

Eco-Friendly Synthesis of Silver Nanoparticles Employing *Ficus racemosa* Stem Bark Extract and Their Antimicrobial Evaluation

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Abstract

The current study concentrated on the environmentally friendly manufacture of silver nanoparticles (AgNPs) utilising *Ficus racemosa* stem bark extract. A colour shift from pale yellow to dark brown indicated the development of AgNPs, which were further examined using FTIR and UV–visible spectroscopy. During the creation of nanoparticles, phytochemicals included in the bark extract served as stabilising and reducing agents. Significant antibacterial efficacy against *Staphylococcus aureus* and *Escherichia coli* was demonstrated by the produced AgNPs. According to the study, plant-mediated AgNPs have significant antibacterial potential and may find usage in biomedical settings.

Keyword: Green synthesis, Silver nanoparticles (AgNPs), *Ficus racemosa* bark extract, Antimicrobial activity, UV–Visible spectroscopy, FTIR analysis.

1. Introduction:

The design, modification, and use of materials at the nanoscale typically between 1 and 100 nm are the focus of the multidisciplinary scientific discipline of nanotechnology [1]. The synthesis and application of chemical, physical, and biological systems with structural characteristics ranging from single atoms or molecules to submicron dimensions, as well as the integration of the resulting nanostructures into larger systems, are all included in the field of nanotechnology [2]. Nanotechnology is one of the most significant technologies of the twenty-first century [3]. Nanoparticles are extremely important in a variety of applications because of their high catalytic effectiveness, better solubility, and greater interaction with biological systems due to their small size and huge surface area [4]. Additionally, metallic nanoparticles—particularly silver

nanoparticles—have potent antibacterial qualities and are frequently utilized in infection control systems, medical device coatings, and wound dressings [5]. Nanotechnology has produced new materials with better qualities for use in industrial settings. Because of their increased strength, durability, and conductivity, nanomaterials are frequently used in coatings, textiles, electronics, and energy systems [6]. Innovative solutions to environmental problems like waste management, water contamination, and pollution are provided by nanotechnology. Because of their strong adsorption capacity and catalytic activity, nanoparticles are useful in eliminating contaminants from air and water [7]. For example, metal and metal oxide nanoparticles can remove harmful microbes from contaminated water, break down organic contaminants, and adsorb heavy metals [8]. The potent antibacterial activity of silver nanoparticles is one of its most significant features. AgNPs work well against a wide range of microorganisms, such as viruses, fungi, and both Gram-positive and Gram-negative bacteria [9]. Phytochemical substances found in plant extracts serve as natural stabilizers and/or reducing agents during the formation of AuNPs and AgNPs [10]. *Ficus racemosa* is one of the several structurally varied and physiologically active phytochemicals found in the genus *Ficus*. *Ficus glomerata*, commonly referred to as the gular or cluster fig, has been extensively studied for its noteworthy secondary metabolites. The foundation for comprehending the ancient medical applications of plants in the Ayurvedic, Siddha, and Unani systems is phytochemistry. The plant is acknowledged in these disciplines for its potential benefits in managing diabetes, protecting the liver, healing wounds, lowering fever, reducing inflammation, and fighting cancer. Nearly every part of *F. racemosa*, including its bark, stem, leaves, fruits, seeds, and latex, contains a range of primary and secondary metabolites, according to numerous phytochemical investigations. Alkaloids, glycosides, flavonoids, tannins, triterpenoids, sterols, phenolic acids, coumarins, and saponins are among them [11]. Phytochemicals are in charge of both reduction and the stability (capping) of nanoparticles. Because of their high surface energy, nanoparticles have a tendency to agglomerate after creation [12]. These phytochemicals improve the biological activity of the produced nanoparticles in addition to aiding in the reduction and stabilization processes. These substances enhance antibacterial, antioxidant, and anti-inflammatory qualities [13]. *Ficus racemosa*, a traditional natural plant, was selected to meet the study's requirements. *Ficus* belongs to the Moraceae family and is well-known for having more than 800 different species of trees, shrubs, epiphytes, and hemiphytes [14]. The genus *Ficus* is a prominent group of trees found in tropical and

subtropical areas, mainly in Asia, America, Australia, and Africa. It is significant in a variety of treatments and possesses a number of medicinal properties [15]. *Ficus religiosa*, *Ficus racemosa*, *Ficus benghalensis*, and *Ficus microcarpa* are the four species groupings of *Ficus* [16]. *Ficus racemosa*'s stem bark includes a variety of bioactive substances, including flavonoids and phenolics, which are crucial for the creation of nanoparticles [17]. *Ficus racemosa* originated in a variety of forest and hillside settings. In addition to growing naturally in forests or on hillsides near a good water source, such a pond or river, this plant can be artificially grown in rural communities for shade and delicious fruits. The leaves are 7.5–10 cm long, green, oval or elliptic, and grow in large clusters from the main trunk. The fruits are green when raw and turn orange, dull reddish, or dark crimson as they mature. These relatively tiny, plentiful, grain-like seeds number twenty-three. The roots are brownish in color and rather long. It smells strongly and has a slightly bitter flavor [18]. The bark is greyish-green, 0.51–1.80 cm thick, and has a brittle, uneven, and frequently broken surface. White papery flakes emerge from the outside surface when scratched; the inner surface is light brown, with a fibrous fracture and a mucilaginous odor [19]. In traditional medicine, *ficus racemosa* has also been widely utilized to cure a wide range of ailments. Its bark, fruits, leaves, roots, latex, and seeds are all used medicinally, often in conjunction with other plants [20]. A bark decoction is used to treat piles, ulcerative colitis, diarrhea, and dysentery. It is also used to treat diabetes and asthma. Applying latex externally to wounds speeds up healing while reducing edema, pain, and inflammation. It is often used with sugar to increase male libido and reduce diarrhea and dysentery, especially in young infants [21].

1. Materials and Methods:

1.1.1 Materials:

The main plant material for the investigation was *Ficus racemosa* stem bark. In February 2026, the bark was purchased from the Indian Institute of Technology Kanpur nursery in Uttar Pradesh, India. Pure bacterial cultures, comprising Gram-positive and Gram-negative bacteria *Escherichia coli*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, and *Bacillus subtilis*, were utilized as biological materials for antimicrobial investigations.

Nutrient agar, nutrient broth, distilled water, 70% ethanol for disinfection, acetone for extraction, and silver nitrate (AgNO_3) were among the substances utilized in this project.

1.1.5 Culture Media Preparation Materials:

Bacterial strains were cultivated and maintained using nutrient agar and nutrient broth. In accordance with the manufacturer's instructions, the media were prepared by dissolving the necessary amount in distilled water and then autoclaving them for 15 minutes at 121°C to sterilize them. Before being used, the sterilized media were allowed to harden after being chilled and aseptically transferred into sterile Petri plates within a laminar airflow environment.

1.2 Methods

1.2.1 Collection of Plant material:

Fresh *Ficus racemosa* Roxb. (Moraceae) stem bark was harvested from mature, healthy trees on the IIT Kanpur campus during active growth phase to capture representative phytochemical profiles. Bark was rinsed with distilled water to remove debris, blot-dried, shade-dried at ambient temperature for 4-5 days to constant weight, pulverized in a grinder, and sieved for uniform particle size. This preprocessing optimized extraction efficiency and minimized microbial load.

1.2.2 Preparation of Plant Extract:

Aqueous extract was obtained via hot-water extraction: 10 g powdered bark in 100 mL distilled water (1:10 w/v) heated at $60-70^\circ\text{C}$ for 10-15 min with stirring, targeting polar phytoconstituents like phenolics and flavonoids. The cooled mixture was filtered through Whatman No. 1 paper, yielding a clear extract stored at 4°C in sterile, light protected vessels. This eco-friendly method avoided organic solvents, preserving bio-reductants for nanoparticle synthesis.

1.2.3 Green synthesis of AgNPs Nanoparticles:

Silver nanoparticles (AgNPs) were biosynthesized by mixing *F. racemosa* aqueous extract (1:9 v/v) with 1 mM AgNO_3 solution under continuous stirring at room temperature in darkness, leveraging phytochemicals as bio-reductants and capping agents. Color change from pale yellow to dark brown indicated surface plasmon resonance (400-450 nm), with phenolics/flavonoids stabilizing particles against aggregation. Incubation proceeded until completion, yielding monodisperse AgNPs.

1.2.4 Characterization of Nanoparticles:

Synthesized AgNPs underwent UV-visible spectroscopy for plasmon resonance and size/shape insights, FTIR for functional group identification and capping agent confirmation, and double disk diffusion for antimicrobial profiling via inhibition zones. These orthogonal techniques correlated physicochemical properties with bioactivity.

1.2.5 Antimicrobial activity of AgNPs:

Agar well diffusion assessed AgNPs against *E. coli* and *S. aureus*: overnight nutrient broth cultures were lawn-inoculated on Mueller-Hinton agar, 6 mm wells filled with 2 mg/3 mL ethanolic AgNPs, incubated 24 h at 37°C, and zones measured (mean $\pm$ SD, n=3). Tetracycline and crude extract served as controls; AgNPs exhibited superior efficacy via membrane disruption, ROS generation, and metabolic interference. Enhanced activity underscored nanoparticle augmentation of plant antimicrobials.

2. Result and Discussion:

2.2 Formation of Silver Nanoparticles:

The synthesis of silver nanoparticles (AgNPs) using stem bark extract of *Ficus racemosa* was initially confirmed by a visible color change of the reaction mixture from pale yellow to dark brown after the addition of aqueous silver nitrate (AgNO_3). This color transition indicates the reduction of silver ions (Ag^+) into metallic silver nanoparticles and is attributed to Surface Plasmon Resonance (SPR). Phytochemicals such as flavonoids, phenolics, and tannins present in the bark extract play a significant role in the reduction and stabilization of AgNPs. The rapid appearance of the brown color suggests efficient synthesis of stable nanoparticles, consistent with previous reports on plant-mediated AgNP synthesis [22].

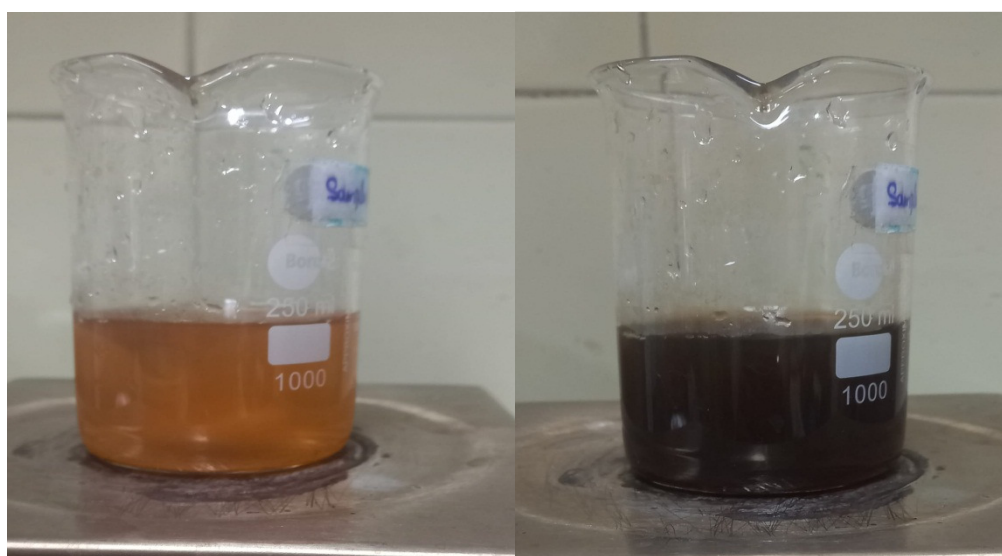
3.2 Optimization of synthesis conditions:

The synthesis conditions for silver nanoparticles (AgNPs) using stem bark extract of *Ficus racemosa* were optimized by varying silver nitrate concentration, extract concentration, temperature, and incubation time [23]. The formation of AgNPs was initially indicated by a color change from pale yellow to dark brown due to Surface Plasmon Resonance (SPR). UV-visible spectroscopy confirmed nanoparticle formation with an absorption peak at 220–340 nm [24].

Optimal synthesis was achieved at 2–3 mM AgNO_3 and 3–5% bark extract concentration, with maximum nanoparticle production observed after 20–30 min incubation at 70–80°C. Higher temperatures accelerated the reduction process and produced smaller, uniformly distributed nanoparticles. These findings demonstrate that synthesis parameters significantly influence the size, stability, and uniformity of AgNPs, in agreement with earlier plant-mediated nanoparticle studies [25].

2.3 UV- Visible Spectral Analysis:

When the aqueous silver nitrate (AgNO_3) solution was added, the reaction mixture's color changed from pale yellow to dark brown, which was the first indication that silver nanoparticles (AgNPs) had been synthesized utilizing the stem bark extract of *Ficus racemosa* [26]. This color shift shows that the phytochemicals in the bark extract are reducing silver ions (Ag^+) into metallic silver nanoparticles (Ag_0) [27]. Previous research has also documented similar UV-visible absorption peaks for green produced AgNPs, indicating successful nanoparticle production **Figure 1** [28].



(a) Initially (Before reaction)

(b) After Reaction (AgNPs Formation)

Figure.1: Visual color change observed during the green synthesis of silver nanoparticles using stem bark extract of *Ficus racemosa*

Wavelength(nm)	Absorbance
290	0.213
300	0.278
310	0.621
320	0.868
330	0.927
335	0.997
340	0.519
360	0.51
370	0.45
380	0.403

Table .1 AgNPs' UV-Visible Absorbance Data

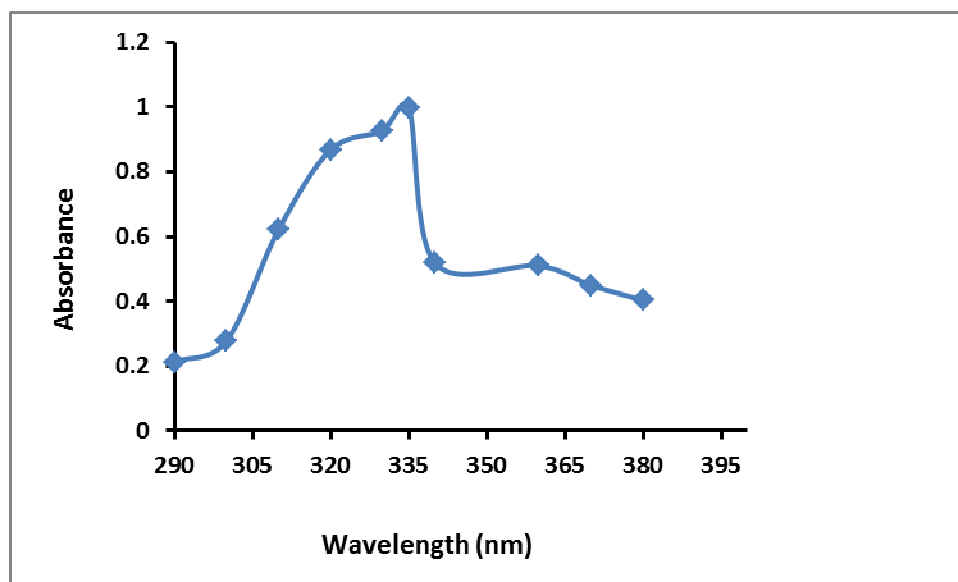


Figure 2 Synthesized AgNPs' UV-Visible Spectrum

2.4 FTIR Analysis of Synthesized AgNPs:

The functional groups involved in the reduction and stabilization of the produced silver nanoparticles (AgNPs) utilizing the stem bark extract of *Ficus racemosa* were identified using Fourier Transform Infrared (FTIR) spectroscopy [29]. The plant extract's bioactive components were represented by distinctive absorption peaks in the FTIR spectrum [30]. The existence of

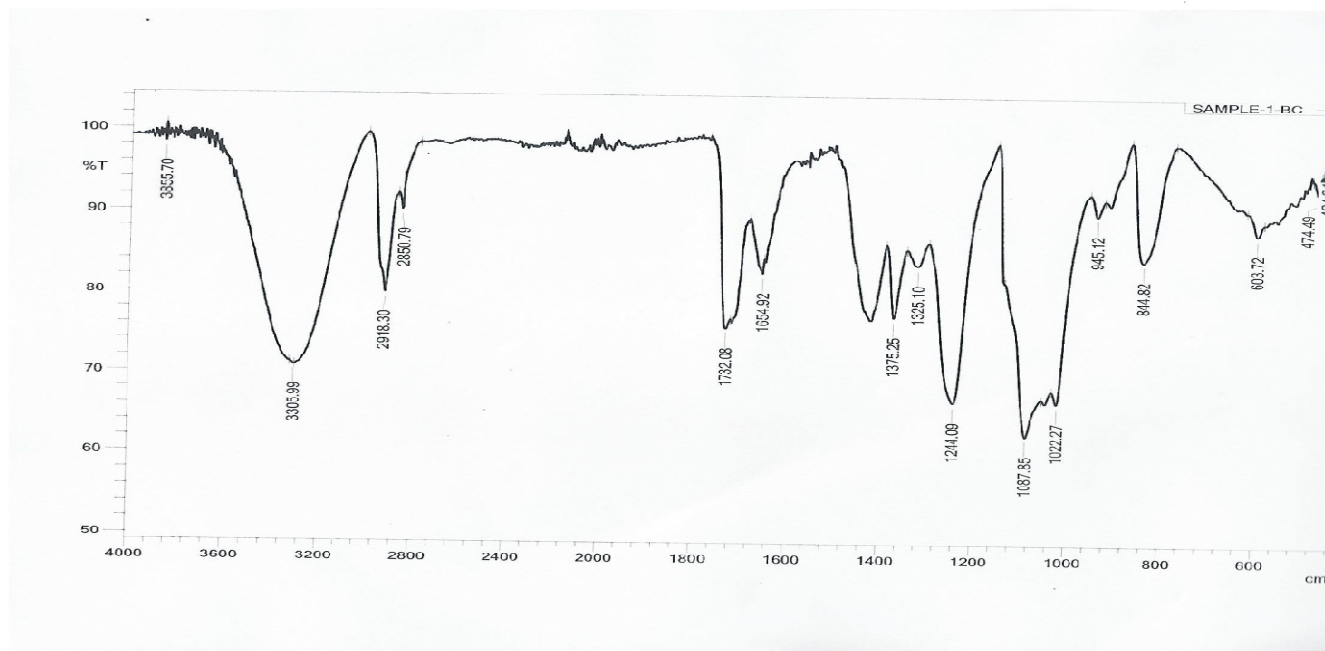


Fig 2. Synthesised AgNPs Using *Ficus racemosa* stem Bark Extract: FTIR Analysis

Flavonoids and polyphenols was confirmed by a large absorption peak around 3200–3400 cm^{-1} , which showed O–H stretching vibrations of phenolic compounds and alcohols. The C=O stretching vibrations of proteins and aromatic compounds were represented by peaks around 1600–1650 cm^{-1} , whereas the C–N stretching vibrations of amines were represented by peaks about 1380–1450 cm^{-1} [31]. Furthermore, C–O stretching vibrations of alcohols and ethers were identified as the source of absorption bands found at approximately 1000–1100 cm^{-1} . These functional groups verify that phytochemicals play a role in the bioreduction of silver ions (Ag^+) into metallic silver nanoparticles (Ag_2), which are then stabilized as capping agents. The significance of plant

biomolecules in the creation and stabilization of nanoparticles has been supported by previous research that revealed similar FTIR absorption patterns for plant-mediated produced AgNPs [32].

2.5 Antibacterial Activity of Synthesized AgNPs:

Using the double disk diffusion method, the antibacterial activity of the synthesized silver nanoparticles (AgNPs) made from *Ficus racemosa* stem bark extract was assessed against strains of Gram-positive (*Staphylococcus aureus*) and Gram-negative (*Escherichia coli*) bacteria. The distinct zones of inhibition surrounding the nanoparticle-containing disks demonstrated the strong antibacterial activity of the produced AgNPs against both bacterial species [33]. Due to variations in cell wall construction, *E. coli* was found to be more sensitive to AgNPs than *S. aureus* among the examined species [34]. AgNPs' potent antibacterial activity is primarily linked to their enormous surface area and nanoscale size, which facilitate efficient contact with microbial cell membranes [35]. Bacterial cell death can result from silver nanoparticles' disruption of membrane integrity, production of reactive oxygen species (ROS), and interference with intracellular macromolecules such as proteins and DNA shown in **Figure 3** [36].

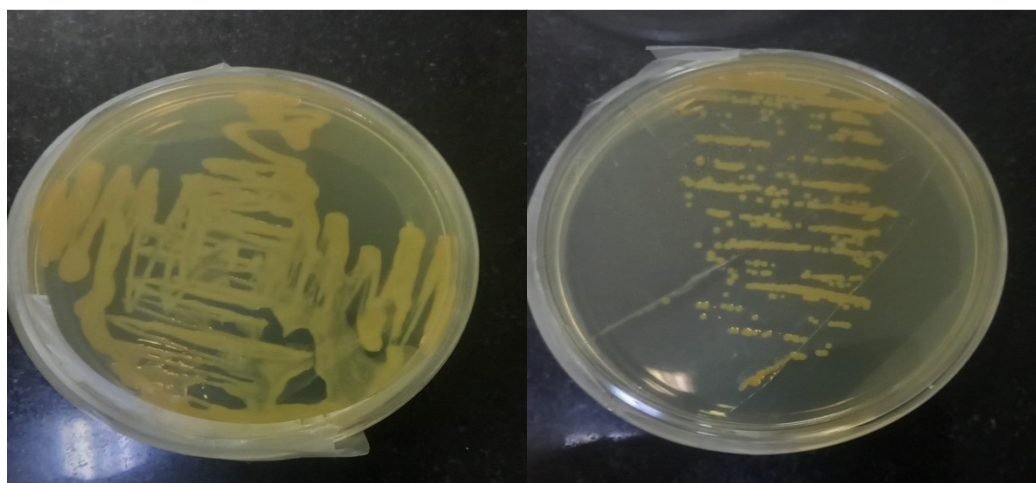


Figure.3: Antibacterial activity of synthesized silver nanoparticles against bacterial strains

2.6 Double Disk Diffusion Assay:

The double disk diffusion experiment was used to assess the antibacterial activity of the manufactured silver nanoparticles (AgNPs) made from *Ficus racemosa* stem bark extract against *Staphylococcus aureus* and *Escherichia coli*. The antibacterial activity of the produced silver

nanoparticles (AgNPs) derived from *Ficus racemosa* stem bark extract against *Staphylococcus aureus* and *Escherichia coli* was evaluated using the double disk diffusion experiment [37]. The significant antibacterial capability of the produced nanoparticles was confirmed by the clear zones of inhibition surrounding the AgNP-loaded disks. AgNPs showed improved inhibitory effect against both kinds of bacteria, but their activity against *E. coli* was relatively higher. Gram-negative bacteria may be more vulnerable because of their weaker peptidoglycan layer, which makes it simpler for nanoparticles to enter the bacterial cell membrane show in **Figure. 4** [38].

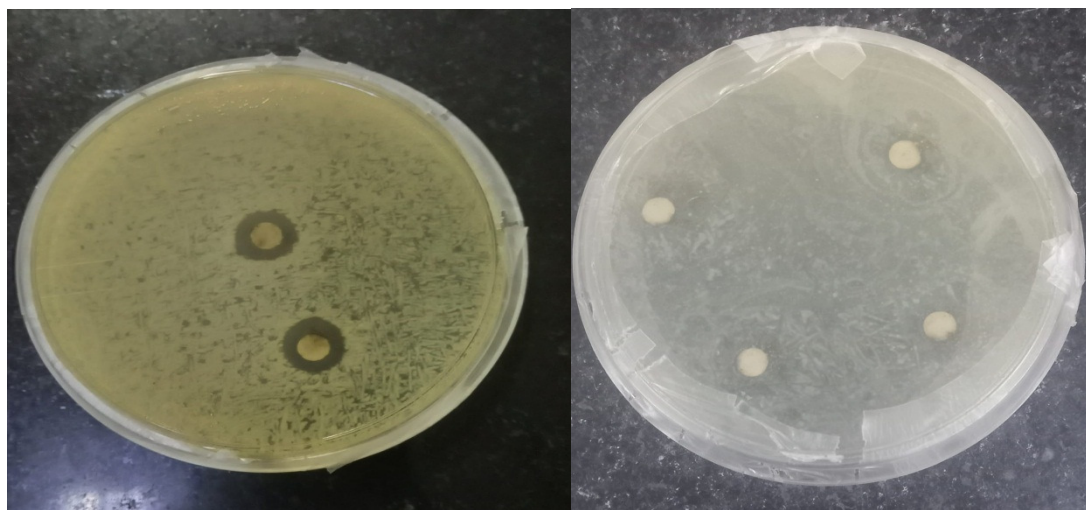


Figure.4 Double disk diffusion assay showing antibacterial activity of synthesized AgNPs

Additionally, enhanced antibacterial activity was shown when AgNPs and antibiotic disks were combined, indicating a potential synergistic interaction between silver nanoparticles and antibiotics. This combined impact could improve the absorption of antimicrobial drugs into bacterial cells and increase membrane permeability [39]. According to the findings, biosynthesized AgNPs have broad-spectrum antibacterial qualities and could be used as antimicrobial agents in biomedical settings [40].

Conclusion:

Using *Ficus racemosa* bark extract and an environmentally friendly process, the study successfully produced silver nanoparticles. The production of stable AgNPs was verified by characterisation, and the nanoparticles demonstrated potent antibacterial activity against tested

bacterial strains. These results suggest that biosynthesised AgNPs have potential uses in the biological and antibacterial domains.

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