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Green synthesis of silver nanoparticles using avocado (*Persea* sp.) peel extract as bioreducing agent: optimization, characterization, stability, and antioxidant activity

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ABSTRACT

The increasing demand for naturally derived antioxidants has driven interest in green synthesis of silver nanoparticles (AgNPs) as a strategy to combine the bioactive properties of plant metabolites with the unique characteristics of nanomaterials. This study reports the green synthesis of AgNPs using avocado (*Persea* sp.) peel extract as a bioreducing and stabilizing agent, with systematic optimization of synthesis parameters, physicochemical characterization, colloidal stability evaluation, and antioxidant activity assessment. Optimum synthesis conditions were established at 2 mM $AgNO_3$, 60 °C, and 60 min reaction time, yielding a characteristic surface plasmon resonance peak at 420 nm. FTIR analysis confirmed the involvement of O–H, C–H, C=C aromatic, and C–O functional groups derived from phenolic and flavonoid compounds in the reduction and nanoparticle stabilization processes. Particle size analysis revealed an average hydrodynamic diameter of 83.5 nm with a polydispersity index of 0.287. Stability studies over six months demonstrated that refrigerated storage at 4 °C in the dark produced the most stable absorbance profile. Antioxidant evaluation by the DPPH radical scavenging assay yielded IC_{50} values of 126.04 µg/mL for AgNPs and 133.11 µg/mL for the parent extract, both classified as moderate antioxidant agents. These findings establish avocado peel as a promising, sustainable bioresource for the fabrication of antioxidant-active AgNPs.

Keywords: antioxidant activity, avocado peel, DPPH assay, green synthesis, silver nanoparticles

PLAIN LANGUAGE SUMMARY

Silver nanoparticles are tiny particles with promising health-related properties, including the ability to neutralize harmful molecules called free radicals. Typically, making these nanoparticles requires hazardous chemicals. In this study, we used avocado peel—a common food waste—as a natural, environmentally friendly alternative to produce silver nanoparticles. We identified the best conditions for their production and confirmed their formation using several analytical techniques. The nanoparticles remained stable for six months under refrigerated, dark storage. When tested for their ability to neutralize free radicals, both the avocado peel extract and the nanoparticles showed moderate antioxidant activity. This work demonstrates that avocado peel waste can be repurposed as a sustainable resource for producing functional nanoparticles.

Introduction

The increasing prevalence of oxidative stress-related conditions has intensified global interest in the discovery of efficient and sustainable antioxidant compounds. Reactive oxygen species (ROS) and other free radicals, generated through normal metabolic processes and environmental exposures, can damage essential cellular components—including DNA, proteins, and lipids—when their accumulation exceeds the capacity of endogenous defense systems [1]. While synthetic antioxidants have been widely applied, growing concerns over their potential toxicity and long-term safety have driven increasing demand for naturally derived alternatives [2]. Plant-based bioactive compounds, particularly phenolics, flavonoids, and tannins, have emerged as promising candidates owing to their potent free radical scavenging capacity, biocompatibility, and renewable availability [3]. The integration of such natural compounds into nanotechnology through the green synthesis of metal nanoparticles represents a particularly attractive strategy, combining the antioxidant properties of plant metabolites with the unique physicochemical characteristics of nanomaterials [4].

Silver nanoparticles (AgNPs) have attracted considerable scientific attention due to their distinctive optical, chemical, and biological

properties, including antioxidant, antimicrobial, and catalytic activities [5]. Conventional physical and chemical synthesis routes for AgNPs, however, often rely on hazardous reducing and stabilizing agents that raise environmental and biosafety concerns [6]. Green synthesis offers a compelling alternative by utilizing biological resources—including plant extracts, fungi, and algae—as natural reducing and capping agents, thereby eliminating the need for toxic chemicals while yielding stable, bioactive nanoparticles [7]. Plant extracts are particularly well-suited for this purpose, as their secondary metabolites (flavonoids, phenolics, tannins, alkaloids, and saponins) are capable of reducing Ag^{+} ions to Ag^{0} while simultaneously stabilizing the formed nanoparticles [8]. Previous studies in our group have demonstrated the feasibility of this approach using extracts of *Muntingia calabura* and *Moringa* sp. for AgNP synthesis [9,10].

Avocado (*Persea* sp.) is a tropical plant widely cultivated in Indonesia and other equatorial regions, and its peel constitutes a significant fraction of agricultural waste generated during food and beverage processing. The peel is rich in secondary metabolites—including flavonoids, phenolics, tannins, alkaloids, and saponins [11]—that are known to function as effective bioreducing and stabilizing agents in nanoparticle synthesis [12]. The aqueous extraction of avocado peel is straightforward, cost-effective, and compatible with sustainable processing principles [13]. A prior study reported the successful synthesis of spherical AgNPs (~24 nm) from avocado peel extract exhibiting antioxidant, antibacterial, and antidiabetic activities [14], and avocado leaf extract has similarly been employed as a capping agent in ZnO nanoparticle synthesis [13]. These findings collectively establish avocado peel as a promising, underutilized bioresource for the fabrication of antioxidant-active AgNPs.

Despite this progress, systematic investigations into the synthesis parameters using avocado peel extract remain limited. In this study, we investigated the influence of key synthesis parameters—particularly $AgNO_3$ concentration, reaction temperature, and heating time—on the formation and physicochemical properties of the synthesized nanoparticles. Furthermore, the long-term colloidal stability of the resulting AgNPs under varied storage conditions remains insufficiently characterized. This study therefore aims to optimize the green synthesis of AgNPs using avocado peel extract, to characterize the synthesized nanoparticles using UV–Vis spectroscopy, FTIR, and particle size analysis, and to evaluate their antioxidant activity using the DPPH radical scavenging assay.

Methods

Preparation and extraction of avocado peel

Avocado peels used in this study were obtained from avocado beverage vendors located around UIN Raden Intan Lampung, Bandar Lampung, Indonesia. The avocado peels were thoroughly washed with clean water, cut into small pieces, and dried in an oven at 60 °C for 3 h. The dried material was then ground into a fine powder using a grinder. A total of 5 g of avocado peel powder was dissolved in 100 mL of distilled water and heated on a hot plate at 60 °C for 30 min. The resulting mixture was filtered through Whatman filter paper, and the filtrate was collected, stored at 4 °C, and subsequently used as a bioreducing agent in the synthesis of silver nanoparticles [13].

Phytochemical screening of avocado peel extract

Phytochemical screening was conducted to identify the presence of flavonoids, phenolics, steroids, tannins, saponins, and alkaloids in the avocado peel extract following previously reported procedures [13]. Flavonoids were detected by the addition of 10% NaOH (≥98%, Merck), which produces a yellow to reddish-brown coloration upon a positive reaction. Phenolics and tannins were identified using 1% $FeCl_3$ (≥97%, Merck), indicated by the formation of a dark greenish-black color. Steroids were tested using Liebermann–Burchard reagent (analytical grade, Merck), while saponins were assessed by heating the extract to boiling, shaking vigorously for 10 s, and adding 3 drops of 2 N HCl to evaluate foam stability. Alkaloids were identified using Dragendorff reagent, indicated by the formation of a brown precipitate.

Synthesis of silver nanoparticles

A 10 mM $AgNO_3$ stock solution was prepared by dissolving 0.170 g of $AgNO_3$ (≥99.9%, Merck) in 100 mL of distilled water in a volumetric flask. Synthesis was performed by mixing 5 mL of avocado peel extract with 25 mL of $AgNO_3$ solution at a 1:5 (v/v) ratio under magnetic stirring, following previously reported procedures with slight modifications [15]. Three synthesis parameters were systematically optimized in sequential order. First, $AgNO_3$ concentration was varied from 0.5 to 2.5 mM at 60 °C for 60 min. Using the optimum concentration, reaction temperature was subsequently varied at 50, 60, 70, 80, and 90 °C for 60 min. Finally, heating time was optimized at 20, 40, 60, 80, and 100 min at the established optimum temperature. After each variation, the resulting AgNP colloid was characterized by UV–Vis spectrophotometry over a wavelength range of 300–600 nm to monitor surface plasmon resonance (SPR) peak formation.

Characterization of silver nanoparticles

The synthesized AgNPs were characterized using Fourier Transform Infrared (FTIR) spectroscopy to identify functional groups involved in the reduction and stabilization processes. Particle size and polydispersity index (PDI) were determined by Particle Size Analysis (PSA) using dynamic light scattering (DLS).

Stability studies

Colloidal stability of AgNPs synthesized under optimum conditions was evaluated over six months under four storage conditions: (1) room temperature with light exposure, (2) room temperature in the dark, (3) 4 °C with light exposure, and (4) 4 °C in the dark. Each condition used a 20 mL aliquot stored in a sealed vial. UV–Vis absorbance was measured monthly over the range of 300–600 nm to monitor changes in SPR peak intensity and position [16].

Antioxidant activity

Antioxidant activity was evaluated using the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay following previously reported procedures [17]. A DPPH stock solution (160 µg/mL) was prepared by dissolving 4 mg of DPPH in 25 mL of methanol and stored in the dark. Sample stock solutions of avocado peel extract and AgNPs were each prepared at 1000 µg/mL in methanol. Working solutions were prepared by serial dilution to final concentrations of 50, 100, 150, 200, and 250 µg/mL, each combined with 1000 µL of DPPH solution and adjusted to a total volume of 5 mL with methanol. Ascorbic acid was used as a positive control at concentrations of 2, 4, 6, 8, and 10 µg/mL. All solutions were prepared in aluminum foil-wrapped vials and incubated for 30 min in the dark prior to absorbance measurement at 517 nm. The percentage of DPPH radical scavenging inhibition was calculated as:

$$\% \text{ Inhibition} = [(A_0 - A_1) / A_0] \times 100\% \quad (1)$$

where A_0 is the absorbance of the blank and A_1 is the absorbance of the sample. The IC_{50} value—defined as the concentration required to scavenge 50% of DPPH radicals—was derived from the linear regression equation $y = a + bx$, where x is sample concentration and y is percentage inhibition, yielding:

$$IC_{50} = (50 - a) / b \quad (2)$$

Antioxidant strength was categorized according to Molyneux (2004) [18]: very strong (IC_{50} < 50 µg/mL), strong (50–100 µg/mL), moderate (100–150 µg/mL), weak (150–200 µg/mL), and very weak (> 200 µg/mL).

Data analysis

All experiments were performed in triplicate and results are expressed as mean ± standard deviation (SD). Linear regression analysis for IC_{50} determination was performed using GraphPad Prism version 10 (GraphPad Software, San Diego, CA, USA). No inferential statistical tests were applied; data interpretation was based on descriptive analysis and IC_{50} comparison.

Results

Extraction and phytochemical screening

Avocado peel extract was successfully obtained as a yellowish-brown filtrate and used directly as a bioreducing agent in the synthesis of silver nanoparticles. Phytochemical screening of the

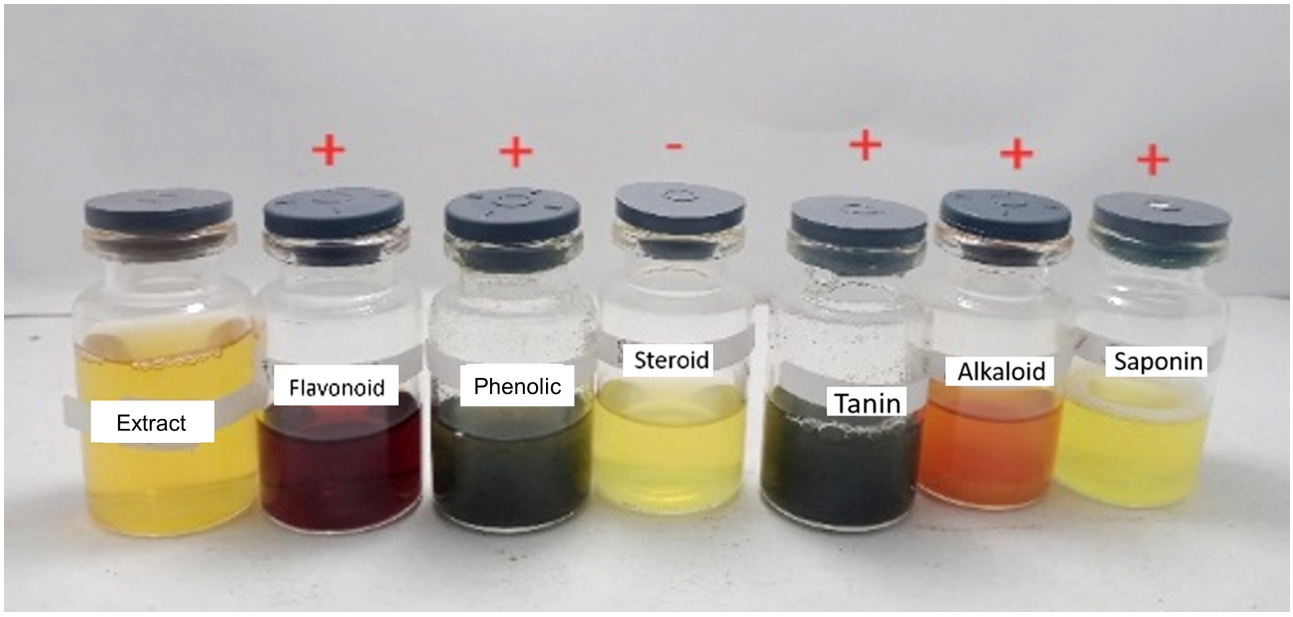

Figure 1. Phytochemical screening of avocado peel extract. Color changes observed after treatment with respective reagents for the detection of flavonoids (NaOH 10%), phenolics and tannins ($FeCl_3$ 1%), steroids (Liebermann–Burchard), alkaloids (Dragendorff), and saponins (HCl 2N). Positive (+) and negative (–) results are summarized in Table 1.

Table 1. Phytochemical screening results of avocado peel extract

No.	Secondary metabolites	Reagents	Observed changes	Results
1	Flavonoid	10% NaOH	Yellow to reddish-brown	+
2	Phenolic	1% $FeCl_3$	Yellow to dark greenish-black	+
3	Steroid	Liberman-Burchard	No changed	-
4	Tannin	1% $FeCl_3$	Yellow to dark greenish-black	+
5	Alkaloid	Dragendorff	Formation of brown precipitate	+
6	Saponin	2N HCl	Formation of stable foam	+

extract confirmed the presence of flavonoids, alkaloids, phenolics, tannins, and saponins, while steroids were not detected (Table 1; Figure 1).

Synthesis of silver nanoparticles

Formation of AgNPs was visually indicated by a color change of the reaction mixture from pale yellow to reddish-brown, consistent with surface plasmon resonance (SPR) of silver nanoparticles. UV–Vis spectra of the resulting colloids are shown in Figure 2A–C.

Variation of $AgNO_3$ concentration (0.5–2.5 mM) at 60 °C for 60 min showed a progressive increase in SPR absorbance from 0.5 to 2 mM, with a maximum absorbance of 0.911 at λ - max = 420 nm at 2 mM. A decrease in absorbance was observed at 2.5 mM, attributed to particle agglomeration at higher precursor concentrations. Accordingly, 2 mM was selected as the optimum $AgNO_3$ concentration (Figure 2A).

Using the optimum concentration, reaction temperature was varied from 50 to 90 °C for 60 min. Absorbance increased at 50 and 60 °C, with the highest SPR peak (absorbance = 0.708, λ - max = 420 nm) observed at 60 °C. Further increases in temperature (70–90 °C) led to a reduction in absorbance, indicating decreased nanoparticle yield at elevated temperatures. The optimum reaction temperature was therefore established at 60 °C (Figure 2B).

Heating time was subsequently varied from 20 to 100 min at 60 °C and 2 mM $AgNO_3$. Absorbance

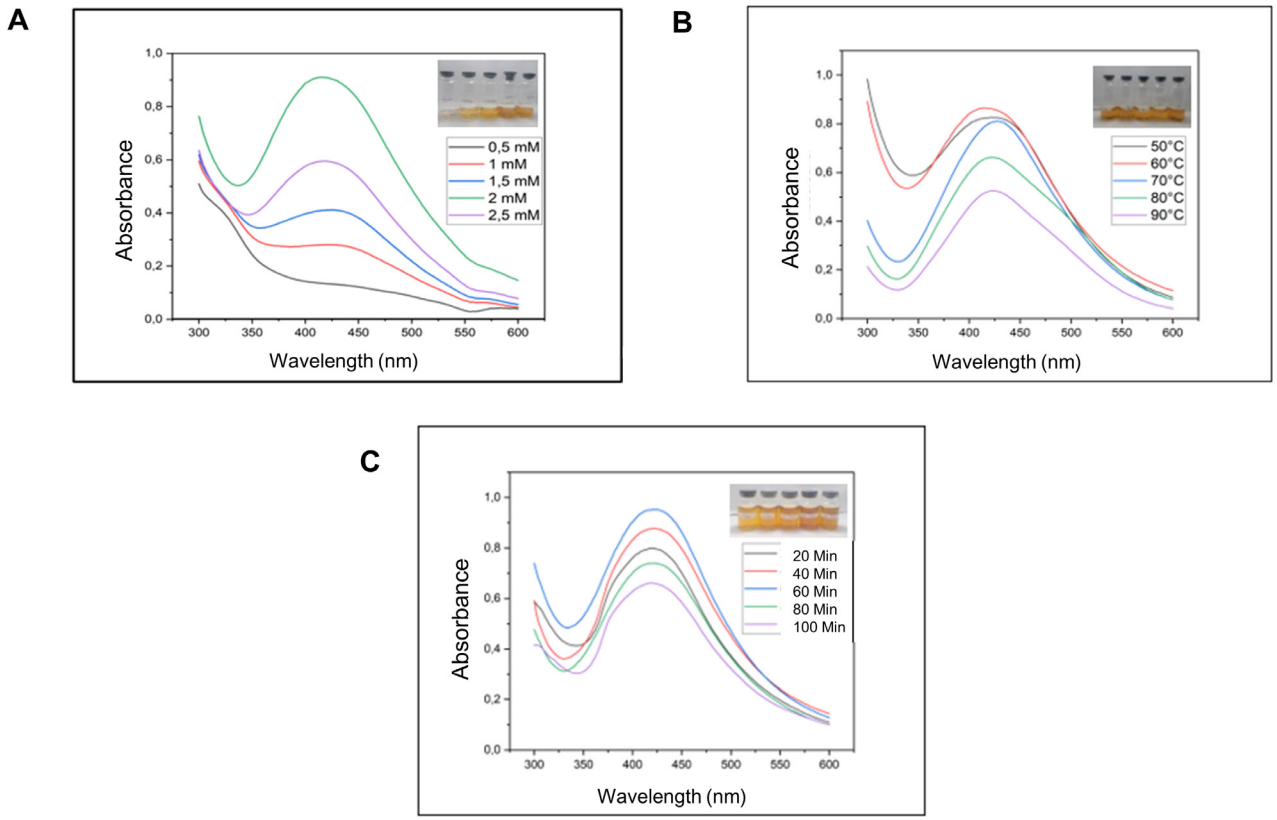

Figure 2. UV–Vis absorption spectra of AgNPs synthesized from avocado peel extract under systematic parameter optimization. (A) Effect of $AgNO_3$ concentration (0.5–2.5 mM) at 60 °C for 60 min. (B) Effect of reaction temperature (50–90 °C) at 2 mM $AgNO_3$ for 60 min. (C) Effect of heating time (20–100 min) at 2 mM $AgNO_3$ and 60 °C. The surface plasmon resonance (SPR) peak at ~420 nm in each panel confirms AgNP formation.

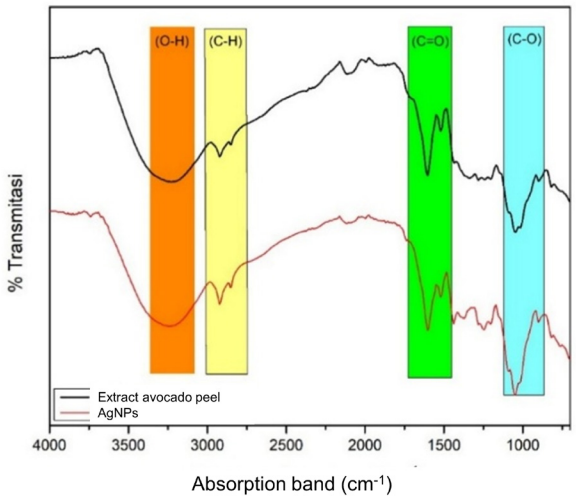

Figure 3. FTIR spectra of avocado peel extract and synthesized AgNPs showing functional groups involved in Ag^+ reduction and nanoparticle stabilization. Absorption bands are observed at 3227/3250 cm^{-1} (O–H stretch), 2922 cm^{-1} (C–H stretch), 1602 cm^{-1} (C=C aromatic stretch), and 1043/1051 cm^{-1} (C–O stretch). Slight wavenumber shifts between the two spectra indicate interaction of surface biomolecules with the AgNP surface.

increased progressively from 20 to 60 min, reaching a maximum of 0.953 at λ - max = 420 nm at 60 min. Beyond 60 min, absorbance declined at 80 and 100 min, suggesting degradation of reducing biomolecules with prolonged heating. The optimum heating time was thus determined to be 60 min (Figure 2C).

Table 2. FTIR analysis of functional groups in avocado peel extract and synthesized AgNPs

Functional group	Wavenumber (cm^{-1})		Assignment
	Extract (cm^{-1})	AgNPs (cm^{-1})	
O-H stretch	3227	3250	Phenolic/alcoholic hydroxyl
C-H stretch	2922	2922	Aliphatic methylene/methyl
C=C stretch	1602	1602	Aromatic ring (phenolics/flavonoids)
C-O stretch	1043	1051	Phenolic/alcoholic C–O

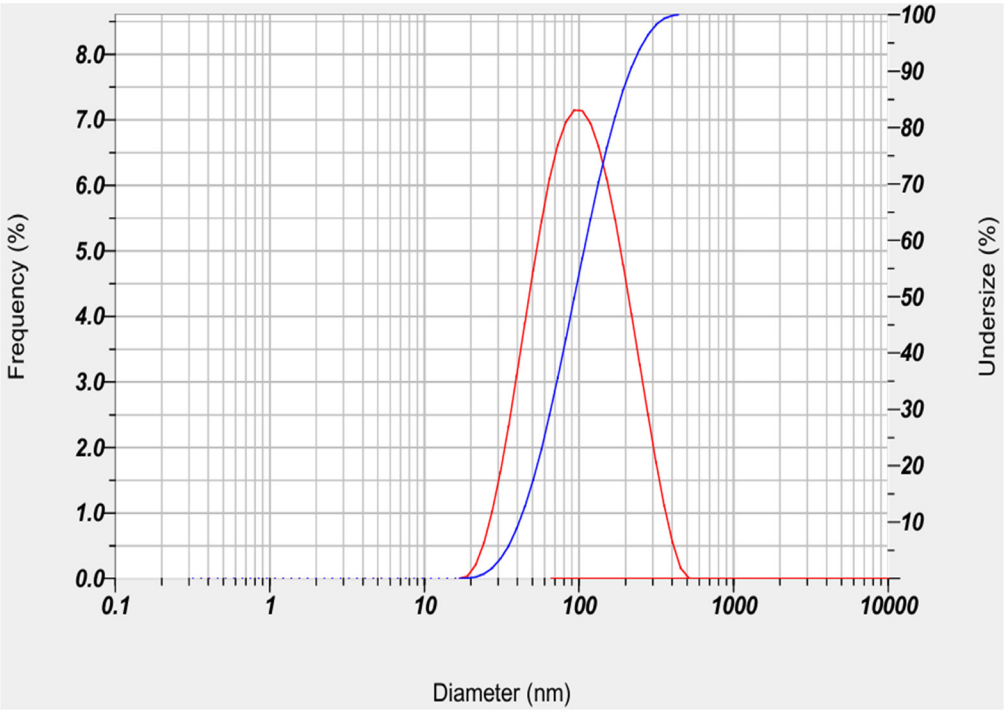

Figure 4. Particle size distribution of AgNPs synthesized from avocado peel extract under optimum conditions. Mean hydrodynamic diameter and polydispersity index (PDI) were determined to be 83.5 nm and 0.287, respectively, by dynamic light scattering (DLS).

Fourier Transform Infrared (FTIR) analysis

FTIR spectra of avocado peel extract and the synthesized AgNPs are compared in Figure 3. Both spectra exhibited broad absorption bands at 3227 cm^{-1} (extract) and 3250 cm^{-1} (AgNPs), corresponding to O–H stretching vibrations characteristic of phenolic and alcoholic hydroxyl groups. C–H stretching vibrations at 2922 cm^{-1} were observed in both samples, attributed to aliphatic methylene and methyl groups commonly associated with lipid components in the aqueous extract. Sharp absorption bands at 1602 cm^{-1} in both spectra are assigned to aromatic C=C stretching vibrations of phenolic ring systems. C–O stretching vibrations were detected at 1043 cm^{-1} (extract) and 1051 cm^{-1} (AgNPs), consistent with C–O bonds of phenolic and alcoholic compounds. A slight shift in wavenumber between the extract and AgNPs spectra was observed across all bands, indicating interaction between the surface biomolecules and the silver nanoparticle surface. The identified functional groups are summarized in Table 2.

Particle size analyzer

Dynamic light scattering (DLS) analysis revealed that the synthesized AgNPs had an average hydrodynamic diameter of 83.5 nm with a polydispersity index (PDI) of 0.287 (Figure 4).

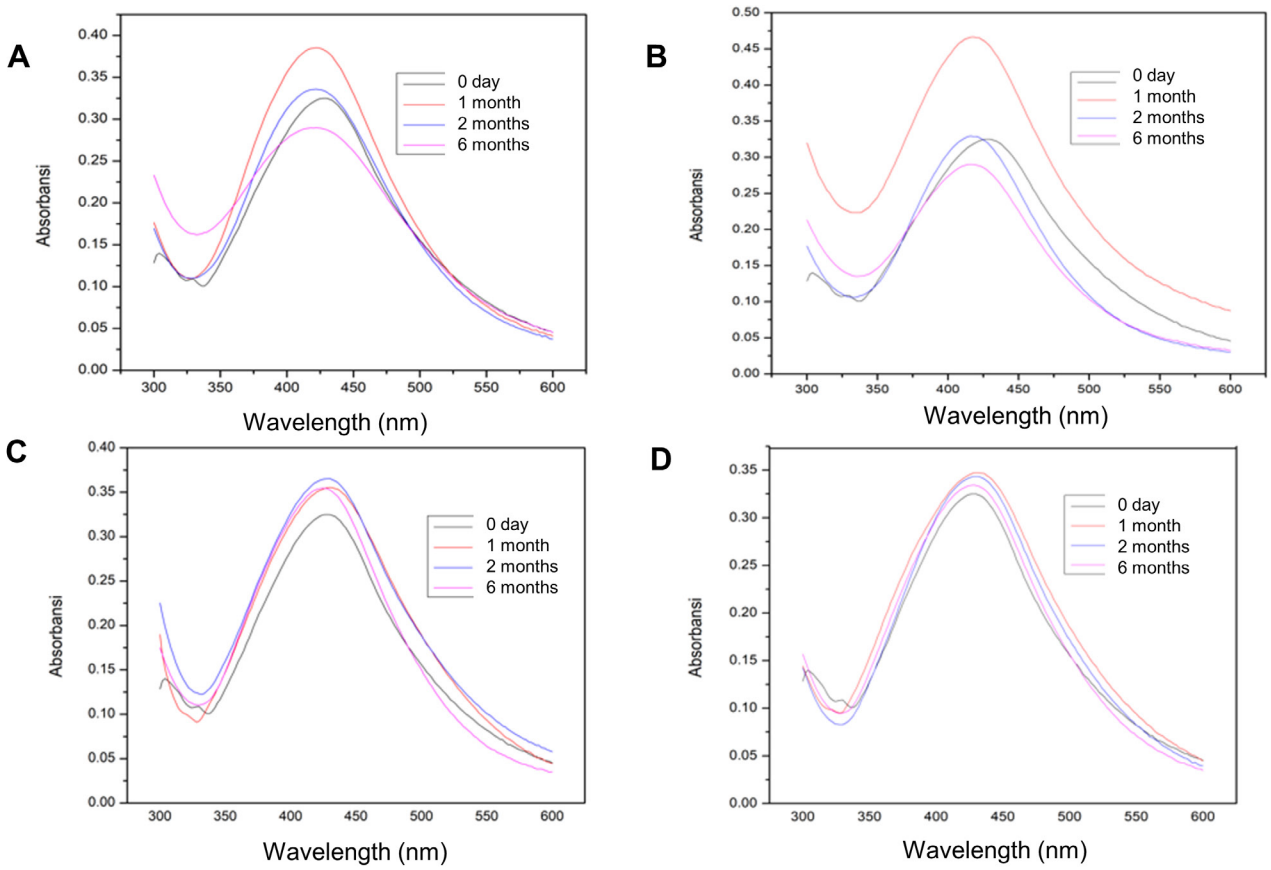

Figure 5. UV–Vis absorbance profiles of AgNPs at λ - max = 420 nm monitored monthly over six months under four storage conditions. (A) Room temperature with light exposure. (B) Room temperature in the dark. (C) Refrigerated storage at 4 °C with light exposure. (D) Refrigerated storage at 4 °C in the dark.

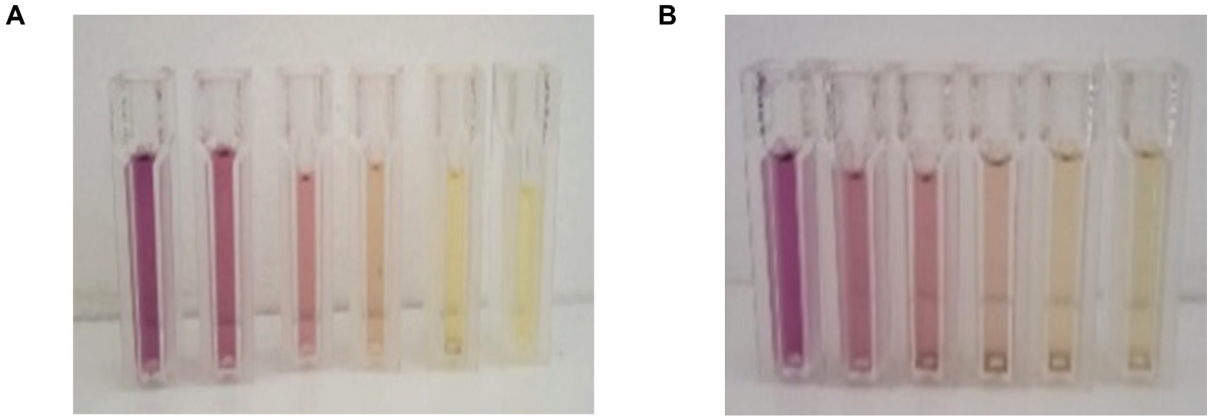

Figure 6. Visual color changes of DPPH solution upon radical scavenging by avocado peel extract and AgNPs. (A) Avocado peel extract and (B) AgNPs at concentrations of 50–250 µg/mL (left to right). Color gradient from deep purple to yellow reflects increasing radical scavenging capacity with increasing sample concentration.

Stability study of AgNPs

Changes in UV–Vis absorbance of AgNPs stored under four conditions over six months are presented in Figure 5a–d. Under room temperature storage with light exposure, absorbance increased during the first month and subsequently declined continuously through to month six. A similar trend was observed under room temperature dark storage, though with a slightly more gradual decrease. AgNPs stored at 4 °C exhibited comparatively smaller fluctuations in absorbance under both light and dark conditions. Among all tested conditions, storage at 4 °C in the dark produced the most stable absorbance profile over the six-month period.

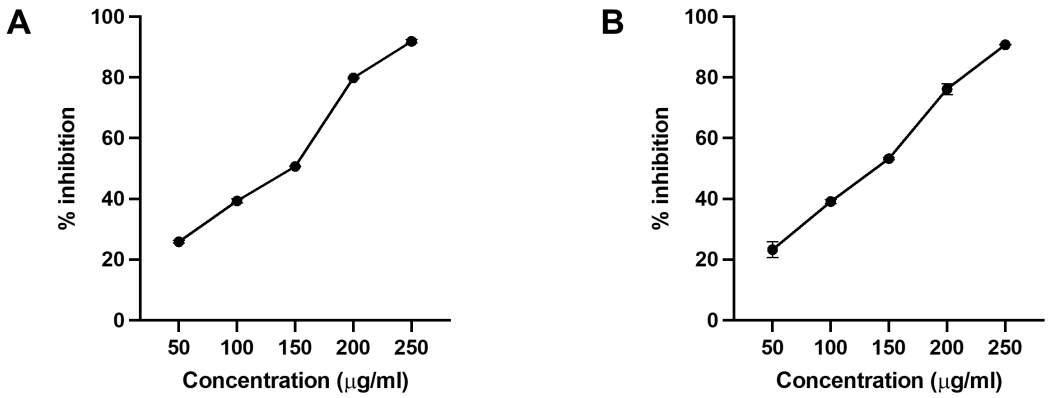

Figure 7. DPPH radical scavenging activity of AgNPs and avocado peel extract as a function of concentration. Percentage inhibition (%) of AgNPs (A), avocado peel extract (B) at concentrations of 50–250 µg/mL (samples). Data are expressed as mean ± SD (n = 3).

Antioxidant activity of AgNPs

The antioxidant activity of avocado peel extract and the synthesized AgNPs was evaluated by the DPPH radical scavenging assay at concentrations of 50–250 µg/mL. A progressive decrease in DPPH absorbance with increasing concentration was observed for all samples, reflected by a visible color change from deep purple to yellow (Figure 6).

The IC_{50} value of AgNPs (126.04 µg/mL) was lower than that of the avocado peel extract (133.11 µg/mL), indicating that incorporation of the extract phytochemicals onto the nanoparticle surface slightly enhanced the overall radical scavenging capacity. Both samples were classified as moderate antioxidant agents based on the criteria of Molyneux (2004).

Discussion

Phytochemical screening of avocado peel extract confirmed the presence of flavonoids, phenolics, tannins, alkaloids, and saponins—a rich repertoire of secondary metabolites known to serve dual roles in green synthesis: as bioreducing agents that donate electrons to reduce Ag^+ ions to Ag^0, and as capping agents that stabilize the formed nanoparticles through surface adsorption [19]. The hydroxyl (–OH) and carboxyl (–COOH) functional groups of phenolic and flavonoid compounds are principally responsible for this reductive capacity, as confirmed by the FTIR spectra showing characteristic absorption bands at 3227/3250 cm^{-1} (O–H stretch) and 1043/1051 cm^{-1} (C–O stretch) in both the extract and AgNPs. Notably, the slight wavenumber shifts observed between the extract and AgNPs spectra indicate that these biomolecules are not merely present in solution but are actively adsorbed onto the nanoparticle surface, where phenolic groups oriented toward the Ag^0 surface participate in reduction while those oriented outward provide electrostatic stabilization [20]. The phytochemical richness of avocado peel is therefore central to both the formation and the functional properties of the synthesized AgNPs.

The formation of AgNPs was confirmed by the appearance of an SPR peak at ~420 nm, consistent with the optical properties of silver nanoparticles in the 10–100 nm size range. Systematic optimization of synthesis parameters revealed that 2 mM $AgNO_3$, 60 °C, and 60 min represented the optimum conditions, yielding maximum SPR absorbance values of 0.911, 0.708, and 0.953, respectively. The decrease in absorbance observed at $AgNO_3$ concentrations above 2 mM is attributable to particle agglomeration arising from an excess of Ag^+ ions relative to available bioreducing sites on the surface biomolecules. The biphasic temperature response—enhanced nanoparticle formation at 50–60 °C followed by reduced absorbance at 70–90 °C—reflects competing processes: moderate heating accelerates electron transfer from phenolic compounds to Ag^+, while excessive temperatures induce denaturation of the protein and enzyme components that contribute to the bioreducing activity [21]. The decline in absorbance beyond 60 min of heating is mechanistically distinct, most

likely resulting from Ostwald ripening or aggregation of already-formed nanoparticles rather than biomolecule degradation per se, as the reduction process would be substantially complete by this point.

The average hydrodynamic diameter of 83.5 nm with a PDI of 0.287 reflects the inherent heterogeneity of green synthesis using a complex plant extract as bioreductor, in contrast to chemically synthesized AgNPs which typically yield narrower size distributions. The PDI value of 0.287, while at the upper boundary of the acceptable range, is consistent with the polydisperse nature of plant-mediated synthesis and indicates adequate colloidal stability for practical applications [22]. It is noteworthy that the particle size obtained in this study is considerably larger than the ~24 nm reported by Ali et al. [14] using avocado peel extract under different synthesis conditions. This difference suggests that parameters such as extract concentration, precursor ratio, and reaction time collectively govern the final particle size in green synthesis systems. The relatively larger particle size observed in this study may be attributed to the balance between nucleation and growth during nanoparticle formation, where limited nucleation results in fewer nuclei and consequently promotes further particle growth.

Colloidal stability was evaluated over six months under four storage conditions. AgNPs stored at 4 °C in the dark exhibited the most stable absorbance profile, while room temperature storage—particularly with light exposure—produced greater fluctuations. The initial increase in absorbance observed during the first month across all conditions is attributed to the continued reduction of residual Ag^+ ions that persists after the heating process is terminated [23]. Subsequent decreases in absorbance reflect partial dissolution of AgNPs into Ag^+ ions, a process accelerated by light exposure and elevated temperature [24]. A blue shift in λ - max from 428 to 420 nm over the storage period, observed consistently across all conditions, further supports partial dissolution and colloidal redistribution of smaller particles, though the magnitude of this shift (<10 nm) indicates that the overall nanoparticle population remained within the nanoscale range throughout the study.

The antioxidant activity of the synthesized AgNPs, expressed as an IC_{50} of 126.04 µg/mL, was slightly but consistently lower than that of the parent avocado peel extract (133.11 µg/mL), placing both in the moderate category according to Molyneux (2004) [18]. The marginal enhancement (~5%) observed upon nanoparticle formation warrants careful interpretation. In green-synthesized AgNPs, the antioxidant activity originates predominantly from the phytochemical corona adsorbed onto the nanoparticle surface rather than from metallic silver itself [25]. This surface-bound phytochemical layer effectively concentrates the bioactive compounds in a confined nanoscale architecture, potentially enhancing their accessibility to DPPH radicals—yet in this case the improvement over the free extract was modest, consistent with reports that the scavenging capacity of green AgNPs is largely inherited from the source extract [26]. The relatively large particle size (83.5 nm) in this study may also be a contributing factor: smaller nanoparticles present a higher surface area-to-volume ratio and consequently expose more surface-bound phytochemicals per unit mass, which could amplify antioxidant activity [27]. This interpretation suggests that further optimization of synthesis conditions to yield smaller, more uniform AgNPs may enhance the antioxidant performance beyond what was observed here.

Comparison with AgNPs synthesized from other plant sources reveals that the IC_{50} of avocado peel-derived AgNPs (126.04 µg/mL) is comparable to those reported for *Odontonema strictum* leaf extract (116 µg/mL) [28] and *Nephrolepis radicans* extract (106.44 µg/mL) [29], and substantially superior to AgNPs from *Chromolaena odorata* (277.29 µg/mL) [30] and *Clinacanthus nutans* (417.05 µg/mL) [31], both of which fall in the weak category. These comparisons collectively establish that avocado peel—an abundant and largely underutilized agricultural by-product—represents a competitive bioresource for the green synthesis of antioxidant-active AgNPs, with performance on par with dedicated medicinal plant extracts.

This study has several limitations that warrant consideration. The antioxidant activity was evaluated solely using the DPPH assay, which represents a single in vitro model and may not fully reflect

the broader radical scavenging capacity of the synthesized AgNPs; complementary assays such as ABTS and FRAP would provide a more comprehensive antioxidant profile. Furthermore, particle size characterization relied exclusively on DLS, which measures hydrodynamic diameter and tends to overestimate actual particle size—morphological confirmation by transmission electron microscopy (TEM) would strengthen the physicochemical characterization. The relatively large particle size (83.5 nm) and moderate PDI (0.287) obtained in this study also suggest that further optimization of the extract-to-precursor ratio and extraction parameters may yield smaller, more uniform nanoparticles with enhanced antioxidant performance. Future work should also explore the fractionation of avocado peel extract to identify the specific phytochemical constituents most responsible for bioreduction and surface capping, as well as investigate the cytotoxicity, antimicrobial activity, and in vivo antioxidant efficacy of the synthesized AgNPs to support their potential biomedical applications.

Conclusion

Green synthesis of silver nanoparticles (AgNPs) using avocado (*Persea* sp.) peel extract as a bioreducing agent was successfully achieved under optimum conditions of 2 mM $AgNO_3$, 60 °C, and 60 min, yielding AgNPs with an average hydrodynamic diameter of 83.5 nm and a PDI of 0.287. FTIR analysis confirmed the involvement of phenolic and flavonoid-derived functional groups—particularly O–H, C–H, C=C aromatic, and C–O—in both the reduction and stabilization processes, with wavenumber shifts indicating active surface adsorption of biomolecules onto the nanoparticle surface. The synthesized AgNPs remained within the nanoscale range over six months of storage, with refrigerated dark storage (4 °C) producing the most stable absorbance profile. Antioxidant evaluation by the DPPH assay yielded an IC_{50} of 126.04 µg/mL for AgNPs and 133.11 µg/mL for the parent extract, both classified as moderate, with the marginal enhancement upon nanoparticle formation attributed to the concentration of surface-bound phytochemicals in a nanoscale architecture. These findings establish avocado peel as a promising, sustainable bioresource for the fabrication of antioxidant-active AgNPs, with performance comparable to AgNPs derived from other plant extracts, and highlight particle size optimization as a key avenue for further improving their functional activity.

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Declaration of interest

Competing interests: No relevant disclosures.

Author contributions

A: Investigation, Methodology, Formal analysis, Writing – original draft; DDY: Conceptualization, Methodology, Supervision, Writing – review & editing, Project administration; AA: Conceptualization, Writing – review & editing; AAJA: Validation, Writing – review & editing; MYS: Validation, Writing – review & editing.

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