

Integrating Traditional Knowledge and Nanotechnology: Green Synthesis of *Hibiscus lobatus* Silver Nanoparticles

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Abstract- Medicinal plants have long been integral to traditional medicine, addressing various health conditions. Although species such as *Hibiscus sabdariffa* and *Hibiscus rosasinensis* have been extensively researched, *Hibiscus lobatus* (*H. lobatus*) remains comparatively underexplored

despite its therapeutic potential. This study investigates the antimicrobial, antidiabetic, and antioxidant properties of *H. lobatus* by synthesizing silver nanoparticles (AgNPs) using its leaf extract. Preliminary phytochemical analysis confirmed the presence of bioactive compounds like phenols, flavonoids, alkaloids, and terpenoids, which were linked to the observed bioactivities. Characterization of the AgNPs using UV-Vis spectrophotometry, XRD, and FTIR revealed a crystalline structure and functional groups such as alcohols, conjugated alkenes, fluoro compounds, and amines involved in the reduction of silver nitrate. Both crude extracts and AgNPs demonstrated effective antimicrobial activity against *Staphylococcus*, *Pseudomonas*, *Candida*, *Bacillus*, and *E. coli*, with AgNPs showing higher efficacy. The minimum inhibitory concentrations ranged from 5 to 25 mg/mL. In vitro α -amylase inhibition assays revealed up to 70% antidiabetic activity in both forms, while the ABTS radical scavenging assay showed AgNPs exhibited superior antioxidant potential compared to crude extracts. These findings suggest that *H. lobatus* possesses significant medicinal properties in both its crude and nano forms, with AgNPs showing enhanced bioactivities. Further research could explore its potential applications in medicine.

Keywords - Silver nanoparticles (AgNPs), Green synthesis, Antidiabetic activity, Antioxidant potential, Phytochemical analysis

I. INTRODUCTION

For centuries, medicinal plants have been integral to human healthcare, serving as the foundation including alkaloids, flavonoids, tannins, terpenoids, saponins, and phenolics, which enhance their medicinal efficacy against infections, inflammation, cardiovascular disorders, and cancer [1]. Noble metal nanoparticles, including zinc, copper, platinum, silver, magnesium, gold, and titanium, are attracting interest in biomedicine for their multifaceted properties. Conventional chemical and physical synthesis processes present environmental risks and include hazardous substances [2]. In comparison to manufactured pharmaceuticals, botanical medicines are often seen as safer, more economical and less prone to induce undesirable side effects. Approximately 25% of pharmaceutical medications are derived from plant sources, indicating that medicinal plants remain a valuable resource for novel drug discoveries [3].

Recent advancements in biotechnology and nanotechnology have broadened the uses of plant-derived chemicals, especially in the field of medicine. Nanotechnology, including materials at the

nanoscale, provides unique benefits owing to the exceptional optical, chemical, and biological characteristics of nanoparticles. The environmentally friendly production of nanoparticles using plant extracts offers an environmentally benign alternative to traditional chemical and physical processes, promoting sustainability and biocompatibility. Due to their inherent biological activity and reduced toxicity, plant-mediated nanoparticles have demonstrated promising results in biomedical applications. Silver nanoparticles (AgNPs) have attracted a lot of attention due to their antimicrobial, antioxidant, and drug-delivery properties. Because of their remarkable antibacterial qualities and capacity to avert the development of multidrug resistance in bacteria and fungi, silver nanoparticles have attracted a lot of attention lately [4]. Size, shape, and concentration are among the physical and chemical properties that are necessary for the development and production of these nanoparticles as an alternative antibiotic treatment. Consequently, more attention should be devoted to the synthesis and characterization of AgNPs in light of this issue [5].

India, with its rich heritage of traditional knowledge systems such as Ayurveda and Siddha, has long emphasized the therapeutic use of plants. Ancient texts describe numerous herbs with curative potential, many of which remain scientifically underexplored [6,7]. Documenting and validating this indigenous wisdom through modern biotechnological and nanotechnological approaches not only preserves cultural knowledge but also offers a path to sustainable drug discovery [8]. Exploring medicinal plants within this framework bridges traditional practices with contemporary science, enabling novel solutions to global health challenges [9]. The Hibiscus genus has been widely studied for its medicinal properties. Species such as *Hibiscus sabdariffa*, *Hibiscus cannabinus*, and *Hibiscus rosa-sinensis* have been traditionally used to manage conditions like hypertension, digestive disorders, and skin ailments. Research highlights their potent antioxidant, anti-inflammatory, and anticancer properties [10].

The annual herb *Hibiscus lobatus* (*H. lobatus*) is a member of the Malvaceae family. In the arid tropical ecosystem of India's Western Ghats, this plant grows seasonally. Despite the extensive research on other Hibiscus species, *H. lobatus* remains relatively unexplored, lack of phytochemical profiling, pharmacological investigations, and nanoparticle studies. The entire plant of this species has been used in traditional medicine to treat wounds, inflammation, spermatorrhea, diabetes, debility, aphrodisiac properties, and coughing [11]. In this study, silver nanoparticles (AgNPs) are synthesized using the leaf extract of *H. lobatus*. After a preliminary

phytochemical screening, their antibacterial qualities and pharmacological characteristics are assessed.

II. MATERIAL AND METHODS

2.1 Plant Collection and Identification

Hibiscus lobatus was collected from the University College for Women, Koti. The specimen was identified and authenticated by the Botanical Survey of India (BSI), Deccan regional office.

2.2 Plant Processing and Extract Preparation

Leaves were washed with double-distilled water, air-dried for 5–7 days at room temperature, powdered, and stored in airtight containers. 5 g of powdered leaves were boiled in 100 mL of distilled water at 60°C, resulting in a greenish solution for the aqueous extract. Ethanolic and methanolic extracts were prepared by macerating 5 g of powder in 100 mL of 95% ethanol and 80% methanol, respectively, for 72 hours, followed by filtration with Whatman No.1 filter paper. All extracts were freshly prepared before use.

2.3 Green Synthesis of Silver Nanoparticles (AgNPs)

2 mL of plant extract was added dropwise to a 20 mM silver nitrate solution at 30°C while being continuously stirred (350 rpm) in order to synthesize AgNP. The reaction was monitored until a dark brown color appeared [12]. After centrifuging the mixture for 20 minutes at 4°C at 6500 rpm, the precipitate was allowed to dry for 48 to 72 hours at room temperature.

2.4 UV-Vis Spectroscopy

A UV-Vis spectrophotometer (200–700 nm) was used to confirm AgNP formation. AgNPs typically exhibit a characteristic surface plasmon resonance (SPR) between 400–500 nm.

2.5 Characterization of AgNPs

Fourier transform infrared spectroscopy (FTIR) and X-ray diffraction (XRD) were carried out. XRD ($2\theta = 20^\circ$ – 100°) was used to determine crystal structure, while FTIR (300 – 4000 cm^{-1}) identified functional groups involved in nanoparticle synthesis.

2.6 Antimicrobial Activity

i. Agar Well Diffusion Assay

The antibacterial activity of crude extracts and AgNPs was tested against *Staphylococcus*, *Pseudomonas*, *Bacillus*, *E. coli*, and antifungal activity against *Candida* using the agar well diffusion method [13]. Streptomycin served as a positive control, and the extraction solvent was

used as a negative control. Wells were punched, 100 μL of test samples (dissolved in DMSO for powdered extracts) were put onto inoculated nutritional agar (bacteria) and potato dextrose agar (fungi) plates. The inhibitory zones on the plates were measured after they were incubated at 37°C .

ii. Minimum Inhibitory Concentration (MIC)

MIC was determined using serial dilutions (50 to 2.5 mg/mL). Wells containing different concentrations were incubated at 37°C , and the lowest concentration inhibiting visible growth was recorded as MIC.

2.7 Antidiabetic Assay (α -Amylase Inhibition Test)

The inhibitory action of α -amylase was evaluated following [14]. 200 μL of sodium phosphate buffer (0.02 M), 20 μL of enzyme (0.4 U/mg), and 100 μL of plant extract (31.25–1000 $\mu\text{g/mL}$) constituted the assay mixture, which was incubated for 10 minutes. Following the addition of 1% starch, 3.5 mL of dinitrosalicylic acid was used to stop the reaction, and it was then heated for five minutes. At 540 nm, absorbance was measured. To calculate inhibition (%), we used:

$$\text{Inhibition (\%)} = \frac{\text{Abs}_{\text{control}} - \text{Abs}_{\text{sample}}}{\text{Abs}_{\text{control}}} \times 100$$

2.8 Antioxidant Assay (ABTS Radical Scavenging)

ABTS solution (2 mM) was prepared with potassium persulfate (17 mM) and incubated overnight in the dark. The sample (200 μL) was mixed with ABTS (1:1 v/v), and absorbance at 734 nm was recorded after 5 min [15]. Results were expressed as:

$$\text{Inhibition (\%)} = \frac{\text{Abs}_{\text{control}} - \text{Abs}_{\text{sample}}}{\text{Abs}_{\text{control}}} \times 100$$

2.9 Phytochemical Screening

Qualitative tests were performed to detect secondary metabolites [16]:

- **Alkaloids (Mayer's test):** Yellow precipitate with Mayer's reagent.
- **Carbohydrates (Molisch's test):** Red/violet ring at the interphase with sulfuric acid.
- **Flavonoids (Alkaline reagent test):** Yellow color turning colorless upon HCl addition.
- **Terpenoids (Salkowski's test):** Reddish-brown precipitate with chloroform and H_2SO_4 .
- **Tannins (Braymer's test):** Blue/green color with ferric chloride.
- **Saponins (Foam test):** Stable foam formation.

- **Cardiac glycosides (Keller-Killiani test):** Brown ring at the interface with acetic acid and ferric chloride.

2.10 Statistical Analysis

Experiments were conducted in triplicate. GraphPad Prism (v9.5.1) and Microsoft Excel were used for data analysis. A significance level of $p < 0.05$ was established.

III. RESULTS AND DISCUSSION

3.1 Synthesis of AgNPs Using *H. lobatus* Leaf Extract

A color shift in the reaction mixture to a brownish-black shade, signifying the reduction of silver ions, visually verified the creation of silver nanoparticles (AgNPs). This transformation, attributed to the surface plasmon resonance (SPR) effect, suggested successful nanoparticle synthesis. Further characterization was performed to confirm synthesis, crystalline structure, and the functional groups involved.

3.2 UV-Vis Spectroscopy Analysis

The UV-Vis absorption spectrum of the green-synthesized AgNPs exhibited a peak at approximately 420 nm (Fig. 1), confirming their formation. This result aligns with findings from *H. Sabdariffa* petal extract-based AgNPs, which showed SPR bands at 421 nm [17]. Although the exact synthesis mechanism remains unclear, it is hypothesized that bioactive compounds aid in the reduction of silver ions in the plant extract [18].

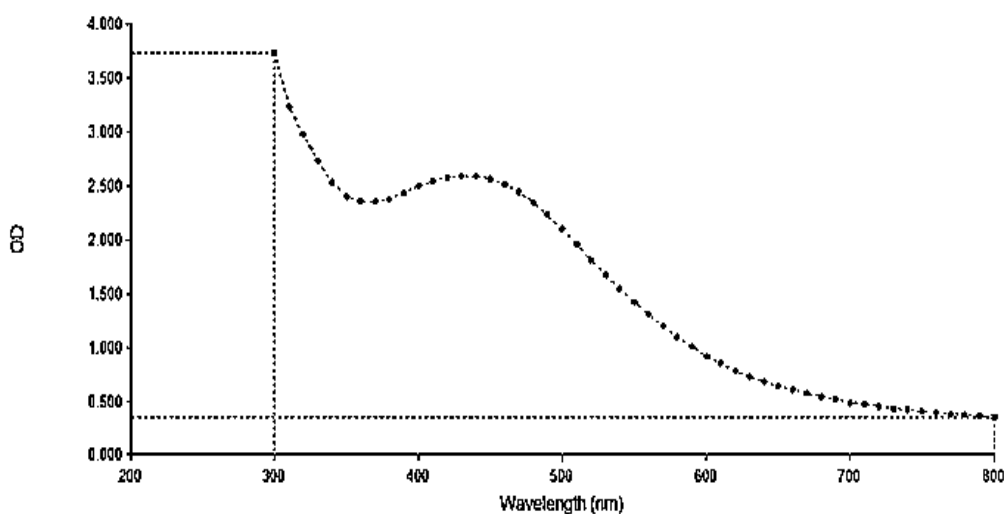


Figure 1. UV-Vis absorption spectrum of AgNPs synthesized from *H. lobatus* leaf extract

3.3 Characterization of Green-Synthesized AgNPs

3.3.1 XRD Analysis

AgNPs' crystalline nature was validated by X-ray diffraction (XRD) analysis, which showed distinctive peaks at 2θ values of 28° , 32° , 46° , 54° , 58° , and 77° (Fig. 2). According to the standard JCPDS file No. 04-0783 [19], these peaks match the face-centered cubic structure of silver. The comparatively large crystalline size of the produced AgNPs is shown by the strong peaks in the XRD pattern.

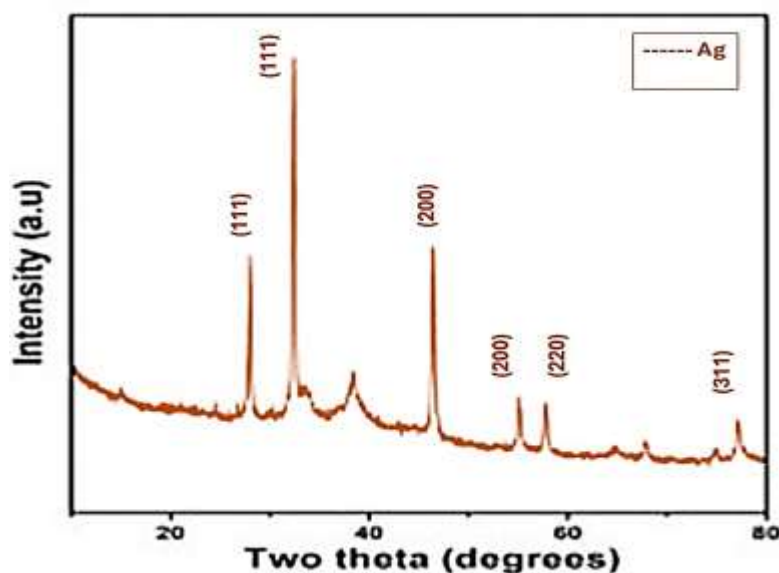


Figure 2. XRD pattern confirming the crystalline structure of synthesized AgNPs

3.3.2 FTIR Analysis

AgNP synthesis functional groups were identified using Fourier Transform Infrared Spectroscopy (FTIR). The presence of phenolics, flavonoids, alkaloids, and terpenoids was indicated by the prominent bands at 3359 cm^{-1} (O-H stretching, phenolic compounds), 1640 cm^{-1} (C=C stretching, aliphatic compounds), 1366 cm^{-1} (C-H stretching), and 1218 cm^{-1} (C-O stretching, aromatic compounds) in the FTIR spectrum of the aqueous *H. lobatus* extract (Fig. 3A).

The FTIR spectrum of the AgNPs (Fig. 3B) showed peaks at 3359 cm^{-1} (O-H group in alcohols), 1600 cm^{-1} (C=C bond in conjugated alkenes), 1400 cm^{-1} (C-F bond in fluoro compounds), and 1000 cm^{-1} (C-N stretch of amines), indicating that these functional groups are involved in the production of AgNPs. The similarity in spectral bands between the extract and synthesized AgNPs further confirmed the role of plant metabolites in nanoparticle stabilization [20].

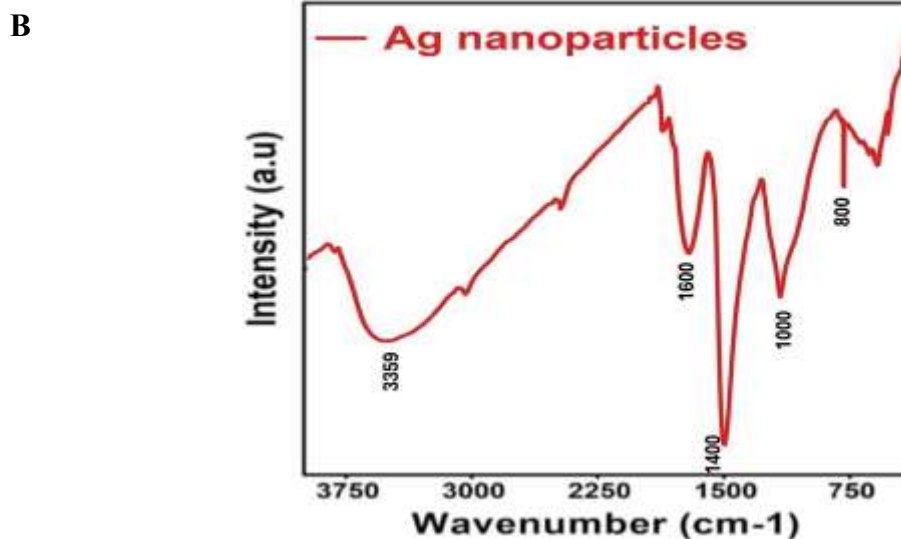
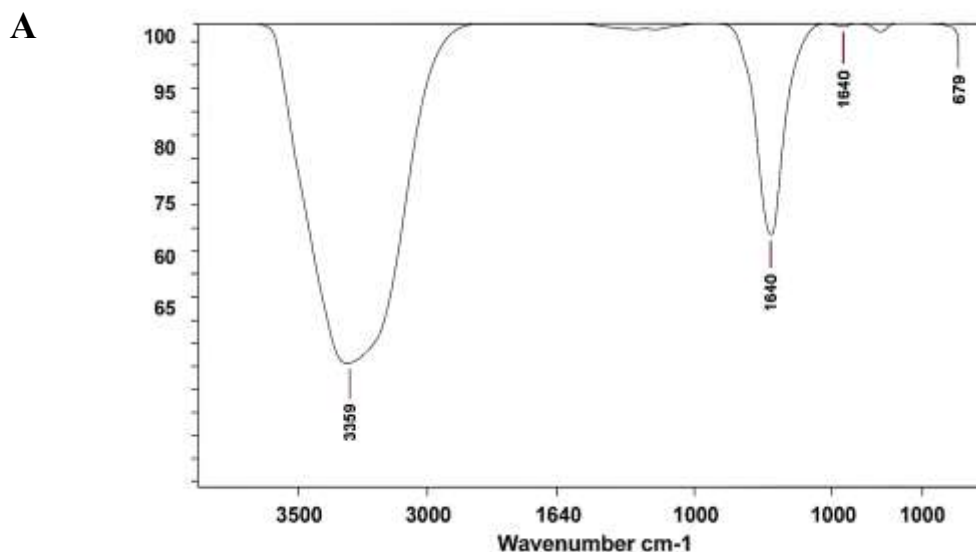


Figure 3. FTIR spectra of *H. lobatus* (A) leaf extract; (B) green-synthesized AgNPs

3.4 Antimicrobial Activity of *H. lobatus* Extracts and AgNPs

Both the crude extract and synthesized AgNPs exhibited antimicrobial activity against all tested pathogens. The inhibition zones ranged from 9 to 13 mm, with *E. coli* showing the highest

inhibition (12.33 ± 0.57 mm) for the aqueous extract, while *Candida* was most affected by AgNPs (13 ± 1.00 mm) (Fig. 4).

Statistical analysis using an F-test revealed a significant difference in inhibition effects among microbial strains ($p = 0.0329$). A highly significant difference ($p = 0.0001$) was observed between crude extracts and AgNPs, confirming the superior antimicrobial efficacy of AgNPs (Table 1). Among all tested microbes, *Bacillus* and *Candida* were most susceptible to AgNPs. The enhanced antimicrobial activity of AgNPs is attributed to their nanoscale size, enabling attachment to bacterial membranes, increased permeability, and disruption of structural integrity. In fungi, AgNPs are known to compromise membrane integrity and spore stability, leading to cell death [21].

Previous studies have demonstrated that *Hibiscus* extracts exhibit antimicrobial properties against various clinical pathogens. For instance, *H. rosa-sinensis* extracts were effective against *Escherichia coli*, *Staphylococcus aureus*, *Salmonella choleraesuis*, and *Salmonella typhimurium* [22]. Furthermore, *Hibiscus* crude extracts have shown potent anti-biofilm activity, prevented *Candida* adhesion, and inhibited biofilm growth at higher concentrations [23].

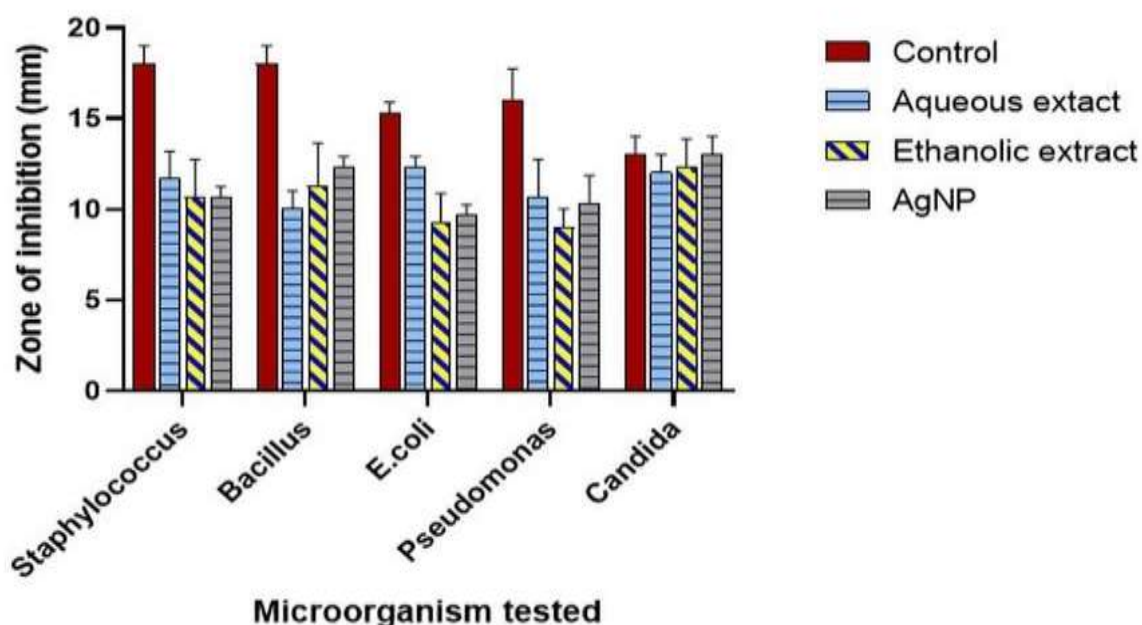


Figure 4. Comparative inhibition zones (mm) for crude extract and AgNPs against tested pathogens

3.5 Minimum Inhibitory Concentration (MIC) Analysis

The MIC values for aqueous and ethanolic extracts, as well as synthesized AgNPs of *H. lobatus*, were determined against tested microbial strains. The results indicated variations in antimicrobial efficacy depending on the extract type and microorganism. Among the tested pathogens, *Candida* and *Pseudomonas* exhibited the lowest MIC values (5–12.5 mg/mL), suggesting higher susceptibility to the bioactive compounds present in *H. lobatus*. Conversely, *Bacillus* and *E. coli* demonstrated the highest MIC values (7.5–25 mg/mL), indicating relative resistance to the extracts. These differences suggest differential interactions between microbial cell components and the phytochemicals or AgNPs. A summary of the MIC values for *H. lobatus* extracts and AgNPs against tested pathogens is provided in Table 1.

The antimicrobial potency of AgNPs was notably higher than that of crude extracts, which aligns with previous findings that attribute enhanced microbial inhibition to the nanoscale size and surface reactivity of silver nanoparticles. AgNPs are known to interact with microbial membranes, induce oxidative stress, and interfere with intracellular functions, leading to cell damage and death [24]. Statistical analysis through one-way ANOVA demonstrated a significant difference ($p < 0.05$) in MIC values among the different treatments, further supporting the enhanced antimicrobial activity of AgNPs over crude extracts.

Table -1 Minimum Inhibitory Concentration (MIC) of *Hibiscus lobatus* Crude Extracts and AgNPs against various Bacterial and Fungal Pathogens.

Pathogen	Aqueous Extract (mg/mL)	Ethanolic Extract (mg/mL)	AgNPs (mg/mL)
Staphylococcus	25	7.5	5
Bacillus	25	7.5	7.5
Escherichia coli	25	7.5	7.5
Pseudomonas	12.5	7.5	5
Candida	12.5	5	7.5

3.5.1 Inhibition of α -Amylase Activity

The α -amylase inhibitory assay demonstrated that *H. lobatus* ethanolic leaf extracts and synthesized AgNPs exhibit potential anti-diabetic activity. At the tested concentrations (31.25–1000 $\mu\text{g/mL}$), both crude extracts and AgNPs samples showed inhibition above 70%, indicating a strong ability to interfere with carbohydrate digestion and glucose release. The inhibition profile of each sample varied, with AgNPs exhibiting slightly enhanced inhibition compared to crude extracts, suggesting a possible synergistic effect of bioactive compounds in their nanoparticle form (Fig. 5). ANOVA analysis showed a significant difference in α -amylase inhibition between the crude extracts and AgNPs ($p = 0.0217$). Similar results have been reported in *H. sabdariffa* L. where flavonoids and tannins were identified as key contributors to enzyme inhibition [25].

The IC₅₀ values could not be precisely determined due to the extremely low concentration required for 50% inhibition. This suggests that the bioactive constituents of *H. lobatus* play a crucial role in modulating α -amylase activity, potentially contributing to its anti-diabetic properties.

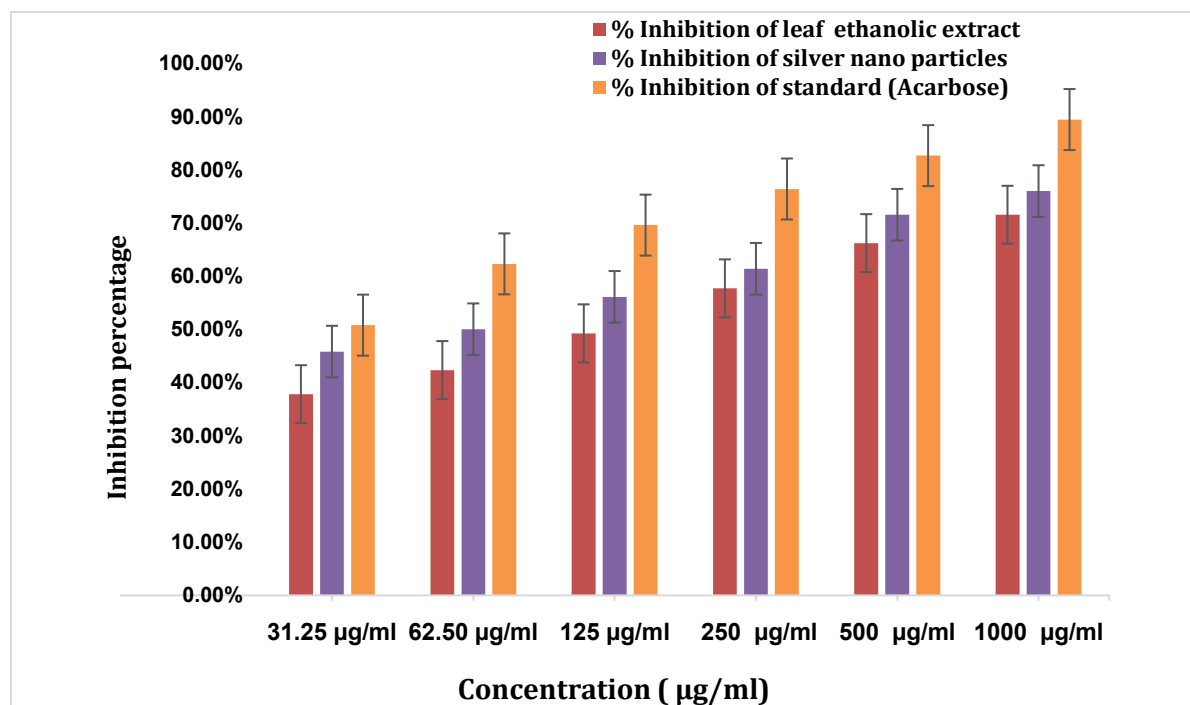


Figure 5. α -Amylase inhibition activity of crude extract and AgNPs from *H. lobatus*

3.6 Preliminary Evaluation of Antioxidant properties of *H. lobatus* Leaf Extracts

The antioxidant potential of *H. lobatus* aqueous and organic extracts, along with synthesized AgNPs, was assessed using ABTS radical scavenging activity. Among the tested samples, the organic extract exhibited the highest antioxidant activity (70.50%), followed by the aqueous extract (66.72%), while AgNPs demonstrated the lowest scavenging ability (37.82%) (Fig. 6). Statistical analysis revealed significant variation among the samples with p-values <0.05. The IC₅₀ values were determined and compared to ascorbic acid. AgNPs had a least IC₅₀ value amongst the tested samples, signifying it to be a more potent antioxidant, meaning less sample is needed to neutralize the radicals and achieve 50% inhibition (Fig. 7). Similarly, AgNPs derived from different *Hibiscus* species like, *H. sabdariffa*, *H. tiliaceus*, *H. rosasinensis* have shown promising antioxidant activity [18; 26; 27].

The observed radical scavenging activity of AgNPs is attributed to the presence of bioactive compounds capable of donating hydrogen molecules. These molecules not only aid in the reduction of silver ions but also enhance the antioxidant properties of the synthesized AgNPs by increasing their surface interaction with free radicals [28]. These findings suggest that *H. lobatus*-derived AgNPs hold potential as natural antioxidants, with prospective applications in biomedical, pharmaceutical, and cosmetic industries.

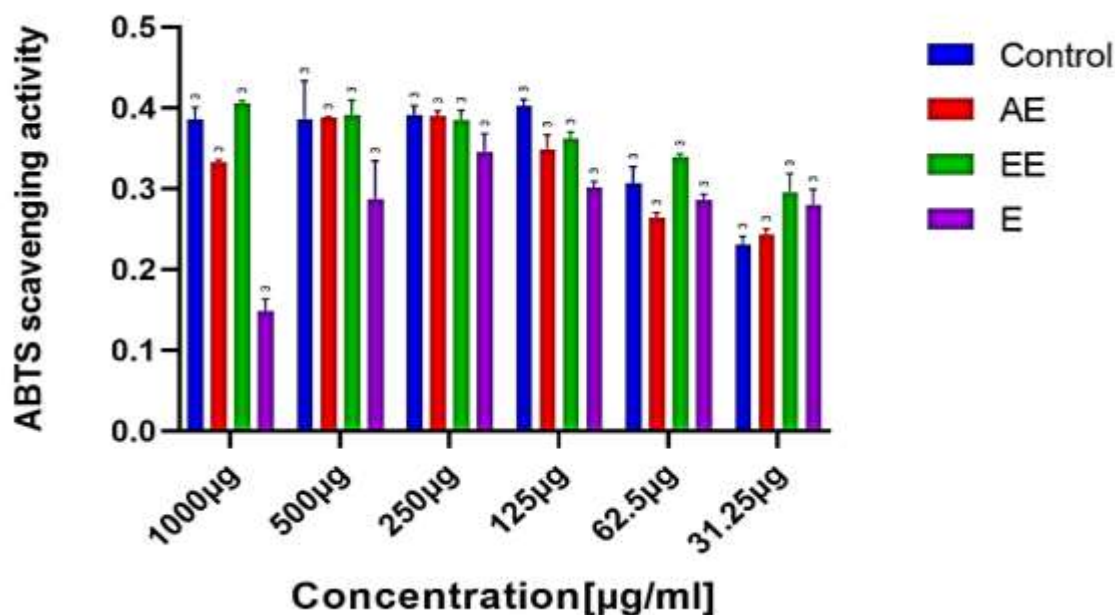


Figure 6. ABTS scavenging activity of *H. lobatus* crude extract and synthesized AgNPs (where AE= Aqueous extract, EE= Ethanolic extract and E= AgNPs)

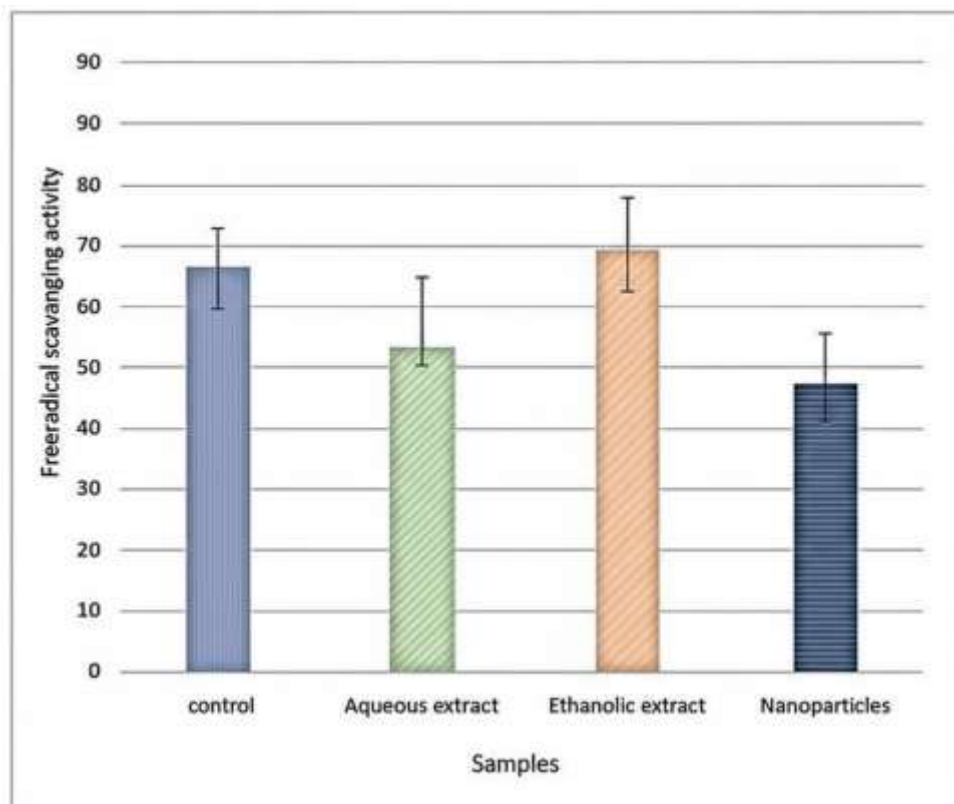


Figure 7. IC_{50} values for antioxidant activity of *H. lobatus* crude extract and green synthesized AgNPs.

3.7 Phytochemical Screening for Secondary Metabolites

Phytochemical analysis was performed to identify the presence of bioactive compounds in *H. lobatus* extracts. The aqueous extract contained a broad range of secondary metabolites, including alkaloids, carbohydrates, flavonoids, terpenoids, tannins, and cardiac glycosides. The ethanolic extract demonstrated the presence of saponins in addition to carbohydrates, terpenoids, and tannins, while the methanolic extract showed the least variety, containing only flavonoids, terpenoids, and tannins (Table 2). These results align with the FTIR findings, indicating that the bioactive compounds in plant extract are involved in the reduction of silver nitrate to AgNPs [29]. The presence of these secondary metabolites further supports the therapeutic potential of *H. lobatus*, particularly in antimicrobial, antidiabetic, and antioxidant applications.

Table -2 Secondary metabolites present in crude extract of *H. lobatus*

Phytochemicals	Aqueous extract	Ethanollic extract	Methanolic extract
Alkaloids	+	+	-
Carbohydrates	+	-	-
Flavonoids	+	-	+
Terpenoids	+	+	+
Tannins	+	+	+
Saponins	-	+	-
Cardiac glycosides	+	-	-

Note: '+' indicates presence, '-' indicates absence.

IV. CONCLUSION

This study assessed the bioactivity of *H. lobatus* in both crude and nanoparticle forms and effectively generated silver nanoparticles (AgNPs) utilizing a green synthesis approach. The synthesized AgNPs exhibited a crystalline structure with surface-functionalized biomolecules. Both crude extracts and AgNPs demonstrated significant antimicrobial potential against clinical pathogens, with AgNPs exhibiting superior activity due to their enhanced interaction with microbial cell membranes. Furthermore, the crude extracts and AgNPs displayed promising antidiabetic activity, inhibiting α -amylase by over 70%. The antioxidant potential was highest in crude extracts, while AgNPs showed relatively lower scavenging activity. Alkaloids, flavonoids, terpenoids, tannins, and saponins were validated by phytochemical screening, and these substances most likely played a role in the bioactivities that were observed.

These findings support the potential therapeutic applications of *H. lobatus*, aligning with the medicinal properties observed in other *Hibiscus* species. The outcomes also resonate with the Indian Knowledge System, where medicinal plants have historically been employed for managing infections, metabolic disorders, and wound healing. By integrating this traditional wisdom with nanotechnology-driven approaches, the present study strengthens the bridge between ancient practices and modern biomedical research. Further studies, including in vivo analysis and detailed characterization of active metabolites, are warranted to explore its full clinical potential in biomedical applications.

REFERENCES

- [1] Refaz Ahmad Dar., Mohd. Shahnawaz., Ahanger M. A., Izaidin Abdul Majid., Exploring the Diverse Bioactive Compounds from Medicinal Plants: A Review. *The Journal of Phytopharmacology*, 12(3) (2023) 189-195. <https://doi.org/10.31254/phyto.2023.12307>
- [2] Naveed M., Bukhari B., Aziz T., Zaib S., Mansoor M.A., Khan A.A., Shahzad M., Dablood A.S., Alruways M.W., Almalki A.A., Alamri A.S, Green synthesis of silver nanoparticles using the plant extract of *Acer oblongifolium* and study of its antibacterial and antiproliferative activity via mathematical approaches, *Molecules*. 27(13) (2022) 4226. <https://doi.org/10.3390/molecules27134226>
- [3] Chaachouay N., Zidane L., Plant-Derived Natural Products: A Source for Drug Discovery and Development, *Drugs and Drug Candidates* 3(1) (2024) 184-207. <https://doi.org/10.3390/ddc3010011>
- [4] Dharavath S.B., Maduru N., Porika M., Chirumamilla P., Veera S., Ponnamm N., Taduri S., Green synthesis of silver nanoparticles using *Nothapodytes foetida* leaf extract: Optical, antibacterial and anticancer activities, *Next Nanotechnology* (2025) 7:100162. <https://doi.org/10.1016/j.nxnano.2025.100162>
- [5] Vankudoth S., Dharavath S., Veera S., Maduru N., Chada R., Chirumamilla P., Gopu C., Taduri S., Green synthesis, characterization, photoluminescence and biological studies of silver nanoparticles from the leaf extract of *Muntingia calabura*, *Biochemical and Biophysical Research Communications* 630 (2022)143-150. <https://doi.org/10.1016/j.bbrc.2022.09.054>
- [6] Patwardhan B., Mashelkar R. A., Traditional medicine-inspired approaches to drug discovery: Can Ayurveda show the way forward? *Drug Discovery Today* 14(15–16) (2009) 804–811. <https://doi.org/10.1016/j.drudis.2009.05.009>
- [7] Rastogi S., Pandey M. M., Rawat A. K. S., Traditional medicine: The goldmine for modern drugs, *Advances in Techniques in Biology & Medicine* 6(1) (2018) 1–5. <https://doi.org/10.4172/2379-1764.1000239>
- [8] Mukherjee P. K., Nema N. K., Venkatesh P., Debnath P. K., Changing scenario for promotion and development of Ayurveda—way forward, *Journal of Ethnopharmacology* 143(2) (2012) 424–434. <https://doi.org/10.1016/j.jep.2012.07.036>

- [9] Sharma R., Martins N., Telang A. M., Emerging trends in nutraceutical research: A visionary perspective through Ayurveda, *Current Pharmaceutical Design* 25(25) (2019) 2777–2786. <https://doi.org/10.2174/1381612825666190903161108>
- [10] Norhisham D., Aizat Saad N. M., Ahmad Usulidin S. R., Vayabari D. A. G., Ilham Z., Ibrahim M. F., Wan-Mohtar W. A. A. Q. I., Bioactivities of Kenaf Biomass Extracts: A Review, *Processes* 11(4) (2023) 1178. <https://doi.org/10.3390/pr11041178>
- [11] Kartik T.D., Krishna V., Giri B.S., Raagavalli K., Syeda A.S, In vitro Regeneration of a Vulnerable Medicinal Plant *Hibiscus lobatus* Kuntze. through Stem Callus Culture Plant Tissue Culture and Biotechnology 34(2) (2024) 247-254. <https://doi.org/10.3329/ptcb.v34i2.78834>
- [12] Ahmed S., Saifullah Ahmad M., Swami B. L., Ikram S., Green synthesis of silver nanoparticles using *Azadirachta indica* aqueous leaf extract, *Journal of Radiation Research and Applied Sciences*, 9(1) (2016) 1-7. <https://doi.org/10.1016/j.jrras.2015.06.006>
- [13] Holder I. A., Boyce, S. T., Agar well diffusion assay testing of bacterial susceptibility to various antimicrobials in concentrations non-toxic for human cells in culture, *Burns* 20(5) (1994) 426-429. [https://doi.org/10.1016/0305-4179\(94\)90035-3](https://doi.org/10.1016/0305-4179(94)90035-3)
- [14] Miller G. L., Use of Dinitrosalicylic Acid Reagent for Determination of Reducing Sugar, *Analytical Chemistry*, 31(3) (1959) 426–428.
- [15] Rehana D., Mahendiran D., Kumar R. S., Rahiman A. K., Evaluation of antioxidant and anticancer activity of copper oxide nanoparticles synthesized using medicinally important plant extracts, *Biomedicine & Pharmacotherapy*, 89 (2017) 1067–1077.
- [16] Roy S., Rao K., Bhuvaneswari Ch., Giri A., Mangamoori L. N., Phytochemical analysis of *Andrographis paniculata* extract and its antimicrobial activity, *World Journal of Microbiology and Biotechnology*, 26(1) (2009) 85–91.
- [17] Tasnim A., Roy A., Akash S. R., Ali H., Habib M. R., Barasarathi J., Muthukumaran M., Sayyed R. Z., Yeasmin T., *Hibiscus sabdariffa* L. petal biomass: A green source of nanoparticles of multifarious potential, *Open Agriculture* 9(1) (2024). <https://doi.org/10.1515/opag-2022-0332>
- [18] Dhanapal V., Subhapriya P., Arangarajan K., Jeevanantham A., Sudhakar P., Kandavelu V., Nivedhitha K. S., Umarfarooq M. A., Banapurmath N. R., Badruddin I. A., Bashir M. N., Ali M. M. A facile synthesis of silver nanoparticles using *Woodfordia fruticosa* flower extracts for certain bacteria inhibition applications *Heliyon* (2025) e42125. <https://doi.org/10.1016/j.heliyon.2025.e42125>

- [19] Ali Md H., Kalam A., Khan K. A., Rahman M. O., Chakma U., Kumer A., Analysis of crystallographic structures and properties of silver nanoparticles synthesized using PKL Extract and nanoscale characterization techniques, ACS Omega 8(31) (2023) 28133-28142. <https://doi.org/10.1021/acsomega.3c01261>
- [20] Alharbi N. S., Alsubhi N. S., Felimban A. I., Green synthesis of silver nanoparticles using medicinal plants: Characterization and application, Journal of Radiation Research and Applied Sciences 15(3) (2022) 109-124. <https://doi.org/10.1016/j.jrras.2022.06.012>
- [21] Kumar R., Singh N. P., Mukopadaya, S., Sah R. P., Ethnomedicinal and pharmacological properties of *Hibiscus sabdariffa*, International Journal of Health Sciences (2022) 9744-9758. <https://doi.org/10.53730/ijhs.v6ns3.8551>
- [22] Salinas-Moreno Y., Arteaga-Garibay R. I., Arroyo-Silva A., Ordaz-Ortiz J. J., Ruvalcaba-Gomez J. M., Galvez-Marroquin L. A., Antimicrobial activity and phenolic composition of varieties of *Hibiscus sabdariffa* L. with red and white calyces Cyta-Journal of Food 21(1) (2023) 1-9. <https://doi.org/10.1080/19476337.2022.2152099>
- [27] Dwivedi M., Sumathi Muralidhar., Saluja D., *Hibiscus sabdariffa* Extract Inhibits Adhesion, Biofilm Initiation and Formation in *Candida albicans*, Indian Journal of Microbiology 60(1) (2019) 96-106. <https://doi.org/10.1007/s12088-019-00835-9>
- [24] Al Mutairi J. F., Al-Otibi F., Alhajri H. M., Alharbi R. I., Alarifi S., Alterary, S. S., Antimicrobial activity of green silver nanoparticles synthesized by different extracts from the leaves of Saudi Palm Tree (*Phoenix dactylifera* L.), Molecules, 27(10) (2022) 3113. <https://doi.org/10.3390/molecules27103113>
- [25] Vasudeva N., Sharma S. K., Biologically active compounds from the genus *Hibiscus*, Pharmaceutical Biology (2008) 145–153. <https://doi.org/10.1080/13880200701575320>
- [26] Bedlovicova Z., Strapac I., Balaz M., Salayova A., A brief overview on antioxidant activity determination of silver nanoparticles, Molecules 25(14) (2020) 3191. <https://doi.org/10.3390/molecules25143191>
- [27] Konduri V. V., Kalagatur N. K., Gunti L., Mangamuri U. K., Kalagadda V. R., Poda S., Krishna., Green synthesis of silver nanoparticles from *Hibiscus tiliaceus* L. Leaves and their applications in dye degradation, antioxidant, antimicrobial, and anticancer activities, South African Journal of Botany 168 (2024) 476-487. <https://doi.org/10.1016/j.sajb.2024.03.035>

[28] Amaratunga T., Kandiah M., Abhaywardena S., Green synthesis of silver nanoparticles using six varieties of *Hibiscus rosa-sinensis* leaf extracts: Evaluation of antioxidant activity, antibacterial activity and photocatalytic properties, GARI International Journal of Multidisciplinary Research (2022)109–130.

<https://diglib.natlib.lk/bitstream/handle/123456789/57261/Triffina%20Amaratunga%20BMS.pdf>

[29] Melkamu W. W., Bitew L. T., Green synthesis of silver nanoparticles using *Hagenia abyssinica* (Bruce) J.F. Gmel plant leaf extract and their antibacterial and anti-oxidant activities, Heliyon 7(11) (2021) e08459. <https://doi.org/10.1016/j.heliyon.2021.e08459>