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Green Nanotechnology synthesized silver Nanoparticles: characterization and testing its antibacterial activity

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Abstract

Developing eco-friendly strategies "for metallic nanoparticle synthesis using natural extracts has gained significant traction. This study explores the potential of Carica papaya leaf extract for the biogenic synthesis of metallic nanoparticles and evaluates their subsequent antimicrobial activity. A reduction reaction under ambient conditions, employing leaf extract, facilitated the nanoparticle formation from metal salts. Characterisation techniques encompassing UV-Vis spectroscopy, FTIR, XRD, and TEM corroborated the successful synthesis of well-dispersed, spherical nanoparticles. The presence of biomolecules within the extract was identified as crucial for both nanoparticle reduction and stabilisation, as evidenced by FTIR analysis. XRD patterns confirmed the crystalline nature of the nanoparticles, with distinct peaks corresponding to specific crystal planes. This antimicrobial efficacy is attributed to the synergistic action between the metallic nanoparticles themselves and the inherent bioactive compounds present within the Carica papaya leaf extract." In conclusion, this work presents a facile and environmentally benign approach for nanoparticle synthesis utilising Carica papaya leaf extract. The synthesised nanoparticles demonstrate promising antimicrobial properties, highlighting the potential of natural extracts for the development of novel biocompatible nanomaterials with diverse applications in the biomedical and environmental fields. Further research is warranted to elucidate the precise mechanisms underlying their antimicrobial action and explore their potential therapeutic applications.

Keywords: Metallic nanoparticles, Anti-microbial activity, Carica papaya, Microbial pathogens.

Introduction

To study the antibacterial effects of *Carica papaya* leaf extract, a significant effort is being made to produce silver nanoparticles. Medicinal plants include several bioactive substances that have been used in traditional medicine for a long time. "These compounds include alkaloids, glycosides, polyphenols, and terpenes. These chemicals have several defensive functions against various diseases and pests. While numerous methods exist for nanoparticle synthesis, the field is currently exploring a specific approach: chemical reduction of metal salts for silver nanoparticle production. This method utilizes various reducing agents, such as sodium borohydride ($NaBH_4$), hydrazine (N_2H_4), or formaldehyde, to convert silver ions from a silver salt precursor into metallic silver nanoparticles. The presence of a stabilizer plays a crucial role in this process, preventing nanoparticle aggregation and ensuring their stability. So, it's crucial to discover safe, low-cost methods to produce silver nanoparticles that won't harm the environment. A few easy steps and some everyday tools should do the trick."Using microorganisms and plants in nanoparticle synthesis is an attractive and ecologically friendly option[1].

Background of the study: Although it is "native to Mexico and Central America, the tropical fruit-bearing plant *Carica papaya* is currently grown all over the globe in tropical and subtropical climates. Papaya trees may reach a height of 10 meters in tropical regions; their big, lobed leaves and melon-like fruits are easily recognizable. Medicinal, culinary, and industrial uses abound for the culturally important and adaptable *Carica papaya* plant. Tropical places across the globe cultivate it extensively because of its nutritional richness and possible health advantages[2].

For a considerable time, it has been recognized that traditional medicine possesses the capacity to address a diverse array of illnesses. The tropical fruit tree *Carica papaya*, or simply papaya, is an American native that is extensively farmed for its fruit and its potential medical uses. The papaya tree is known for its many uses, but its leaves have recently gained popularity due to their powerful therapeutic qualities. Among the bioactive components that contribute to the medicinal benefits of *Carica papaya* leaf extract include essential oils, phenolic compounds, alkaloids, and flavonoids. Papaya leaf extract has shown antibacterial effectiveness against many pathogens, including viruses, fungi, and bacteria, according to multiple investigations[3].

The wide variety of bioactive chemicals found in natural goods, especially plant extracts, and their antimicrobial capabilities have been known for quite some time. The exceptional physicochemical characteristics of silver nanoparticles, also known as AgNPs, have made them a potential antimicrobial agent. Silver nanoparticles with improved biocompatibility and therapeutic effectiveness may be synthesized with the help of plant extracts, which function as decreasing, capping, and stabilizing agents[4].

A “number of research have documented the manufacture of silver nanoparticles utilizing extracts from plants, notably the leaves of the *Carica papaya* plant, and have tested these nanoparticles for antibacterial efficacy against various bacteria and viruses. The researchers were unable to find any studies that looked at the anti-dengue properties of silver nanoparticles made from *Carica papaya* leaf extract. Background information from the research supports the idea that silver nanoparticles and *Carica papaya* leaf extract might be a powerful antibacterial combination. The goal of this research is to help find long-term solutions to the problem of antibiotic resistance by investigating the connection between the composition of extracts, the creation of nanoparticles, and their antibacterial efficacy[5].

Purpose of the study: This “research intends to contribute to the development of antimicrobial agents that are both sustainable and effective. This will be accomplished by utilizing the probable of natural extracts for the blend of metallic nanoparticles, with a particular emphasis on *Carica papaya* leaf extract. Additionally, the research will investigate the applications of these nanoparticles in the fields of biomedicine and environmental science.

Literature Review: An effective”bio-reductant use is the use of *Carica papaya* latex extract, derived from a crop with large commercial output, in the manufacture of very stable silver nanoparticles (CPAgNPs). The first noticeable sign of a decrease is a shift in colour from light brown to dark brown. The presence of silver nanoparticles, as seen by UV-visible spectroscopy with their unique peaks at 410 nm, provides further evidence of this transformation. The images captured by a high-resolution transmission electron microscope (HRTEM) show that CPAgNPs are polydisperse and spherical, with an average size of 12 ± 6 millimetres in the nanometer range[6].

In addition, CPAgNPs have been shown to possess considerable antibacterial action against a wide range of human pathogens, including as bacteria such as bacteria such as *Escherichia coli, among others. Vibrio cholera, Klebsiella pneumoniae, and Proteus mirabilis*[7].

Furthermore, “the exceptional chemotherapeutic potential of these nanoparticles has been shown by in vitro anticancer tests that were carried out on the human breast carcinoma cell line (MCF-7). The synthesized CPAgNPs demonstrate anticancer effects that are dependent on the dosage, with an IC50 value of 19.88 µg/ml. This indicates that they have the potential to play a significant role in the development of nano-drug formulations for the treatment of infections caused by bacteria and breast cancer chemotherapy[8].

Research questions: i. What is the green synthesis of silver nanoparticles using various concentrations of *Carica papaya* leaf extract as the reducing agent? ii. How to examine the antimicrobial against various bacterial strains, i.e., *E. coli* and *S. aureus* etc.

Methodology

Figure-1: Conceptual Framework.

Hypothesis: According to the findings of the current study, the fruit of the *Carica papaya* tree contains phytochemicals and other components that possess antibacterial characteristics. Flavonoids are plant chemicals that have antibacterial and antioxidant characteristics. “Flavonoids may be found in papaya fruit. Flavonoids, such as quercetin and kaempferol, which are found in papaya, have antibacterial characteristics and have the potential to protect against a broad range of microorganisms. Tannins and phenolic acids are two of the polyphenolic chemicals that have been found in papaya throughout the years. The antibacterial properties of these chemicals, in particular their ability to combat bacteria, have recently been the subject of much investigation. Extensive research is currently being conducted to investigate the mechanisms of action of these compounds, as well as their prospective use in the fields of food preservation, medicine, and personal care products[9].

An important link between antibacterial action, silver nanoparticles, and *Carica papaya* leaf extract is postulated in the theory. This study aims to provide evidence that silver nanoparticles generated using *Carica papaya* leaf extract have better antibacterial capabilities than those manufactured using more traditional techniques. This process guarantees that the nanoparticles incorporate the extract's bioactive components, which may increase their antibacterial efficacy[10].

Nanoparticles of silver have inherent antibacterial characteristics because of their tiny size, large surface area, and capacity for dispensing silver ions. Nanoparticles can suppress microbial development by interfering with biological processes, inducing oxidative stress, and disrupting microbial membranes. Based on these findings, it seems that nanoparticle production using natural extracts might be a promising avenue for the discovery of new antimicrobial agents with potential uses in environmental research, biotechnology, and medicine[11].

Based on the above discussion, the researcher formulated the following hypothesis, which will investigate the relationship between Antimicrobial properties and *Carica papaya* leaf extract combined with silver nanoparticles.

H_{01}: There is no significant relationship between Antimicrobial properties and Carica papaya leaves extract combined with silver nanoparticles.
H_1: There is a significant relationship between Antimicrobial properties and Carica papaya leaves extract combined with silver nanoparticles.

Research design: Collection: The study involved the utilization of laboratory-grade silver nitrate and *Carica papaya* plant extract as the substances. Various reagents and other substances of laboratory quality were employed in the experiment.

Microorganisms Used: The bacteria, including *Staphylococcus aureus*, *Escherichia coli*, *Bacillus subtilis*, *and Pseudomonas aeruginosa*, were isolated from the Microbiology Postgraduate laboratory at the University. To obtain pure cultures, the bacteria were sub-cultured multiple times.

Active constituents and synthesis mechanisms of silver nanoparticles: The antioxidant phenolic compounds found in papaya leaves are one of many phytochemicals found in the fruit. Because of its two primary physiologically active components, chymopapain and papain, *Carica papaya* is often used to treat gastrointestinal ailments. Papain, caricain, chymopain, and glycerine endopeptidase are all derived from *Carica papaya*, which may make pepsin more amenable to hydrolysis in acidic situations. The insoluble crude papain, hydrolase, and active components lipase (CPL) are all found in *Carica papaya*. What is called naturally immobilized biocatalysts are these magical little creatures. The riboflavin-rich papaya leaf extracts contribute to the synthesis of the bound co-enzymes flavin mononucleotide (FMN) and flavin adenine dinucleotide (FAD), which in turn catalyze several reduction and oxidation processes.

Preparation of silver nanoparticles: “A solution of 5 millilitres of filtered bio leaves and a solution of pure aqueous silver nitrate are combined and agitated for one hour to produce silver nanoparticles from silver nitrate. The solution's coloursvary from yellow to brownish-yellow to deep brown when Ag+ nanoparticles are reduced to AgO; the specific shade depends on the investigated factors, such as the concentration of the extract. When the silver nanoparticles become brown, it means the synthesis is complete. Altering the concentration of an extract from *Carica papaya* leaves yields silver nanoparticles.

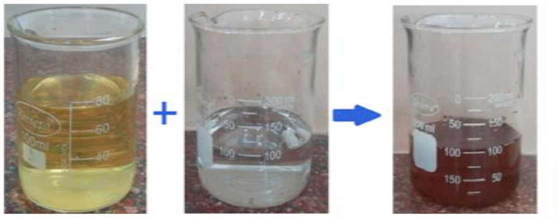

Figure-2: Preparation of silver nanoparticles.

Visible observation: shows a combination of silver nanoparticles derived from papaya leaf extracts in various volumes (5 ml, 10 ml, 15 ml, 20 ml, and 25 ml). As seen, the reaction mixture's colour changes after one hour depending on the proportion of *Carica papaya* leaf extract. An increase in the concentration of papaya leaf extract from 5 ml to 25 ml causes the reaction mixture to take on a reddish-brown hue.

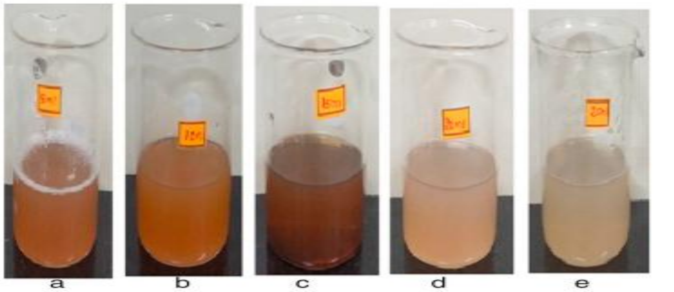

Figure-3: Silver nanoparticles using (a) 5 ml, (b) 10 ml,(c) 15 ml, (d) 20 ml, € 25 ml of Carica papaya leaves extract after 1 h of incubation.

The deepest, darkest shade is achieved with a 15 ml concentration of papaya leaf extract. When the extract concentration drops to 20–25ml, the hue becomes hardly noticeable, almost like a faint brown. A deeper brown colouration of the reaction mixtures occurred at a papaya leaf extract concentration of 15ml, indicating an increase in the number of silver nanoparticles. When the concentration of papaya leaf extract goes above 15ml, the reaction mixtures become a pale brown hue, which means that the number of silver nanoparticles has decreased. Agglomeration of the generated silver nanoparticles occurs at higher concentrations of papaya leaf extract.

Aggregating silver nanoparticles reduces their stability. More and more silver nanoparticles are being produced as the reaction time increases exponentially,” as shown by the reaction mixes becoming a darker shade of brown.

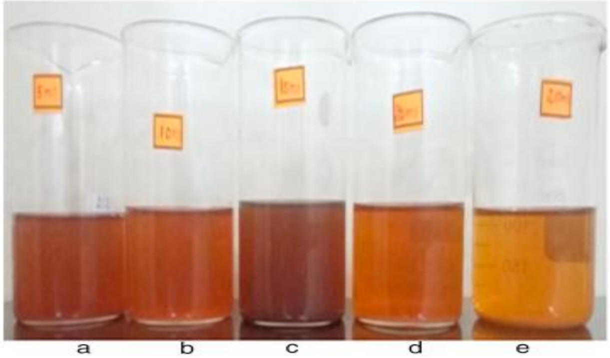

Figure-4: Visible observation of silver nanoparticles using (a) 5ml, (b) 10ml, (c) 15ml, (d) 20ml, (e) 25ml of papaya leaves extract after 24 h of incubation.

UV–visible spectral analysis: After a day of incubation at room temperature, the UV-visible absorption spectra of silver nanoparticles at five different concentrations (5, 10, 15, 20, and 25 ml respectively) are shown. The absorbance (or surface plasmon resonance) band is seen at 410, 420, 435, 422, and 418 nm respectively for 5, 10, 15, 20, and 25 ml concentrations respectively of silver nanoparticles facilitated by papaya leaves. When the papaya leaf extract concentration is 15 ml, the SPR peak is 435 nm, and when the concentration is 25 ml, it is 418 nm, the weakest peak.

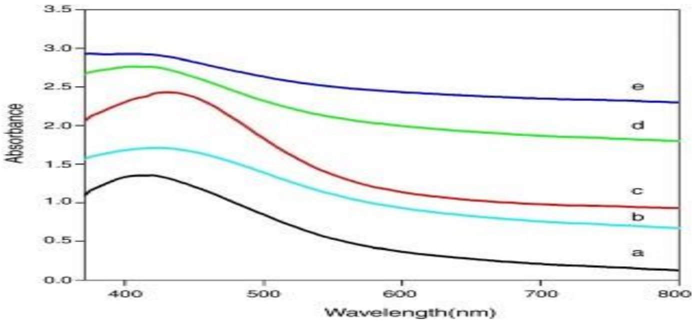

Figure-5: UV-visible spectra of silver nanoparticles using (a) 5ml, (b) 10ml, (c) 15ml, (d) 20ml, (e) 25ml of papaya leaves extract.

Additionally, the redshift occurs as a result of an increase in the AgNPs absorption peak wavelength, which occurs when the intensity of" papaya leaf extract rises from 5 to 15 ml. This instance demonstrates that the average diameter of silver nanoparticles is increasing with time, as seen by the redshift. Twenty and twenty-five-millilitre concentrations of papaya leaf extract also show a blue shift, which is associated with a reduction in the absorption wavelength of AgNPs. The steady reduction of the mean diameter of the silver nanoparticles is emphasized by this transition to blue. At each concentration, the researcher presented the optical band gap value of the *Carica papaya* leaf extract. As the concentration of papaya leaf extract drops from 5 to 15 ml, the energy band gap drops and particle size goes up. Results from the XRD examination are in agreement with the fact that the optical band gap rises at concentrations of 20 and 25 ml of papaya leaf extract, respectively. This establishes, beyond a shadow of a doubt, that the concentrated silver nanoparticles are much smaller.

Table-1: Optical band gap value of silver nanoparticles.

Sample	Optical Band Gap (ev)
5 ml	4.9
10 ml	4.7
15 ml	4.6
20 ml	4.7
25 ml	4.8

Time-dependent UV–visible spectral analysis: The ultraviolet-visible spectra of silver nanoparticles collected from papaya leaf extract at five, ten, fifteen, twenty, and twenty-five millilitres are shown in the Figure-1,2,3. Changes occur in the spectrum throughout time. Following the beginning of the reaction, the UV-visible spectra of silver nanoparticles are collected at 0, 15, 30, 45, 60, and 24 hours. While the reaction mixture is being incubated, the absorbance spectra that include surface resonance show that there is a consistent increase. The band of plasmon resonance. Because there is less creation of silver nanoparticles in the reaction mixture, the absorption peak intensity is decreased when the reaction time is lowered to 0 minutes. "This is because the reaction duration is shortened. The absorption peak strength rises across all dosages of papaya leaf extract as the response time increases from 0 to 60 minutes. This growth in absorption peak strength indicates that the combination contains an increasing concentration of silver nanoparticles. All of the reaction mixtures have produced silver nanoparticles when the absorption peak "intensity reaches its maximum after twenty-four hours of incubation" from the beginning of the reaction. This indicates that the overall reaction has been successful.

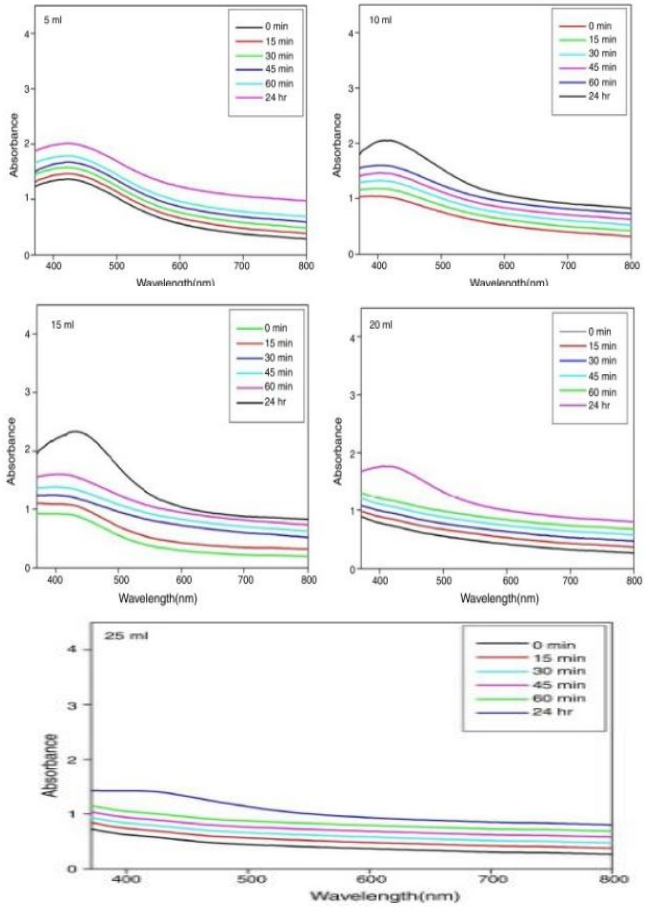

Figure-6: Time-dependent UV-visible spectra of silver nanoparticles using (a) 5 ml, (b) 10 ml, (c) 15 ml, (d) 20 ml, and (e) 25 ml concentration of leaves extract.

FT-IR analysis: At five,” ten, fifteen, twenty, and twenty-five millilitres, the spectra of silver nanoparticles in papaya leaves extract are seen here, shifting over time. At 0,15,30,45,60, and 24 hours post-procedure, you may collect the UV-visible spectra of the silver nanoparticles. With time spent incubating the reaction mixture, the surface resonance absorbance spectra become more pronounced. The radiation spectrum of plasma. There are fewer silver nanoparticles extracted from the reaction mixture at the zero-minute mark because the absorption peak strength is lower. The absorption peak intensity for all dosages of papaya leaf extract grows as the response time rises from 0 to 60 minutes, revealing the concentration of silver nanoparticles in the mixture. At the end of the first day of incubation, the absorption peak intensity is at its highest, indicating that all of the reaction mixtures have successfully created silver nanoparticles.

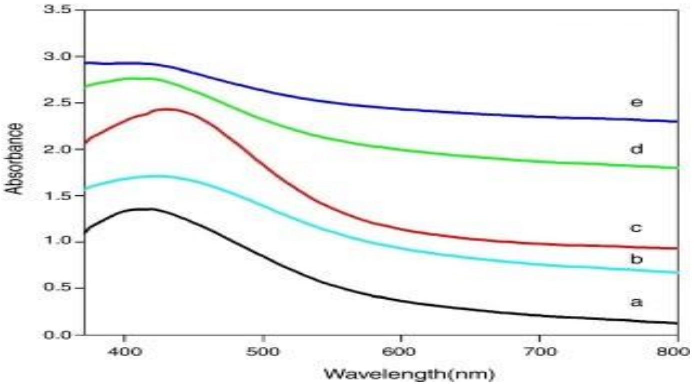

Figure-7: FT-IR spectrum of papaya leaves extract.

Displays the Fourier transform infrared (FT-IR) spectra of silver nanoparticles (AgNPs) used to mediate the extract of *Carica papaya* leaves at a variety of concentrations (5ml, 10ml, 15ml, 20 ml, and 25 ml). Around 700-750 cm–^{1}, 950-980cm–^{1}, 1000-1150cm–^{1}, 1200-1300cm–^{1}, 1330-1370cm–^{1}, 1500-1550cm–^{1}, 1600-1650cm–^{1} and 3100-3400cm–^{1} are the typical absorption bands seen in the FT-IR spectra. According to Khalil et al. (2014)[12], the bands seen at around 700-750cm−1 might be caused by the stretching vibrations of C-Cl alkyl halides”. The bands seen at 950-980cm–^{1} may be caused by the bending vibrations of alkenes with a double bond C-H group. The stretching vibrations of carboxylic acids might be responsible for the absorption band seen between 1000 and 1150cm–^{1}. The N-H bend amines are linked to the bands about 1200-1300cm–^{1}.

The bands seen between 1330 and 1370cm−1 could be a result of the C-N stretch amine group. Nitro compounds with an N-O asymmetric stretch are shown by the bands that circle 1500–1550 cm–^{1}. According to research the bands seen between 1600 and 1650 MHz might be associated with the stretching vibrations of both primary and secondary amines. The stretching of carboxylic acids' C-double bonds might be responsible for the bands seen at 3100-3400cm–^{1}.

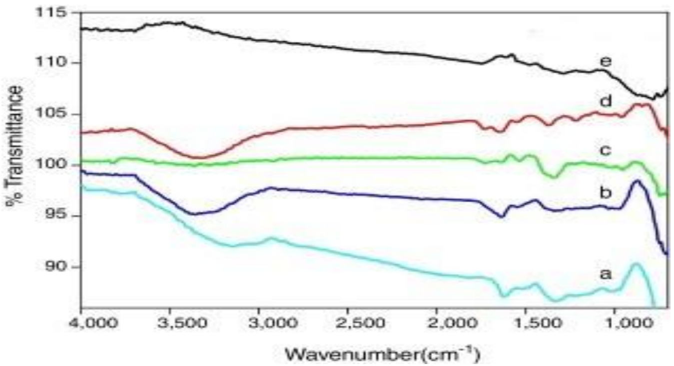

Figure-8: FT-IR spectra of silver nanoparticles using (a) 5ml, (b) 10ml, (c) 15ml, (d) 20ml, (e) 25ml of papaya leaves extract.

SEM Analysis: The surface morphology and morphologies of silver nanoparticles are studied by scanning electron microscopy (SEM) research. Silver nanoparticles generated with 5ml, 10ml, 15ml, 20ml, and 25ml concentrations of *Carica papaya* peel broth are shown in SEM pictures of different magnifications in Figure-9 (a-e). As the concentration of the extract changes, the size and form of the silver nanoparticles, which are shown to be spherical, are also altered. There are no aggregations and the particles are evenly dispersed in 5–15ml of peel extract. Figure-9 (d-e) shows that at a papaya extract concentration of more than 15ml, the particles clump together. Particle aggregation causes silver nanoparticles” to become unstable.

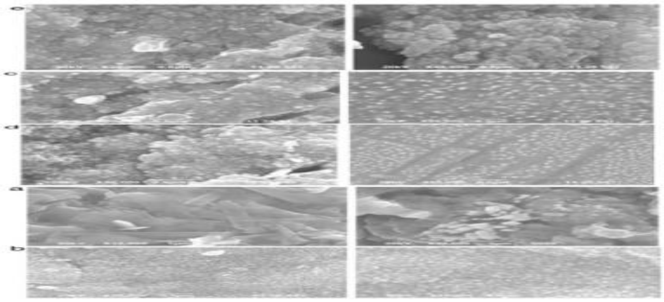

Figure-9: SEM images of silver nanoparticles using (a) 5ml, (b) 10ml, (c) 15ml, (d) 20ml, (e) 25ml of papaya leaves extract.

Plant Materials Collection and Processing: Fresh *Carica papaya* leaves were obtained separately from a nearby farm. The University Department of Pharmacognosy and Natural Medicine was tasked with identifying and authenticating the plant species. To eliminate any dust or debris that might have accumulated on the plant leaves, they were vigorously rinsed with tap water. After the dust removal process, the leaves were allowed to dry in the shade for an entire day. The subsequent step involved using an electric blender to pulverize the dried leaves.

Figure-10: *Carica papaya* leaves.

Data Analysis: Extraction Procedure: Fifty grams of powdered plant material was placed in a 500mL conical flask, and 250mL of distilled water was added. The flask was covered with aluminium foil and shaken continuously at 150 rpm for 24 hours on a reciprocating shaker to ensure thorough mixing.

Subsequently, the extract was filtered using muslin cloth and Whatman no. 1 filter paper. The resulting solution was utilized for nanoparticle synthesis.

Synthesis of "Silver Nanoparticles Using Aqueous Extracts of *Carica papaya* (Leaves) with Model Drug: A 10 mL solution of 1% silver nitrate ($AgNO_3$) was prepared by dissolving 0.1 g of $AgNO_3$ in 10 mL of water. Subsequently, 5 mL of the extract was added drop by drop under constant stirring using a magnetic stirrer for 5 minutes to create an [Ag]+ dispersion. Following this, a 25 mL portion of freshly prepared *Carica papaya* leaf extract (acting as a reducing agent) was added to the mixture, which was then maintained at 40˚C for 24 hours. The resulting silver nanoparticle" suspension was lyophilized using a Vertis 2KBTXL-75 Benchtop SLC Freeze Dryer for further analysis.

Characterization of Silver Nano-Composites: UV-VIS spectroscopy was utilized to ascertain the Surface Plasmon Resonance (SPR) characteristic of the synthesized silver nanoparticles.

Antimicrobial Studies of *Carica* Silver-Nanocomposites: Using the agar well diffusion technique described by Okeke et al.[13], 2021, the antibacterial activity of silver nanoparticles biosynthesised from *Carica papaya* leaf extract was tested.

A sterile bench hockey stick was used to aseptically disseminate 0.1 ml of each organism across the surface of the Muller-Hinton agar plate. "The plates were allowed to sit on the bench for half an hour so they could pre-disperse into the medium. To puncture the agar plates, a sterile cock borer measuring 5mm was used. Concentrations of silver nanoparticles were ranked from 100mg/ml to 500mg/ml. For each diluted silver nanoparticle, about half a millilitre was added to the agar wells created in the Muller-Hinton agar plates. After an hour of standing, the plates were given another chance to let the extract permeate the medium. Used 1% silver nitrate as the control. Plates were kept at 37˚C for a period of 24 to 48 hours for incubation. By measuring the inhibition zone width in cm, the antimicrobial activity of the silver nanoparticles and the control against microbiological isolates was assessed. To find the minimum inhibitory doses, various quantities of 200mg/ml, 100 mg/ml, 50mg/ml, and 25mg/ml with the medium were combined. Then, streaked the organisms onto the plates and incubated them for 24 hours at 37˚C. To determine the minimal inhibitory concentration, the streaking line representing the lowest concentration of silver nanoparticles that did not cause growth" was seen on the plate.

Results and Discussion

Table-2 displays the outcomes of the nanoparticle characterisation process. Similarly, the findings of the antibacterial activity of the produced silver nanoparticles are presented in Table-3 and 4.

Antimicrobial Studies: Both Gram-positive and Gram-negative bacteria were tested for the antibacterial activity of silver nanoparticles and were effectively inhibited by the produced silver nanoparticles. There is evidence that silver can kill germs. Infections were treated with diluted silver nitrate solutions as early as the nineteenth century. For that reason, the study's control system consisted of a "silver nitrate solution.

The Table-2 outlines the quantities of distilled water, $AgNO_3$, and *Carica papaya* leaf extract used in the synthesis process, along with the observed colour change and the surface plasmon resonance (SPR) peak wavelength of the resulting silver nanoparticles. The table below illustrates the zones of inhibition observed for each microorganism when treated with both the control (silver nitrate solution) and the *Carica papaya* silver Nano-composite.

Table-2: SPR bands of silver nanoparticles characterization.

Distilled Water (mL)	$AgNO_3$(g)	Reducing Agent (*Carica papaya* leaf Extract) (mL)	Color	SPR Peak Change (nm)
10	0.1	5	Reddish Brown	435

Table-3: Antimicrobial activities of nanoparticles synthesized.

Microorganism	Zone of Inhibition (CM)	
	Control (Silver Nitrate)	*Carica Papaya* Silver Nani-composite
Pseudomonas aeruginosa	1.0	1.5
Escherichia coli	1.5	1.5
Bacillus subtilis	1.5	1.5
Staphylococusaureus	1.2	1.3

Table-4: Minimum inhibitory concentrations of Carica papaya silver nano-composites.

Microorganism	Minimum inhibitory Concentrations (mg/ml)	
Control (Silver Nitrate)	Control (Silver Nitrate)	*Carica Papaya* Silver Nani-composite
Pseudomonas aeruginosa	100 (mg/ml)	25 (mg/ml)
Escherichia coli	100 (mg/ml)	50 (mg/ml)
Bacillus subtilis	100 (mg/ml)	100 (mg/ml)
Staphylococusaureus	100 (mg/ml)	100 (mg/ml)

Table-4 illustrates “the minimum inhibitory concentrations required inhibiting the growth of each microorganism when treated with both the control (silver nitrate solution) and the *Carica papaya* silver Nano-composite.

Agar plate inhibition zones of 1.5cm for Pseudomonas aeruginosa, 1.5cm for *Escherichia coli*, 1.5cm for *Bacillus subtilis*, and 1.3 cm for *Staphylococcus aureus* demonstrated the antibacterial activity of the extract. Silver nanoparticles had a minimum inhibitory concentration (MIC) ranging from 25 to 100mg/ml. The most sensitive bacteria, *Pseudomonas aeruginosa*, had a MIC of 25mg/ml, while the least sensitive, *Staphylococcus aureus* and *Bacillus subtilis*, showed the least sensitivity. Based on the research and findings, silver nanoparticles made from *Carica papaya* were effective against the four pathogen strains tested: *Pseudomonas aeruginosa*, *Escherichia coli*, *Bacillus subtilis*, and *Staphylococcus aureus*.

Discussion: The discussion surrounding the rapid biosynthesis of silver nanoparticles using *Carica papaya* leaf extract encompasses several key aspects, including the synthesis process, characterization of nanoparticles, their antimicrobial properties, and potential applications.

Synthesis Process: The utilization “of *Carica papaya* leaf extract for the biosynthesis of silver nanoparticles offers a green and sustainable approach. The bioactive compounds present in the leaf extract act as reducing and capping agents, facilitating the reduction of silver ions to nanoparticles. This method presents several advantages, including simplicity, cost-effectiveness, and eco-friendliness compared to conventional chemical synthesis methods.

Characterization of Nanoparticles: The synthesized “silver nanoparticles undergo rigorous characterization to confirm their formation and assess their properties. Techniques such as UV-Vis spectroscopy provide valuable insights into the optical properties of nanoparticles, with a characteristic absorption peak observed at 435nm due to the Surface Plasmon Resonance (SPR) phenomenon. Additional characterization methods, including TEM imaging, XRD analysis, and FTIR spectroscopy, can further elucidate the size, shape, crystallinity, and chemical composition of nanoparticles.

Antimicrobial Properties: One of the most “significant aspects of the discussion revolves around the antimicrobial efficacy of the synthesized silver nanoparticles. The nanoparticles exhibit potent antimicrobial activity against a variety of pathogenic microorganisms, including bacteria such as *Pseudomonas aeruginosa*, *Escherichia coli*, *Bacillus subtilis*, and *Staphylococcus aureus*. Overall, the discussion on the” synthesis, characterization, antimicrobial properties, and potential applications of *Carica papaya* silver nanoparticles underscores their significance as a promising antimicrobial agent with diverse biomedical and environmental applications[14].

Conclusion

The swift and efficient “biosynthesis of silver nanoparticles using *Carica papaya* leaf extract presents a compelling avenue for synthesis, offering a method that is both cost-effective and environmentally friendly. A notable hallmark of this synthesis process is the distinct change in colour observed, transitioning from a colourless solution to a reddish-brown hue, indicative of the presence of silver nanoparticles. Moreover, the “synthesized nanoparticles were subjected to rigorous evaluation for their antimicrobial efficacy against a spectrum of microbial strains, including *Pseudomonas aeruginosa, Escherichia coli, Bacillus subtilis, and Staphylococcus aureus.* Encouragingly, the synthesized nanoparticles exhibited substantial inhibitory effects against all four mentioned microorganisms, signifying their potential as antimicrobial agents. Among the tested strains, *Pseudomonas aeruginosa* displayed the highest sensitivity to the nanoparticles,” suggesting their promising antimicrobial activity across a range of pathogens[15].

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