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Green Synthesis of Nanoparticles from Angel-wing Jasmine *Jasminum laurifolium* with Enhanced Antibacterial Activity

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Abstract

Background: Recent developments in nanotechnology, notably green synthesis with plant extracts, have enabled the synthesis of biologically compatible nanoparticles with more efficient pharmacological properties. **Aim:** The present study focused on the phytochemical profiling and green synthesis of angel-wing jasmine (*Jasminum laurifolium* Roxb. Ex Hornem.) with an emphasis on its antibacterial potentiality. **Methodology:** *J. laurifolium* leaf powder was extracted with Soxhlet using aqueous and organic solvents, i.e., hexane, chloroform, and ethyl acetate. The obtained leaf extracts were subjected to qualitative and quantitative studies. Green-synthesised AgNPs were characterised using UV–Visible spectroscopy, Fourier Transform Infrared Spectroscopy (FTIR), X-ray Diffraction (XRD), and Scanning Electron Microscopy (SEM). The antibacterial potential of the obtained solvent extracts and AgNPs was tested against *Bacillus megaterium, Streptococcus mutans, Xanthomonas campestris* and *Klebsiella pneumonia.* **Results:** Qualitative screening of leaf extract showed the presence of thirty-one phytochemical constituents, whereas quantitative estimation reported the significant levels of alkaloids, phenols, flavonoids, saponins, steroids, and coumarins. An antibacterial study reported that both solvent extracts and synthesised AgNPs showed potent inhibition of microbial growth; however, AgNPs showed higher efficacy even at lower concentrations. **Conclusion:** The results indicate that leaves of *J. laurifolium* are a good source of bioactive secondary metabolites and provide a sustainable method for creating nanoparticles, and could potentially be used as natural antibacterials.

Major Findings: *Jasminum laurifolium* leaves are high in bioactive phytochemicals (alkaloids, phenols, flavonoids, saponins, steroids, and coumarins) that have substantial antibacterial properties. Green-synthesized silver nanoparticles (AgNPs) had higher antibacterial activity than solvent extracts, successfully inhibiting both Gram-positive and Gram-negative bacteria at lower doses.

Keywords: AgNPs, Green Synthesis, Jasmine, Phytochemicals, Solvents

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1. Introduction

Nature serves as an essential source of medicinal plants, many of which have been utilised for generations to treat a variety of ailments in humans and animals. Historical data indicate that medicinal plants are the basis for traditional and alternative healing systems[1]. Recent studies in phytochemistry and analysis reveal that these plants possess a diverse array of bioactive substances referred to as secondary metabolites, such as alkaloids, flavonoids, phenolics, saponins, steroids, and tannins, which play a crucial role in their medicinal effectiveness[2].

The rapidly growing domain of nanotechnology has unveiled new possibilities in biomedical sciences by producing functional nanomaterials with specific physicochemical properties and exceptional biocompatibility[3]. Among these, the plant-based/ "green" synthesis of metallic nanoparticles has gathered increasing interest due to their eco-friendly, economical, and sustainable features compared to traditional physical and chemical techniques. Phytochemicals serve as natural reducing and stabilising agents in nanoparticle synthesis and provide extra biological potentiality[4,5]. These green synthesised nanoparticles, specifically silver nanoparticles (AgNPs), display exceptional antibacterial, antioxidant, and cytoprotective activities[6,7].

Plants belonging to the genus *Jasminum* are widely recognised for their fragrant and therapeutic properties and have been enormously utilised in traditional medical practices[8,9]. In conventional medicine, *Jasminum* leaves are used to treat ear disorders, whereas flowers are having excellent ability to relieve stress and to alleviate headaches. The plant also has aphrodisiac and antifertility properties, enhancing its vital role in ethnomedicine[10,11].

Phytochemical studies on various *Jasminum* species, specifically *J. officinale, J. sambac*, and *J. grandiflorum* have exhibited a reservoir of secondary metabolites, which account for their pharmacological activities[12,9]. Recent studies also revealed that both crude extracts and essential oils from *Jasminum* reported extensive antibacterial activity against bacterial and fungal pathogens[8,12]. Additionally, the biogenic synthesis of metallic nanoparticles using *Jasminum* extracts has shown significant antibacterial properties, highlighting its efficacy as a sustainable basis for nanopharmaceutical uses[6,7].

Jasminum laurifolium is a native of the commonly named Angel wing/Angel hair jasmine. In Hindi, it is called as Raj Chameli and in Telugu is Kagadamalle. It is a tropical shrub with woody branches. The leaves are dark green in colour with glossy, leathery, elliptic, and lance-shaped leaves with opposite phyllotaxy. Flowers are in snow white, pinwheel with multi-petalled tubular and fragrant, corolla is with 8-12 lobes. Generally, flowers during December to February.

Jasminum laurifolium, an ethnomedicinally important species, contains a variety of phytochemicals that can act as both bioactive molecules and reducing/stabilising agents in nanoparticle formation. However, to the best of our knowledge, no systematic investigation has examined or compared the antibacterial activity of herbal nanoparticles and silver nanoparticles generated from *Jasminum laurifolium*. Such a comparison method is required to assess if antibacterial efficacy is mostly due to the plant's intrinsic phytochemicals or the increased physicochemical qualities supplied by metallic nanoparticles. Thus, the current study was conducted to develop green synthetic silver nanoparticles and herbal nanoparticles utilising *J. laurifolium* and to compare their antibacterial capabilities. It is anticipated that this study will throw additional insight into the nanobiotechnological uses of *J. laurifolium* and may aid in the manufacturing of innovative plant-based antibacterial nanomaterials for use in biomedical and pharmaceutical applications.

2. Materials and Methods

2.1 Plant Identification

The *Jasminum laurifolium* plant specimen (16°22'41.5"N 80°31'33.4" E) was obtained in November 2024 from Acharya Nagarjuna University. The geographical parameter of the study region was recorded using a Garmin GPS instrument (model: Oregon 550). The plant was recognised using floras (Gamble)[13] and authenticated by the Department of Botany, Acharya Nagarjuna University, Guntur, AP, India, with herbarium voucher number ANUBOTHS678.

2.2 Phytochemical Analysis

2.2.1 Plant Sample Processing and Preparation of Extracts

The collected leaves were washed thoroughly under tap water to eliminate impurities (dust particles, spores,

etc.). They were shade-dried and pulverised into a fine powder using an electric grinder.

2.2.2 Aqueous Extract Preparation

Aqueous leaf extract was prepared by dissolving 10 g of leaf powder in 250 ml distilled water for 14 h, and filtered using Whatman No. 1 filter paper.

2.2.3 Organic Extract Preparation

Powdered leaf sample (150 g) was extracted with different organic solvents, i.e. methanol, acetone, ethyl acetate, chloroform, n-Hexane, according to their polarity gradient at their boiling points successively for about 12-18 h. This polarity-based extraction technique increases the recovery of chemically varied secondary metabolites while also improving overall extraction efficiency for future phytochemical and biological investigations. The crude leaf extracts were evaporated using a vacuum rotary evaporator (Buchi Labortech Ag, model l, R-215) under reduced pressure. The crude extracts were stored in amber bottles at 4 °C.

2.2.4 Preliminary Phytochemical Screening

Preliminary phytochemical screening was performed using standard protocols[14-16].

2.2.5 Quantitative Determination of Phytochemicals

2.2.5.1 Phenols (mg/g)

Total phenolic content present in the leaf sample was determined[17]. A cocktail of reaction mixture was made using leaf extract (0.5 ml), 10% Folin-Ciocalteu's reagent (2.5 ml), 7.5% of $NaHCO_3$ (2.5 ml). The samples were incubated at 45 °C for 45 min. The absorbance was determined using a spectrophotometer at 765 nm. Gallic acid is used as the standard.

2.2.5.2 Tannins (mg/g)

The Folin-Ciocalteu method was used to measure the content of tannins[18]. To 0.1 ml of the leaf extract, a cocktail mixture containing distilled water (7.5 ml), Folin-Ciocalteu phenol reagent (0.5 ml) and 35% sodium carbonate (1 ml) was prepared. The mixture was stirred and incubated for 30 minutes. Absorbance was measured at 700 nm.

2.2.5.3 Cardiac Glycosides

Cardiac glycosides were estimated according to Muhammad and Abubakar[19]. To 8 ml of leaf extract, 60 ml of H_2O and 8 ml of 12.5% lead acetate were added. To the filtrate, 8 ml of 47% Na_2HPO_4 was added to precipitate excess Pb^{2+} ions. The mixture was filtered twice and removed the excess lead phosphate. To 10 ml of purified filtrate, 10 ml of Baljet reagent was added. The colour intensity was measured at 495nm.

Calculation:

$$\%Total\ glycosides = \frac{Ax100}{77}$$

$$Where\ A = absorbance$$

2.2.5.4 Steroids (µg/ml)

The steroid content of the leaf sample was measured[20]. To 1 ml of leaf extract, 4N sulphuric acid (2 ml), and iron (III), 0.5% chloride (2 ml), and 0.5% potassium hexacyanoferrate (III) solution (0.5 ml) were added. The contents were subjected to 70°C for 30 minutes. The absorbance was measured at 780 nm.

2.2.5.5 Coumarins (m/g)

Coumarin content was estimated and analysed[21,22]. To 500 µl of leaf extract, 2 ml of distilled water and 500 µl of lead acetate (5%, w/v) solution were added. The contents were shaken vigorously and mixed with distilled water (7 ml). From this solution, 2 ml was taken and mixed with 8 ml of 0.1 M (v/v) hydrochloric acid. The solution was incubated for 30 minutes. The absorbance was measured at 320 nm.

2.2.5.6 Alkaloids (mg/g)

The leaf extract (1 mg) was dissolved in dimethyl sulphoxide (DMSO) and 1 ml of 2 N HCl. This solution was agitated with bromocresol green solution (5 ml) and phosphate buffer (5 ml). The mixture was subjected to vigorous shaking with 1, 2, 3 and 4 ml of chloroform. A standard was prepared by using atropine. The absorbance was measured at 470 nm[23].

2.2.5.7 Saponins (%)

To the leaf extract (20 g), 20 % aqueous ethanol (100 ml) was added. The solution was subjected to heating (55°C) for 4 h with constant stirring. The solution was filtered and extracted with 20 % ethanol (200 ml). Both extracts were mixed and evaporated to 40%.

The concentrate was extracted with diethyl ether (20 ml). The aqueous layer was recovered and purified with n-butanol (60 ml). Further, it was washed with 5 % aqueous NaCl (10 ml). The saponin content was measured on a dry weight basis[24,25].

2.3 Green Synthesis of Silver Nanoparticles

Silver nanoparticles are prepared by using leaf powder[26]. 15 mg of plant leaf powder mixed with 500 ml of distilled water and boiled at 60 °C for 15 minutes, and then let them cool and are filtered. From this 20ml of filtrate is taken, and to it 80ml of $AgNO_3$ (1 mM) was added, and heated at 60 °C. The appearance of a brown-yellow coloured solution indicates the formation of silver nanoparticles, and this solution was centrifuged at 20,000 rpm for 30 minutes. The pellet, which was obtained washed three times and dried at 60 °C for 1 hour.

2.4 Characterisation of Leaf Nanoparticles

The crude leaf extracts obtained from the selected medicinal plant were further subjected to characterisation.

2.4.1 UV-Vis

The leaf powder sample was dissolved in methanol and analysed using a UV-Vis spectrophotometer (LM-44; Perkin Elmer, Germany) operated from the UV to NIR (200-900 nm).

2.4.2 XRD

The leaf powder was coated onto an XRD grid and analysed at 40 kV and 30 mA with cu kal radiation (Schimadzu –6100 X-Ray Diffractometer). The diffracted intensities were recorded from 10° to 60° at 20 angles. The size of the nanoparticles is estimated by the Debye-Scherrer formula[27].

$$D = 0.94 \lambda / \beta \cos \theta$$

Where D is the average crystallite domain size, λ is the X-ray wavelength, β is the full width at half maximum (FWHM), and θ is the diffraction angle.

2.4.3 SEM

SEM analysis was carried out using a Carl Zeiss Japan model machine. A thin film of leaf sample was coated on carbon tape and subjected to ultraviolet light under a mercury lamp for 5 min. The AMT Camera System (Carl Zeiss, Japan) was operated at 100 kV and 10000 X magnification.

2.4.4 Analysis of Silver Nanoparticle Jasminum laurifolium by Using FTIR

One milligram of the leaf sample and 200 mg fine KBr powder were macerated together, weighed, and the quantities were transferred into a mortar and mixed well with the help of a spatula. The bottom and the top portions of KBr were assembled at the press assembly, and one of the 13 mm dies with the polished surface up inside the press. The KBr sample mixture was transferred to a KBr press assembly. The sample was slowly compressed in a KBr press assembly at a pressure of 2000 kg/cm2 for about 60 sec. The prepared disc was then subjected to scanning between 500-4000-1 cm (Schimatzu IR Affinity - 1S spectrophotometer).

2.5 Antibacterial Activity

Crude extracts of leaves and synthesised AgNPs from *Jasminum laurifolium* leaves were tested for their antibacterial ability[26] against *Bacillus megaterium, Streptococcus mutans, Xanthomonas campestris* and *Klebsiella pneumonia* by agar well diffusion method. Nutrient agar (NA) was used for culturing the test bacteria. Sterilised nutrient agar medium (100 ml) was inoculated with 0.1 ml of the test microbial suspension in three replicates. After solidification, wells of about 5 mm diameter were punched, and solvent leaf extracts of 50 µl, 100 µl and 150 µl were added to each well, and the addition of solvent alone served as a control. The plates were incubated at 30 °C, and the zone of inhibition was measured after 24 h. After incubation, the diameter of the zone of inhibition was measured.

3. Results and Discussion

The results obtained in the present investigations on photosynthesis, qualitative and quantitative phytochemical analysis, microbial activity and synthesis of nanoparticles in *J. laurifolium are* presented below.

3.1 Qualitative Screening of Phytochemicals

The preliminary phytochemical screening results revealed the existence of flavonoids, tannins,

quinones, alkaloids, and coumarins in all the solvent extractions (Table 1). Saponins and resins are absent in the methanol extract, whereas terpenoids and resins are not found in aqueous extracts. Chloroform extracts showed only flavonoids, quinines and resins, and the remaining are all absent. In n-Hexane extract, saponins, cardiac glycosides, steroids, and quinones are absent, and all the remaining compounds are present. Acetone and ethyl acetate are more positive towards the presence of all tested phytochemical constituents. Similar trends of results were earlier reported in mangrove species[28] and in *Alstonia scholaris*[29].

3.2 Quantitative Screening of Phytochemicals

The content of various phytochemicals present in the leaf samples was measured and tabulated in Table 2 and Figure 1.

3.2.1 Flavonoids

Among all six solvents, the presence of flavonoids was found to be maximum in methanol extract (1.80 mg/g) and minimum in n-Hexane (0.32 mg/g), with a mean value (0.78 mg/g). In the case of chloroform, the preliminary phytochemical screening revealed the absence of flavonoids. Pharmacologically active flavonoids were extracted from *Cassia angustifolia*[30]. Potent anticancer, antioxidant and antibacterial flavonoids were reported in *Asplenium nidus*[31].

3.2.2 Phenols

Phenolic compounds are essential for the growth and reproduction of plants, and plays prominent role in plant defence mechanisms. Using the standard plot of gallic acid ($y=0.0289x+0.0311$, $R^2=0.9936$), the phenols extracted with different solvents were measured. Of all the six solvents phenols content ranged between

Table 1. Preliminary phytochemical analysis of aqueous and organic solvent extracts

Name of Phytochemical	Aqueous	Methanol	Acetone	Ethyl-acetate	n-Hexane	Chloroform
Flavonoids	+	+	+	+	+	+
Phenols	+	+	+	+	+	-
Tannins	+	+	+	+	+	-
Cardiac Glycosides	+	+	+	+	-	-
Steroids	+	+	+	+	-	-
Terpenoids	-	+	+	+	+	-
Coumarins	+	+	+	+	+	-
Alkaloids	+	+	+	+	+	-
Saponins	-	-	+	+	-	-
Resins	-	-	+	+	+	+
Quinones	+	+	+	+	-	+

Table 2. Quantitative analysis of phytochemicals in different solvents

Name of phytochemical	Aqueous	Methanol	Acetone	Ethyl-acetate	n-Hexane	Chloroform
Flavonoids (mg/g)	0.78	1.80	0.40	0.62	0.32	-
Phenols (mg/g)	0.08	0.14	0.32	0.36	0.32	2.75
Tannins (mg/g)	6.18	5.98	5.88	5.94	6.25	-
Glycosides (g/100g)	1.25	2.9	11.12	0.75	-	-
Steroids (µg/ml)	0.34	0.37	0.15	0.16	-	-
Terpenoids (mg/ml)	-	0.16	0.12	0.02	-	-
Coumarins (mg/ml)	0.92	2.73	0.26	0.42	-	-
Alkaloids (mg/g)	0.11	0.28	0.2	0.03	0.03	-
Saponins (mg/g)	-	-	0.14	0.14	-	-

2.57 mg/g to 0.08 mg/g with an average of 0.63 mg/g is present. Maximum amount is present in chloroform extract (2.57 mg/g) followed by Ethyl acetate extract (0.36 mg/g) n- Hexane extract (0. 32 mg/g). Purified phenols were earlier reported in Ivorian plants[32]. Peach and Pumpkin extracts also showed the presence of phenols[33].

3.2.3 Tannins

To determine the number of tannins, present in the leaf extracts, a standard plot was drawn by using tannic acid as a standard (0.0005x+0.0487, R^2=0.9947). Among all the solvents, the tannin content ranged between 6.27 mg/g to 5.88 mg/g. The average of tannins contents is 6.05 mg/1g. Of all the solvents, maximum extraction of tannins was observed in n-Hexane extract (6.27 mg/g), followed by aqueous extract (6.18 mg/g), and methanol extract (5.98 mg/g). Tannins from the leaves of *Rubus idaeus, Cydonia oblonga* and *Rumex acetosa*[34] were reported earlier. Doss *et al.*, screened and quantified the tannins from *Solanum trilobatum* leaves[35].

3.2.4 Cardiac Glycosides

The amount of cardiac glycoside extracted with different solvents was estimated and tabulated in Table 2. The maximum cardiac glycoside content was observed in the acetone extract (11.12 g/100g), whereas the minimum was extracted with ethyl acetate extract (0.75g/100g), with a mean value of 0.75 g/100 g. Similar reports were observed in leaves of *Prosopis cineraria, Curcuma amada* and *Citrullus colocynthis*[25]. The ethyl acetate extract from the stem bark of *Alstonia boonei* showed high amounts of cardiac glycosides[36].

3.2.5 Steroids

Of all the solvents, maximum steroid content was extracted in the methanol extract (0.37 µg/mg), whereas the minimum steroid content was observed in the acetone extract (0.15 µg/mg), with an average of 0.25 µg/mg. A standard graph was plotted for the steroids by using cycloartenol as a standard (y=3.74+0.048, R^2=0.996) and expressed in *µg*/mg. A similar trend of results was reported in the roots extracts of *Smilax lanceaefolia* Roxb[37]. Root extracts of *Momordica boivinii* also reported the existence of steroids[38].

3.2.6 Terpenoids

In the present study maximum content of terpenoids was extracted in methanol (0.16 mg/g), followed by acetone extract (0.12 mg/g), ethyl acetate extract (0.02 mg/g), with an average of 0.1 mg/1g. Doss *et al.*, screened and quantified the tannins from *Solanum trilobatum*[35]. Chinou *et al.*, also screened the terpenoids from *Peucedanum luxurians*[39].

3.2.7 Coumarins

Coumarin content was estimated using coumarin equivalents as standard (CE mg/g) (y=13.9x-0.392, R^2=0.966). The coumarins present in the maximum amount in methanol extract (2:37 mg/g), followed by aqueous extract (0.92 mg/g), ethyl acetate (0.42 mg/g) and the minimum amount of coumarins identified in acetone extract (0.26 mg/g), with an average of 0.99 mg/1g. Coumarins from *Peucedanum ruthenicum* and *Peucedanum luxurians* were extracted earlier[39,40].

3.2.8 Alkaloids

The alkaloid content of the leaf extract was expressed in terms of atropine equivalent. In the present study, maximum total alkaloid content was extracted with methanol (0.28 mg/g), and minimum alkaloids were extracted with acetone (0.02 mg/g) (Table 2). Djilani *et al.*, extracted alkaloids from *Hyoscyamus muticus, Datura stramonium* and *Ruta graveolens*[41].

3.2.9 Saponins

Of all the plants, saponin content was found to be higher (2.56% w/w) when extracted with methanol (Table 2). Less saponin content was extracted in n-Hexane solvent. Matsui *et al.*, extracted and purified a high amount of saponin from tea leaf extracts[42]. Shah *et al.*, also confirmed the presence of saponins from *Teucrium stocksianum*[43].

3.3 Nanoparticle Characterisation

The leaf powder was characterised to determine the formation of nanoparticles.

3.3.1 UV-Vis

The UV-Vis spectrum revealed a maximum peak between 236-241 nm, confirming the formation of silver nanoparticles (AgNPs)[44] (Figure 2).

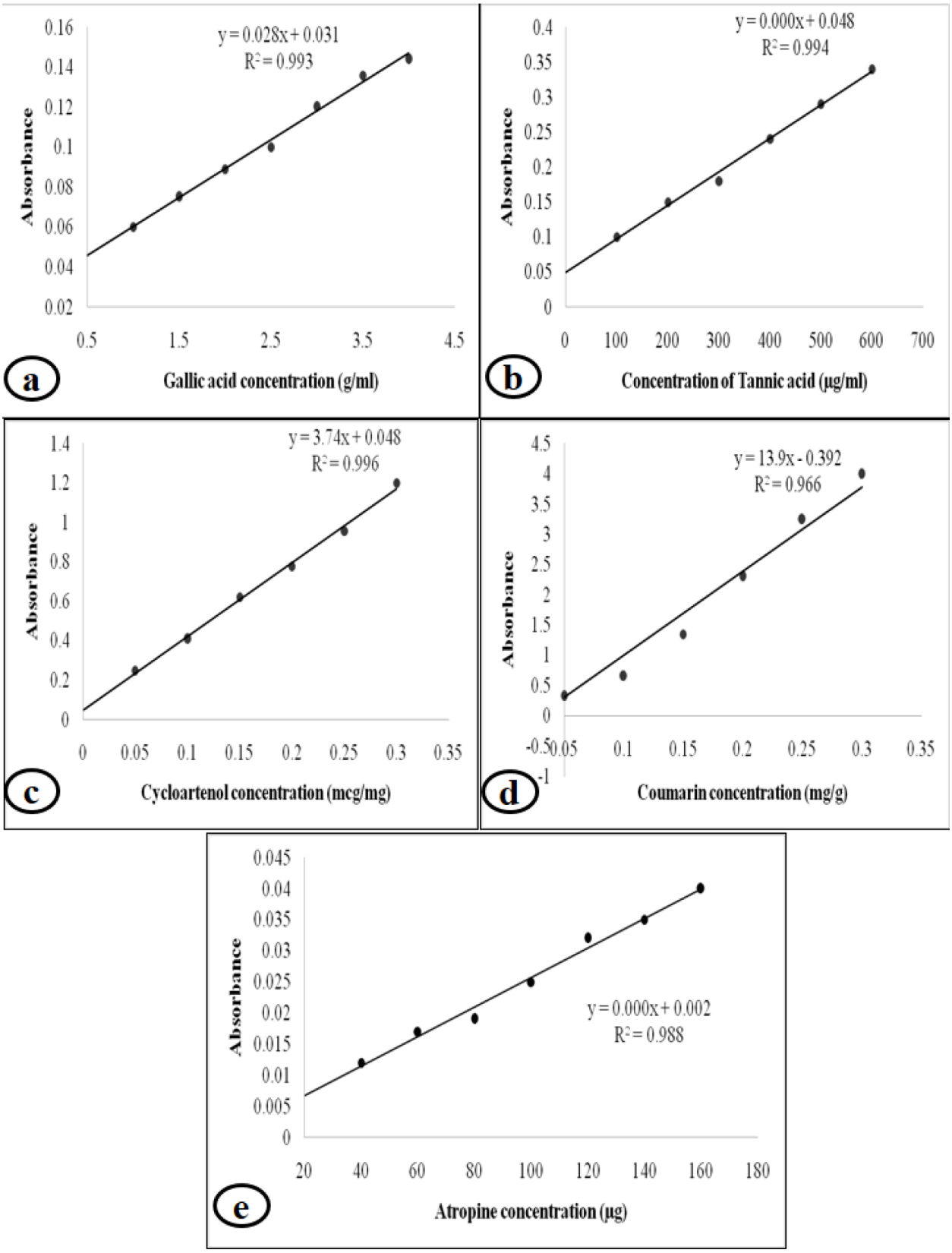


Figure 1. Standard graphs for quantification of **(a).** Gallic acid for phenols; **(b).** Tannic acid for tannins; **(c).** Cycloartenol for steroids; **(d).** Coumarins; **(e).** Atropine for alkaloids.

3.3.2 XRD

The presence of several sharp, distinct peaks, especially the strong peak at 29.65°, indicates that the sample contains crystalline phases (Table 3). From the computed sizes, we can say the crystallites are nanometric. However, the combination of (i) several distinct crystalline peaks and (ii) mixed peak widths suggests a polycrystalline nanoparticle sample with a particle size of 48.32 nm (Figure 2).

3.3.3 SEM

The scanning electron microscopy revealed that the synthesised nanoparticles possess an irregular and faceted external morphology with an average particle size of approximately 42 nm. The particles were found to be unevenly distributed. The sharp edges and crystalline texture observed in the SEM image indicate that the particles are crystalline in nature rather than amorphous. These morphological features are in good agreement with the XRD (Figure 2).

3.3.4 FTIR

The obtained FTIR showed various peaks based on the presence of different functional groups (Table 4). A broad and strong absorption peak at 3322 cm^{-1} is characteristic of O–H stretching, indicating the presence of alcohols or phenols, likely with extensive hydrogen bonding. The sharp peak at 2956 cm^{-1} corresponds to C–H stretching from alkane groups. A strong peak at 1616 cm^{-1} suggests the presence of C=C stretching, which could be from an alkene or an aromatic ring. The peaks around 1037 cm^{-1} and 1289 cm^{-1} fall within the fingerprint region and can be attributed to C–O single bond stretching, which aligns with the presence of an alcohol. The spectrum collectively suggests the compound contains a hydroxyl group, C–H bonds, and a C=C bond[29].

Table 3. XRD analysis of *J. laurifolium*

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing [Å]	Rel. Int. [%]
15.1744	75.83	0.6298	5.83874	16.08
21.3758	218.31	0.3149	4.15682	46.31
24.2776	326.36	0.2272	3.66614	69.23
29.6488	471.42	0.0984	3.01308	100.00
36.2491	48.16	0.6298	2.47817	10.22
39.7596	96.42	0.3149	2.26709	20.45
43.5731	75.28	0.2362	2.07711	15.97
47.9199	62.45	0.6298	1.89835	13.25
48.9602	58.70	0.6720	1.85889	12.45
58.0800	41.00	0.0900	1.58815	8.70

3.4 Antibacterial Activity of Leaf Extracts

The antibacterial activity of different solvent extracts was examined against selected bacterial strains, including *Klebsiella pneumoniae*, *Bacillus megaterium*, *Streptococcus mutans*, and *Xanthomonas campestris* (Table 5). The results obtained revealed the significant variations in microbial inhibition among all the solvents, indicating differences in the solubility and extraction efficiency of bioactive phytochemicals. Methanolic extracts reported inhibition zones ranging between 13–16 mm, indicating the presence of moderately polar secondary metabolites such as flavonoids, phenolics, and tannins, which are known for their broad-spectrum antibacterial potential[22,45]. The aqueous extracts showed comparatively less antibacterial activity (6–9 mm), which may be due to the limited solubility of nonpolar antibacterial compounds in water. Similar results were observed in *Jasminum officinale*[1]. In the present study, acetone extracts recorded the maximum antibacterial activity, with inhibition zones ranging from 10–18 mm. The maximum zone of inhibition, 18 mm, was observed against *Bacillus megaterium* at 150 µL. Acetone is an intermediate-polarity solvent and capable of dissolving both polar and nonpolar phytoconstituents like terpenoids and flavonoids, which may be the reason for its higher antibacterial activity[3]. The ethyl acetate extracts reported inhibition zones between 12–14 mm, suggesting its moderate antibacterial potentiality may be due to the extraction of phenolic acids and alkaloids[7]. Chloroform extracts displayed a zone of inhibition between 10–17 mm, with a notable activity against *K. pneumoniae* at 150 µL, revealing the presence of medium-polarity compounds with lipid-soluble antibacterial properties[6]. Conversely, n-hexane extracts exhibited the minimum inhibitory activity, i.e., 5–10 mm, consistent with its nonpolar nature, which basically extracts fatty acids and hydrocarbons with relatively weak antibacterial efficieny[4,5].

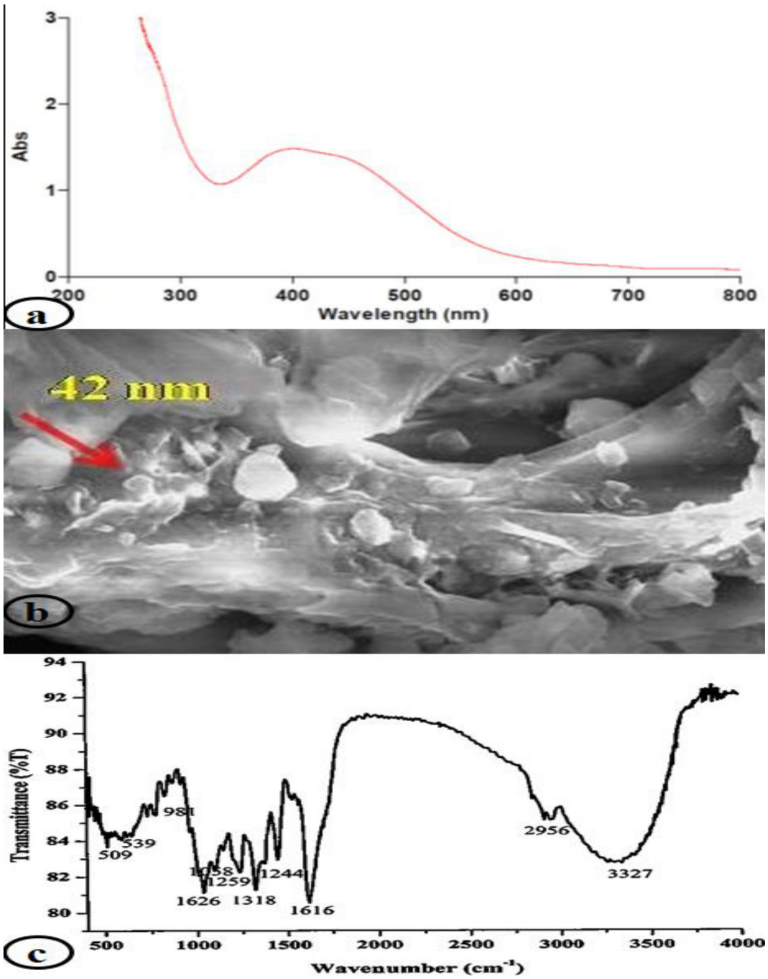


Figure 2. Characterisation of silver nanoparticles by **(a).** UV-Vis, **(b).** SEM, **(c).** FTIR.

Table 4. FTIR spectroscopy analysis of *J. laurifolium*

Peak (cm^{-1})	Functional group(s)	Stretch/secondary metabolites
3327	O–H, N–H	Broad O–H stretch (alcohols/phenols, hydrogen-bonded) and/or N–H stretch (amines, amides)
2956	aliphatic C–H (–CH_2, –CH_3)	Aliphatic C–H stretch (methyl/methylene groups) — indicates presence of aliphatics or fatty-chain fragments
1616	C=C (aromatic/alkene), C=O (amide I sometimes)	Aromatic ring C=C stretch or conjugated C=O (amide I if protein/peptide present)
1318	C–N, C–H in-plane, aromatic ring modes	Possible C–N stretching (amines) or in-plane aromatic C–H deformation
1259	C–O, C–N, aromatic C–H	C–O (aryl ether or ester) and/or C–N (amines) or substituted aromatic ring vibration
1244	C–O (ethers, esters), P=O (phosphates)	C–O stretch (ethers/esters) or possible phosphate P=O if sample is phosphorylated
1098	C–O (alcohols/ethers), P–O (phosphates)	Strong C–O stretching (alcohols/ethers/carbohydrates) or phosphate P–O stretch
781	=C–H out-of-plane, C–O (some cases)	=C–H out-of-plane bending of substituted alkenes/aromatics; skeletal vibration in heterocycles
539	C–H out-of-plane (aromatic)	Aromatic C–H out-of-plane bend-indicates substitution pattern on the aromatic ring
509	Skeletal modes, C–Br/C–Cl (rare in organics), metal-oxygen	Low-energy bending/skeletal vibration; sometimes metal–O or halide-related vibrations

Table 5. Comparative analysis of antibacterial activity (mm) in tested bacteria

Name of the Bacteria	*S. mutans*			*B. megateium*			*X. campestris*			*K. pneumonia*		
Solvent (µl)	**50**	**100**	**150**	**50**	**100**	**150**	**50**	**100**	**150**	**50**	**100**	**150**
Methanol	13±0.50	15±0.82	16±0.50	14±0.25	14±0.46	15±0.98	13±0.59	13±0.32	16±0.69	13±0.55	14±0.00	16±0.11
Aqueous	0	6±1.26	6±1.50	-	8±0.45	9±0.25	-	9±1.10	9±0.56	-	8±0.12	9±1.25
Acetone	10±2.38	12±1.92	16±1.63	15±1.96	16±1.5	18±1.6	10±0.11	12±1.12	14±0.22	11±0.39	14±1.26	16±1.56
Ethyl acetate	12±0.00	14±1.15	14±0.50		14±0.36	14±0.25		12±0.25	13±0.98	12±0.54	12±1.36	14±0.28
n-Hexane	5±0.50	5±0.50	7±0.96	6±0.99	8±0.54	9±0.00	6±2.25	6±1.33	8±1.20	6±0.66	8±0.98	9±0.39
Chloroform	10±3.00	12±2.22	14±1.50	10±1.00	12±0.28	16±1.10	10±1.14	11±0.22	14±0.25	16±0.53	16±0.68	17±1.10

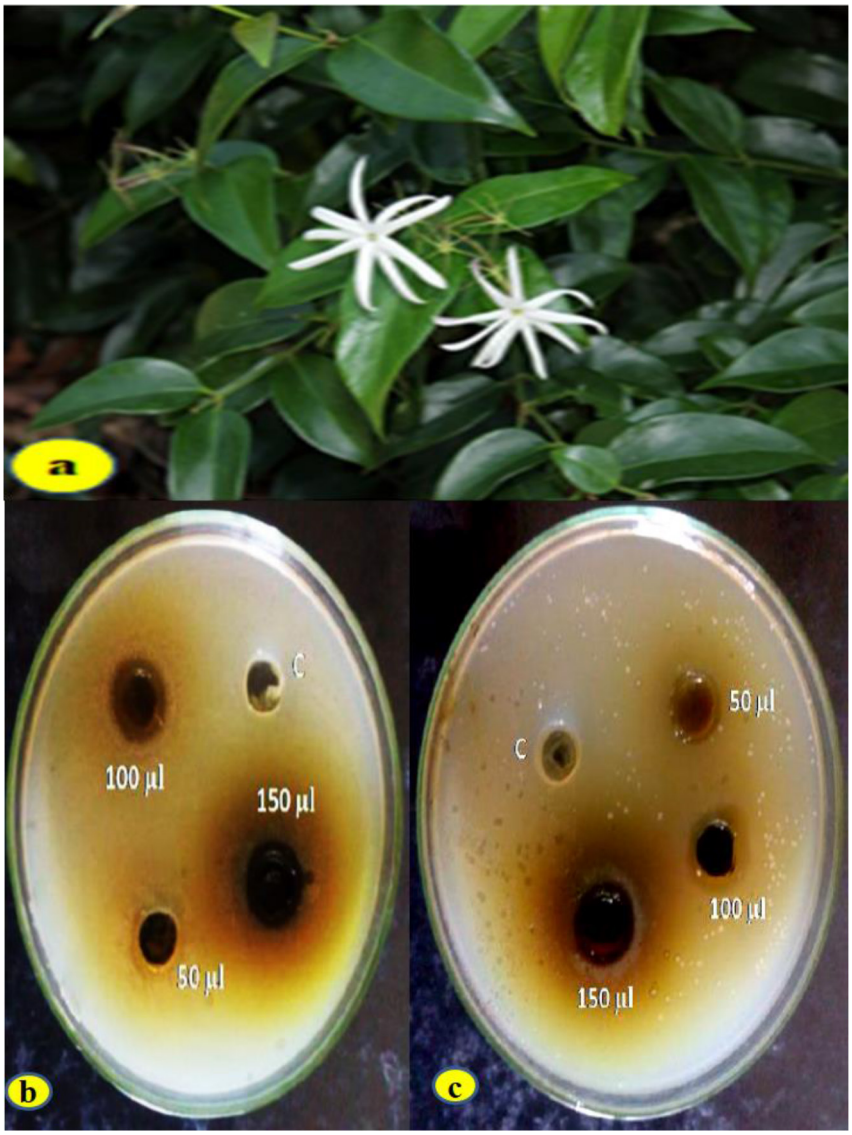


Figure 3. **(a).** Sample plant; **(b).** and **(c).** zone of inhibition in *B. megaterium* and *K. pneumoniae.*

3.5 Antibacterial Activity of Ag Nanoparticles

The antibacterial activity of green-synthesised silver nanoparticles (AgNPs) was tested against *K. pneumoniae*, *B. megaterium*, *S. mutans*, and *X. campestris*. The AgNPs showed distinct antibacterial efficacy, with a zone of inhibition ranging from 15 mm to 24 mm (Figure 3). Among the studied microorganisms, *K. pneumoniae* showed the highest sensitivity to AgNPs, with an inhibition zone of 24 mm, followed by *X. campestris* and *S. mutans* with inhibition zones of 22 mm each at 150 µL concentration (Figure 3). The highest inhibition observed against *K. pneumoniae* may be attributed to the interaction of AgNPs with bacterial cell walls and membranes, resulting in structural damage, increased membrane permeability, and subsequent leakage of intracellular components[3,7]. Furthermore, the smaller the size of the nanoparticle higher the surface area, which enhances the release of Ag^+ ions, and these interact with thiol groups of vital enzymes and DNA, leading to oxidative stress and cell death[6,2]. Noticeable antibacterial response was observed with *X. campestris* and *S. mutans,* further supports the broad-spectrum efficiency of green-synthesised AgNPs. This variation in susceptibility among bacterial species can be attributed to differences in cell wall composition, with Gram-negative bacteria exhibiting higher sensitivity due to AgNPs' affinity for lipopolysaccharide components[4,5]. Studies on green-synthesised AgNPs of *Jasminum* showed a similar trend of results, demonstrating the synergistic effect of phytochemical capping agents in improving the stability and antibacterial effectiveness of nanoparticles[12,45].

4. Conclusion

The current research on *J. laurifolium* offers substantial proof of its phytochemical abundance, efficient nanoparticle production ability, and significant antibacterial effectiveness. Qualitative and quantitative analyses indicated the existence of essential secondary metabolites. These bioactive components probably function as reducing and stabilising agents in the green synthesis of silver nanoparticles (AgNPs). The UV–Vis's absorption peak observed between 236–241 nm, along with the crystalline characteristics indicated by XRD (average particle size 48 nm), validated the successful synthesis of AgNPs. The FTIR spectra revealed the existence of hydroxyl, carbonyl, and amine functional groups, confirming the involvement of plant phytochemicals in the stabilisation of nanoparticles. The SEM micrographs additionally illustrated the uneven yet crystalline structure of the produced nanoparticles, which corresponded well with their XRD features. Antibacterial studies revealed that solvent extracts demonstrated differing inhibitory effects based on polarity, with acetone and chloroform extracts displaying enhanced antibacterial activity, due to their effective extraction of medium polarity bioactive compounds like terpenoids and flavonoids. The green-synthesised AgNPs exhibited markedly improved antibacterial activity (15–24 mm), exceeding the potency of crude extracts. *K. pneumoniae* demonstrated the greatest susceptibility (24 mm zone), followed by *X. campestris*. These results collectively emphasise *J. laurifolium* as a potential biogenic source for environmentally friendly nanoparticle production and antibacterial medication development. Additional studies combining molecular docking and in vivo testing may clarify the mechanistic pathways and clinical relevance of the synergy between phytochemicals and nanoparticles.

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Author Contribution

Babu Kakumanu, V.N.D. Rao Yenumula and M.V. V. Satyaveni designed and data developed, Nagendra Prasad Kosuri data developed and preparation of graphical abstract, Venkatesh Rampilla and Praveen Kumar Nagadesi supervised the experimental work and analyzed the data, corrected the manuscript. All authors have read and agreed to the published version of the manuscript.