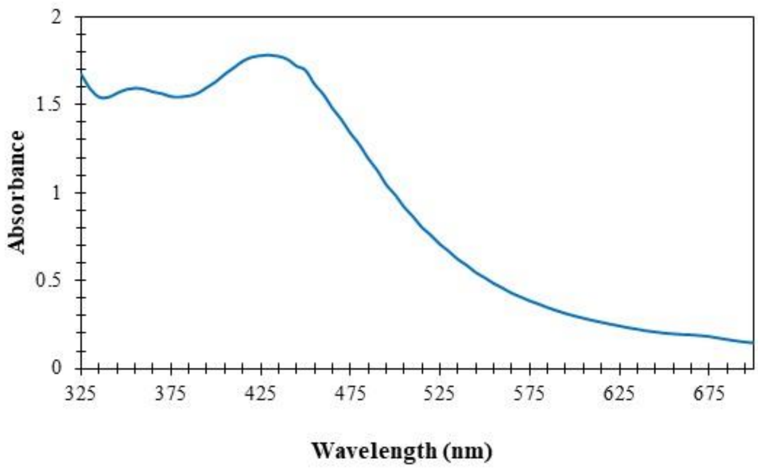

Figure 2. UV-Vis Spectra of AgNPs

The current study exhibits improved synthesis efficiency and enhanced particle uniformity. The use of Camellia sinensis extract as a bioreducing and stabilizing agent in ultrasonic-assisted extraction (UAE) conditions significantly improved mass transfer and expedited nucleation, resulting in the formation of uniformly dispersed AgNPs with a distinct SPR peak around 430 nm. The findings indicate that the UAE-assisted green synthesis method not only maintains the environmentally friendly properties of plant-based reduction but also enhances particle uniformity and reaction kinetics relative to traditional ambient-temperature techniques documented in previous research. The method developed in this study offers a more rapid, energy-efficient, and reproducible approach for the synthesis of AgNPs, while preserving the inherent benefits of phytochemical-mediated reduction.

The particle size analysis (PSA) depicted in Figure 3 indicated that silver nanoparticles (AgNPs) synthesized via tea extract under ultrasonic-assisted extraction (UAE) had a Z-average of 96.6 ± 2.1 nm and a polydispersity index (PDI) of 0.489, suggesting moderately uniform particle dispersion. The small size and acceptable PDI indicate that ultrasound treatment improved the reduction efficiency of phytochemicals in the tea extract, including polyphenols, flavonoids, and catechins, by facilitating rapid nucleation and inhibiting agglomeration during synthesis. Other studies, Ali et al (2022), have reported similar findings, indicating that the application of UAE promotes the formation of smaller and more monodisperse AgNPs. For instance, green syntheses utilizing Camellia sinensis or other polyphenol-rich plant extracts have yielded nanoparticles ranging from 52 nm under ultrasonic conditions by using Transmission Electron Microscope (TEM). The results indicate that UAE serves as an effective intensification technique, enhancing both particle size control and distribution uniformity in tea-mediated AgNP synthesis.

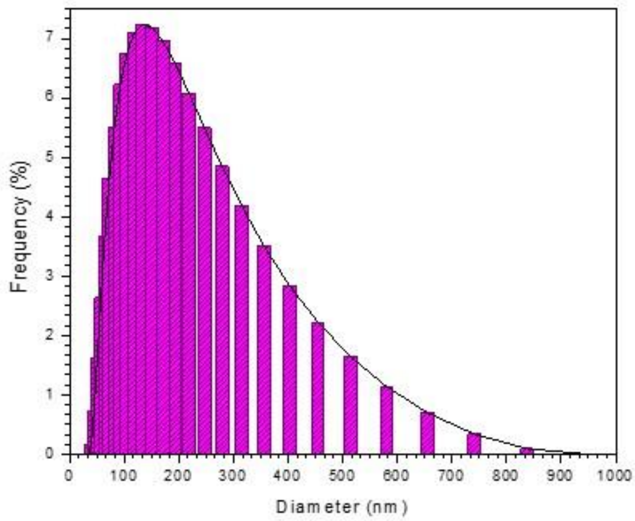

Figure 3. PSA Analysis of AgNPs

Detection of Fe(III) ion with AgNPs

The performance of the biosynthesized AgNPs from green tea leaf extract in detecting Fe^{3+} ions was further evaluated through quantitative analysis. The sensitivity of the system was assessed by constructing a calibration curve, in which the absorbance response of AgNPs to varying Fe^{3+} concentrations was measured (Riyanto et al., 2021). The calibration plot exhibited good linearity with a correlation coefficient (R^2) of 0.9908, indicating a strong relationship between Fe^{3+} concentration and the optical response of AgNPs (Fig 4). Such high linearity demonstrates the reliability of green-synthesized AgNPs as effective colorimetric probes for Fe^{3+} detection (Singh et al., 2018). In addition to sensitivity, the accuracy of Fe^{3+} quantification was evaluated using recovery studies. Accuracy reflects the degree of conformity between the experimental results and the true or reference values (Sugito et al., 2022).

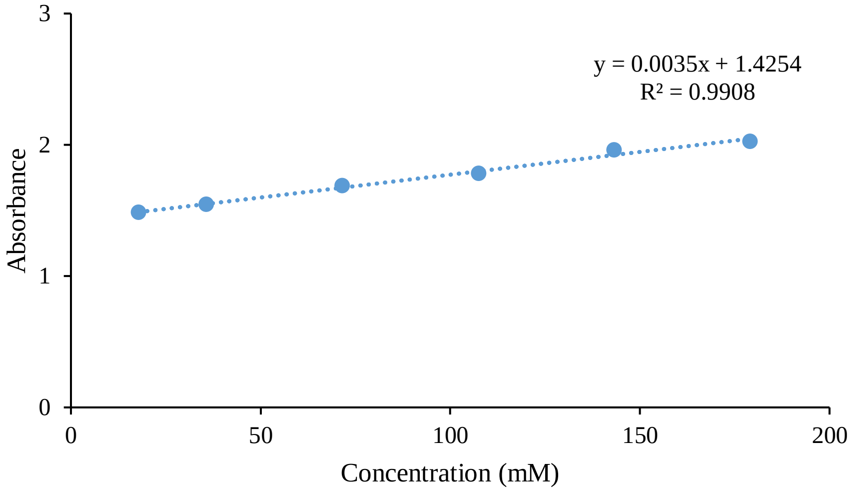

Figure 4. Calibration Curve of Fe^{3+} Ion

In this study, the percentage recovery obtained for the test sample was 102%, which falls within the generally accepted range of 95–105% as recommended by (AOAC, 2016). This result indicates that the developed AgNP-based colorimetric method not only provides reliable sensitivity but also ensures accurate determination of Fe^{3+} levels in aqueous samples. The combination of high linearity and acceptable recovery highlights the potential of ultrasonic-assisted, green-synthesized AgNPs as eco-friendly and efficient nanoprobes for monitoring Fe^{3+} contamination in aquatic environments (Suryani et al., 2022).

Overall, the results demonstrate that silver nanoparticles synthesized via ultrasonic-assisted green synthesis using green tea leaf extract exhibit excellent potential as eco-friendly colorimetric sensors for Fe^{3+} ions (Istihara, 2019). The presence of extract played a crucial role as natural reducing and stabilizing agents, enabling the formation of stable AgNPs with distinct optical properties (Muliawati et al., 2021). The AgNPs showed strong sensitivity, high linearity (R^2 = 0.9908), and satisfactory accuracy with recovery values within the acceptable range (102%), highlighting their reliability for practical application in water quality monitoring. These findings reinforce the promise of plant-mediated green nanotechnology as a sustainable approach for developing low-cost and effective nanosensors for heavy metal detection in aquatic environments (Kumar et al., 2019); (Riyanto et al., 2021).

CONCLUSION

This study successfully demonstrated the green synthesis of silver nanoparticles (AgNPs) using ethanol extract of green tea leaves assisted by ultrasonic treatment. The polyphenolic compounds, particularly flavonoids and tannins, acted as efficient natural reducing and stabilizing agents, enabling the formation of stable AgNPs, as confirmed by UV–Vis spectrophotometry with a distinct surface plasmon resonance absorption peak at 430 nm. The synthesized AgNPs exhibited excellent performance as colorimetric nano sensors for Fe^{3+} ion detection, showing high sensitivity with a strong linear correlation (R^2 = 0.9908) and acceptable accuracy (recovery value of 102%).

These findings emphasize the potential of plant-mediated green nanotechnology as an environmentally friendly, simple, and cost-effective approach for developing metal ion sensors, particularly for Fe^{3+} monitoring in environmental samples. Future research should concentrate on broadening the application of the synthesized AgNPs for detecting other environmentally significant heavy metal ions, such as Cu^{2+}, Pb^{2+}, or Hg^{2+}, to assess their selectivity and versatility. Further optimization of the ultrasonic-assisted synthesis process is recommended to enhance yield, improve particle uniformity, and facilitate large-scale production, thereby broadening the practical impact of this sustainable nanomaterial in environmental monitoring and analytical sensing technologies.

ACKNOWLEDGEMENTS

Authors thank our colleagues from IPB University who provided funding through Hibah Penugasan Program Studi No. 6418/IT3.S3/PT.01.03/P/T/2025 to Novia Amalia Sholeha.

BIBLIOGRAPHY

Adhiksana, A. (2017). Perbandingan metode konvensional ekstraksi pektin dari kulit buah pisang dengan metode ultrasonik. *Journal of Research and Technology, 3*(2), 80–88. https://doi.org/10.55732/jrt.v3i2.276

Ahmed, S., Ahmad, M., Swami, B. L., & Ikram, S. (2016). A review on plants extract mediated synthesis of silver nanoparticles for antimicrobial applications: A green expertise. *Journal of Advanced Research, 7*(1), 17–28. https://doi.org/10.1016/j.jare.2015.02.007

Ali, S. G., Jalal, M., Ahmad, H., Sharma, D., Ahmad, A., Umar, K., & Khan, H. M. (2022). *Green synthesis of silver nanoparticles from* Camellia sinensis *and its antimicrobial and antibiofilm effect against clinical isolates*. *Materials, 15*(19), 6978. https://doi.org/10.3390/ma15196978

AOAC. (2016). *AOAC guidelines for single laboratory validation of chemical methods for dietary supplements and botanicals.* AOAC International.

Demesa, A.G., Saavala, S., Poysa, M., & Koiranen, T. (2024). Overview and Toxicity Assessment of Ultrasound-Assisted Extraction of Natural Ingredients from Plants. *Foods*. 13(19), 3066. https://doi.org/10.3390/foods13193066

Handoko, V., Yusradinan, A., Nursyahid, A., Wandira, A., & Wulandari, A. P. (2022). Green synthesis nanopartikel perak dengan bioreduktor ekstrak daun rami (*Boehmeria nivea*) melalui iradiasi microwave. *Chimica et Natura Acta, 10*(1), 15–21. https://doi.org/10.24198/cna.v10.n1.35755

Haryani, Y., Kartika, G. F., Yuharmen, Y., Putri, E. M., Alchalish, D. T., & Melanie, Y. (2016). Pemanfaatan ekstrak air rimpang jahe merah (*Zingiber officinale* Linn. var. *rubrum*) pada biosintesis sederhana nanopartikel perak. *Chimica et Natura Acta, 4*(3), 151–155. https://doi.org/10.24198/cna.v4.n3.10989

Haryono, E., Ernawati, E., & Erliyana, A. H. (2018). Kinerja ekstraksi minyak akar wangi dengan metode ultrasonikasi dan soxhletasi. *Jurnal Rekayasa Bahan Alam dan Energi Berkelanjutan*, *2*(1), 1–6. https://doi.org/10.21776/ub.rbaet.2018.002.01.01

Ibrahim, A. M., Yuniantha, & Sriherfyna, F. H. (2015). The effect of temperature and extraction time on the chemical and physical properties in the production of red ginger juice (*Zingiber officinale var. rubrum*) with the addition of honey as a sweetener. *Journal of Food and Agroindustry, 3*(2), 530–541.

Istihara, I. (2019). Reduction of iron (Fe) content using an aeration unit in water. *INA-Rxiv*. https://doi.org/10.31227/osf.io/49t3c

Jasmin, F., Handayani, A., & Akmal, T. (2025). Optimization of Extraction Parameters for Phenolics and Flavonoids from Peony (Paeonia lactiflora) Flowers Using Ultrasound-

Assisted Extraction. Hydrogen: Jurnal Kependidikan Kimia, 13(1), 1-11. https://doi.org/10.33394/hjkk.v13i1.14346

Kristina, C. V. M., Yusasrini, N. L. A., & Yusa, N. M. (2022). Pengaruh waktu ekstraksi dengan menggunakan metode ultrasonic assisted extraction (UAE) terhadap aktivitas antioksidan ekstrak daun duwet (*Syzygium cumini*). *Itepa: Jurnal Ilmu dan Teknologi Pangan*, *11*(1), 13–21. https://doi.org/10.24843/itepa.2022.v11.i01.p02

Kumar, B., Smita, K., Cumbal, L., & Debut, A. (2019). Green synthesis of silver nanoparticles using Andean blackberry fruit extract and evaluation of their antibacterial activity. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 122*, 64–67. https://doi.org/10.1016/j.saa.2013.11.105

Lestari, G. A. D., Suprihatin, I. E., & Sibarani, J. (2019). Synthesis of silver nanoparticles (NPAg) using andaliman (*Zanthoxylum acanthopodium* DC.) fruit water extract and its application in indigosol blue photodegradation. *Journal of Scientific and Applied Chemistry*, *22*(5), 200–205. https://doi.org/10.14710/jksa.22.5.200-205

Manjamadha, V. P., & Muthukumar, K. (2016). Ultrasound assisted green synthesis of silver nanoparticles using weed plant. *Bioprocess and Biosystems Engineering, 39*(3), 401–411. https://doi.org/10.1007/s00449-015-1523-3

Mohamed, T.K., Widdatallah, M.O., Ali, M.M., Alhaj, A.M., & Elhag, D.A. (2021). Green Synthesis, Characterization, and Evaluation of theAntimicrobial Activity of *Camellia sinensis* Silver Nanoparticles. *Journal of Nanotechnology*, 7(2867404). https://doi.org/10.1155/2021/2867404

Muliawati, N.T., Siswanta, D., & Aprilita, N.H. (2021), Development of a Simple Fe(II) Ion Colorimetric Sensor from the Immobilization of 1,10-Phenanthroline In Alginate/Pectin Film. 21(2). 411-420. https://doi.org/10.22146/ijc.56759

Omidi, S., Sedaghat, S., Tahvildari, K., Derakhsi, P., & Motiee, F. (2018). Biosynthesis of Silver Nanoparticles with *Adiantum capillus-veneris L* Leaf Extract in the Batch Process and Assessment of Antibacterial Activity. *Green Chemistry Letters and Reviews*. 11(4), 544-551. https://doi.org/10.1080/17518253.2018.1546410

Purnamasari, G. A. P. P., Lestari, G. A. D., Cahyadi, K. D., Esati, N. K., & Suprihatin, I. E. (2021). Biosintesis nanopartikel perak menggunakan ekstrak air daun cemmem (*Spondias pinnata* (L.f) Kurz.) dan aktivitasnya sebagai antibakteri. *Indonesian E-Journal of Applied Chemistry*, *8*(2), 75–80.

Putri, J. Y., Nastiti, K., & Hidayah, N. (2023). Pengaruh pelarut etanol 70% dan metanol terhadap kadar flavonoid total ekstrak daun sirsak (*Annona muricata* Linn). *Journal of Pharmaceutical Care and Sciences, 3*(2), 20–29.

Rahim, D. M., Herawati, N., & Hasri, H. (2020). Sintesis nanopartikel perak menggunakan bioreduktor ekstrak daun teh hijau (*Camellia sinensis*) dengan iradiasi microwave. *Chemica: Jurnal Ilmiah Kimia dan Pendidikan Kimia, 21*(1), 30. https://doi.org/10.35580/chemica.v21i1.14835

Riyanto, E., Taufik, M., & Saputri, M. (2021). Analysis of iron (Fe) level reduction in dug wells using the aeration filtration time variation method with bubble aerators and slow sand filter variations. *Surya Beton: Journal of Civil Engineering, 5*(1), 1–9. https://doi.org/10.37729/suryabeton.v5i1.1102

Rumagit, H. M., Runtuwene, M. R. J., & Sudewi, S. (2015). Phytochemical and antioxidant activity tests of ethanol extracts from *Lamello Dysidea herbacea* sponges. *Journal of Pharmaceutical Sciences, 4*(3), 183–192. https://doi.org/10.35799/pha.4.2015.8858

Sapkota, A., Sharma, N., Karki, D., Rayamajhi, A., Sharma, S., & Adhikari, A. (2024). *Green synthesis of silver nanoparticles using Curcuma longa extract and its application in heavy metal sensing, photocatalytic, and antibacterial activities.* SSRN Electronic Journal. https://doi.org/10.2139/ssrn.4805651

Sekarsari, S., Widarta, I. W. R., & Jambe, A. A. (2019). Pengaruh suhu dan waktu ekstraksi dengan gelombang ultrasonik terhadap aktivitas antioksidan ekstrak daun jambu biji (*Psidium guajava* L.). *Jurnal Ilmu dan Teknologi Pangan, 8*(3), 267–277. https://doi.org/10.24843/itepa.2019.v08.i03.p05

Shameli, K., Ahmad, M. B., Jazayeri, S. D., Sedaghat, S., Shabanzadeh, P., Jahangirian, H., Mahdavi, M., & Abdollahi, Y. (2012). Synthesis and characterization of polyethylene glycol mediated silver nanoparticles by the green method. *International Journal of Molecular Sciences, 13*(6), 6639–6650. https://doi.org/10.3390/ijms13066639

Singh, P., Pandit, S., Bhadwal, A. S., Mokkapati, V. R. S. S., Garg, A., Ravikumar, V., & Mijakovic, I. (2018). Gold nanoparticles in diagnostics and therapeutics for human cancer. *International Journal of Molecular Sciences, 19*(7), 1979. https://doi.org/10.3390/ijms19071979

Sugito, H., Yulianti, E., & Prasetyo, D. (2022). Method validation and performance characteristics of spectrophotometric analysis for trace metal determination in water. *Journal of Applied Chemistry Research*, *14*(2), 45–55.

Sugito, M. S. D., Marliyan, M., & Apriana, H. D. (2022). Performance test of Shimadzu 6650 F atomic absorption spectrophotometer (AAS) on Fe and Zn metals in inorganic chemistry practicum at the UNS Integrated Laboratory UPT. *Indonesian Journal of Laboratory, 5*(2), 83–89. https://doi.org/10.22146/ijl.v5i2.75876

Sulistyani, S., Rustiah, W., Kristianingrum, S., Fillaeli, A., & PS, F. N. H. (2022). Pengembangan Teknik Deteksi Ion Logam Fe (III) dengan Menggunakan Nanopartikel Perak yang Distabilkan Kitosan-Formaldehida sebagai Sensor pada Spektrofotometer UV-Vis. *Jurnal Sains Dasar*, 11(1), 16-22. https://dx.doi.org/10.21831/jsd.v11i1.48305

Suryani, M. Y., Paramita, A., Susilo, H., & Maharsih, I. K. (2022). Analysis of iron (Fe) content determination in coal mine wastewater using UV-Vis spectrophotometer. *Indonesian Journal of Laboratory, 5*(1), 7–15. https://doi.org/10.22146/ijl.v0i0.72451

Suryati, E., & Maksuk, M. (2024). Analysis of drinking water quality and environmental health risk of iron (Fe) pollution from dug wells in the working area of Community Health Center in Ogan Komering Ilir Regency. *Epidemiological Journal of Indonesia, 3*(2), 68–71. https://journal.paei.or.id/eji/article/view/30

Widatalla, H. A., Yassin, L. F., Alrasheid, A. A., Ahmed, S. A., Widdatallah, M. O., Eltilib, S. H., & Mohamed, A. A. (2022). Green synthesis of silver nanoparticles using green tea leaf extract, characterization and evaluation of antimicrobial activity. *Nanoscale Advances, 4*(17), 3647–366. https://doi.org/10.1039/D1NA00509J

Windarti, T., Dewi, A. L., Bulan, C. R. I., & Pramesti, R. (2022). Sintesis CeO_2 dengan metode green synthesis: studi sifat fluoresen. *Greensphere Journal of Environmental Chemistry, 2*(2), 13–17. https://doi.org/10.14710/baf.%25v.%25i.%25Y.223-233

Wulandari, A., Farida, Y., & Taurhesia, S. (2020). Perbandingan aktivitas ekstrak daun kelor dan teh hijau serta kombinasi sebagai antibakteri penyebab jerawat. *Jurnal Fitofarmaka Indonesia*, *7*(2), 23–29. https://doi.org/10.33096/jffi.v7i2.535