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Development of Herbal Nano-Finished Cotton Fabric Using *Azadirachta indica* and *Ocimum basilicum* Extracts for Antioxidant, Antimicrobial, and Skin Therapeutic Applications

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KEYWORDS

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ABSTRACT:

The development of eco-friendly antimicrobial textiles has gained significant attention due to the increasing demand for sustainable healthcare materials. The present study investigates the green synthesis of silver nanoparticles using leaf extracts of Azadirachta indica (Neem) and Ocimum basilicum (Sweet Basil) and their application in cotton fabric to produce functional medical textiles. Phytochemical screening of the plant extracts confirmed the presence of various bioactive compounds such as phenols, flavonoids, tannins, alkaloids, glycosides, and terpenoids, which play a key role in the reduction and stabilization of silver nanoparticles. The formation of nanoparticles was initially indicated by a visible color change and further confirmed through UV–Visible spectroscopy, showing a characteristic absorption peak at 470.9 nm. Structural and compositional characterization using FT-IR, SEM, EDX, and XRD analyses confirmed the morphology, elemental composition, and crystalline nature of the synthesized nanoparticles. The antioxidant potential evaluated using the DPPH assay revealed concentration-dependent free radical scavenging activity. Furthermore, the nanoparticle-coated cotton fabric demonstrated effective antibacterial activity against Staphylococcus aureus and Streptococcus pyogenes. Physical tests including stiffness, crease recovery, abrasion resistance, yarn count, and thickness indicated that the nanosynthesis treatment preserved the structural integrity and durability of the cotton fabric. Overall, the study highlights the potential of plant-mediated silver nanoparticles as a sustainable approach for developing multifunctional antimicrobial textiles with promising applications in medical and healthcare sectors.

Journal of Chemical Health Risks
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1. Introduction

The growing demand for sustainable and functional textiles has led to increasing interest in the development of antimicrobial fabrics for healthcare and biomedical applications. Conventional textile finishing methods often rely on synthetic chemicals that may cause environmental pollution and potential health hazards. As a result, eco-friendly alternatives based on plant-derived bioactive compounds and nanotechnology have gained considerable attention in recent years (Dastjerdi & Montazer, 2010; Rai et al., 2012).

Nanotechnology has emerged as an innovative approach in textile engineering, particularly for the development of antimicrobial and functional fabrics. Among various nanomaterials, silver nanoparticles (AgNPs) have attracted significant interest due to their strong antimicrobial, antioxidant, and catalytic properties. Silver nanoparticles exhibit broad-spectrum antimicrobial activity against bacteria, fungi, and viruses by disrupting microbial cell membranes, generating reactive oxygen species, and interfering with DNA replication (Morones et al., 2005; Rai et al., 2009). Because of these properties, AgNPs have been widely incorporated into medical textiles, wound dressings, surgical garments, and protective clothing.

Green synthesis of nanoparticles using plant extracts has gained prominence as an environmentally friendly alternative to chemical and physical synthesis methods. Plant-mediated synthesis is advantageous because it is cost-effective, non-toxic, and does not require hazardous reagents or high energy inputs. Plant extracts contain various phytochemicals such as flavonoids, phenols, terpenoids, alkaloids, and proteins, which act as natural reducing and stabilizing agents during nanoparticle synthesis (Iravani, 2011; Mittal et al., 2013). These phytochemicals facilitate the conversion of metal ions into stable nanoparticles through environmentally friendly processes (Makarov et al., 2014; Jeevanandam et al., 2018).

Medicinal plants play an important role in nanoparticle synthesis due to their rich phytochemical composition and therapeutic properties. Among these plants, Azadirachta indica (Neem) is widely recognized for its antimicrobial, antioxidant, anti-inflammatory, and wound-healing properties. Neem leaves contain biologically active compounds such as azadirachtin, nimbin, quercetin, and limonoids that contribute to its strong antimicrobial activity (Subapriya & Nagini, 2005). Similarly, Ocimum basilicum (Sweet Basil) is an aromatic medicinal herb rich in essential oils, phenolic compounds, and flavonoids, which exhibit strong antioxidant and antibacterial properties (Prakash & Gupta, 2005; Purushothaman et al., 2018).

The incorporation of nanoparticles into textile materials has opened new opportunities for the development of functional fabrics with enhanced biological properties. Cotton is one of the most widely used natural fibers in medical textiles because of its comfort, breathability, and biocompatibility. However, untreated cotton fabrics are susceptible to microbial contamination, which may lead to unpleasant odors and infections. The application of silver nanoparticles onto cotton textiles has been shown to significantly improve their antimicrobial performance while maintaining their mechanical properties (Perelshtein et al., 2008; Dastjerdi & Montazer, 2010).

Based on the above-discussed matters, this study aims to develop and evaluate a herbal functional textile by incorporating bioactive nano extracts derived from *Azadirachta indica* (Neem) and *Ocimum basilicum* (Sweet Basil) onto 80's count cotton fabric using a spray coating technique. The study further aims to extract phytocomponents from the selected medicinal plants through the hot percolation method, apply the nano herbal extract onto the cotton fabric, and assess the antioxidant and antimicrobial properties of the treated fabric. In addition, the research intends to evaluate the effectiveness of the developed herbal fabric among individuals suffering from skin diseases, thereby exploring its potential as a natural and eco-friendly therapeutic textile.

2. Materials and Methods

2.1. Selection of the fabric

Fabric selection is an important aspect of the apparel industry because it influences the comfort, durability, appearance, and performance of the final product. Factors such as texture, weight, drape, durability, and care requirements must be considered when choosing fabrics. Various materials, including cotton, linen, silk, polyester, nylon, and leather, are commonly used in garment manufacturing. Among these, cotton is widely preferred for medical textiles due to its versatility, comfort,

Journal of Chemical Health Risks
www.jchr.org
JCHR (2026) 16(2), 895-908 | ISSN:2251-6727

breathability, and high absorbency. These properties make cotton suitable for healthcare applications such as surgical gowns, drapes, and wound dressings, where hygiene and comfort are essential. For the present study, cotton fabric was procured from Sarathas, a clothing store in Trichy, and approximately one meter of fabric was purchased for experimental purposes.

Figure 1: Cotton fabric used for this study

2.2. Pre-treatment

The fabric pre-treatment process includes several processes under both dry and wet. Some pre-treatment processes are shearing and cropping, singeing, desizing, scouring, bleaching, washing, mercerizing, and dyeing/printing. Desizing is the process in which the sizing materials are removed from the warp yarns of the woven fabrics. Purchased cotton fabric is taken under the hot running water for 10 minutes. The fabric is then squeezed and soaked in the acid or enzyme bath for one to two hours at the respective temperature.

Figure 2: Pretreatment of the Fabric

After desizing the fabric is washed first with hot water and then with cold water thoroughly to remove the impurities and the residual chemicals (acid or enzyme). The fabric is then dried in the air and used for further purposes.

2.3. Collection and processing of herbs

Leaves of *Azadirachta indica* (Neem) were collected from nearby local areas, while *Ocimum basilicum* (Sweet Basil) leaves were obtained from a local market in Tiruchirappalli. The collected leaves were thoroughly washed with cold water to remove dust and other impurities. The leaves were then separated from the stems and cut into small pieces. The chopped leaves were spread on a clean surface and subjected to shade drying at room temperature for approximately 7–10 days. Shade drying was chosen because it helps preserve important phytochemicals such as monomeric anthocyanins, flavonoids, hydrolysable tannins, and other antioxidant compounds. During the drying process, the plant materials were kept away from direct sunlight and maintained under normal room temperature conditions to retain their bioactive properties.

2.4. Selection of extraction

Hot percolation is a commonly used extraction technique for isolating bioactive compounds from plant materials such as leaves and other plant parts. In this method, heat is applied to enhance the extraction efficiency of phytoconstituents from the herbal materials. For the present study, the dried leaves of Azadirachta indica (Neem) and Ocimum basilicum (Sweet Basil) were used in a 1:1 ratio. The selected herbs were mixed thoroughly and subjected to extraction using ethanol as the solvent. Approximately 100 mL of ethanol was added to the herbal mixture, and the extraction was carried out through the hot percolation method using a water bath maintained at about 102–105 °C. The mixture was allowed to remain in the water bath for approximately 24 hours to ensure efficient extraction of the phytochemical compounds from the plant materials.

Journal of Chemical Health Risks
www.jchr.org
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Figure 3: Preparation of herbal extract using the hot percolation method showing the mixture of *Azadirachta indica* (Neem) and *Ocimum basilicum* (Sweet Basil) leaves before filtration (left) and the filtered herbal extract (right) obtained after extraction.

2.5. Qualitative Phytochemical analysis

The phytochemical analysis of the ethanol extract of Neem and Sweet basil is based on the precipitation and coloration method. The test was performed for saponin, tannin, terpenoid, Phlobatannins, flavonoids, protein, anthraquinone, cardiac glycosides, carbohydrates, xanthoproteins, leucoanthocyanin, phenol, emodin, steroids, anthocyanin, alkaloids, glycosides, coumarin (Harborne, 1998; Sofowora, 1993; Trease, & Evans, 2009; Evans, 2002).

2.6. NANO SYNTHESIS OF EXTRACT

Nano synthesis refers to the process of producing nanoparticles with dimensions in the nanometer scale. In green synthesis methods, plant extracts are commonly used as reducing and stabilizing agents for the formation of metal nanoparticles. In the present study, silver nanoparticles were synthesized using plant extracts obtained from Azadirachta indica (Neem) and Ocimum basilicum (Sweet Basil).

The filtered herbal extract was mixed with a solution of the metal salt to facilitate nanoparticle formation. Silver nitrate ($AgNO_3$) was used as the metal precursor for nanoparticle synthesis. A 1 mM solution of silver nitrate was prepared by dissolving the required amount of silver nitrate in 100 mL of distilled water. The prepared silver nitrate solution was stored in a dark condition and kept away from direct sunlight to prevent photodegradation. The diluted silver nitrate solution was then combined with the plant extract under controlled conditions, allowing the phytochemicals present in the extract to reduce silver ions and form silver nanoparticles (Vanlalveni et al., 2021).

2.6.1. Characterization of silver nanoparticles

The synthesized silver nanoparticles were characterized using various analytical techniques to determine their optical properties, functional groups, crystalline nature, morphology, particle size, and elemental composition. Techniques such as UV–Visible spectroscopy, Fourier Transform Infrared Spectroscopy (FT-IR), X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), and Energy Dispersive X-ray Analysis (EDX/EDAX) were used for the comprehensive characterization of the nanoparticles (Vanlalveni et al., 2021).

2.6.2. Uv-visible spectroscopy

V–Visible spectroscopy was employed to evaluate the optical properties of the synthesized silver nanoparticles. In this method, the plant extract obtained from Azadirachta indica and Ocimum basilicum was mixed with silver nitrate solution. After incubation for approximately 24 hours, the formation of silver nanoparticles was monitored using a UV–Visible spectrophotometer. The absorbance spectrum was recorded within the wavelength range of 350–500 nm, where silver nanoparticles typically exhibit a characteristic surface plasmon resonance peak (Ahmed et al., 2016).

2.6.3. X-Ray diffraction

X-ray diffraction analysis was carried out to determine the crystalline structure, grain size, and phase nature of the synthesized silver nanoparticles. XRD patterns provide information about the crystalline characteristics and confirm the formation of metallic silver nanoparticles through their distinct diffraction peaks (Iravani, 2011; Singh et al., 2023).

2.6.4. FT-IR

Fourier Transform Infrared Spectroscopy (FT-IR) was used to identify the functional groups present in the plant extract that are responsible for the reduction and stabilization of silver nanoparticles. The FT-IR spectra were recorded in the range of 4000–400 cm^{-1}, which helps determine the involvement of biomolecules such as proteins, phenolics, and flavonoids in the nanoparticle synthesis process (Sharma et al., 2020; Vanlalveni et al., 2021).

Journal of Chemical Health Risks
www.jchr.org
JCHR (2026) 16(2), 895-908 | ISSN:2251-6727

2.6.5. Scanning electron microscope (SEM)

Scanning Electron Microscopy (SEM) was used to examine the surface morphology and size distribution of the synthesized silver nanoparticles. SEM images provide detailed information about the shape, structure, and aggregation pattern of the nanoparticles, confirming their successful formation (Ahmed et al., 2016).

2.6.6. Energy Dispersive X-ray Analysis (EDX)

Energy Dispersive X-ray Analysis (EDX) was conducted to determine the elemental composition of the synthesized nanoparticles. This technique confirms the presence of silver as the major element in the sample and provides quantitative information about the elemental distribution within the nanoparticles (Iravani, 2011; Singh et al., 2023).

2.7. Antioxidant activity DPPH assay method

The antioxidant activity of the synthesized silver nanoparticles was evaluated using the stable DPPH (2,2-diphenyl-1-picrylhydrazyl) free radical scavenging assay. In this method, 500 µL of ethanolic DPPH solution (0.05 mM) was added to 1000 µL of synthesized silver nanoparticles prepared at different concentrations ranging from 20 to 100 µg/mL. The freshly prepared DPPH solution was stored in the dark at 4 °C to prevent degradation. Subsequently, 2.7 mL of 96% ethanol was added to the reaction mixture and the solution was mixed thoroughly by vigorous shaking. The mixture was then allowed to stand for 5 minutes to facilitate the reaction between the DPPH radicals and the antioxidant compounds present in the nanoparticles. After incubation, the absorbance of the solution was measured at 540 nm using a UV–Visible spectrophotometer. Ethanol was used as the blank to calibrate the instrument. A control sample containing the same volume of ethanol and DPPH solution without nanoparticles was also prepared. All experiments were performed in triplicate to ensure accuracy and reproducibility of the results. The antioxidant activity of the samples was expressed as the percentage of DPPH radical inhibition, which indicates the free radical scavenging ability of the synthesized nanoparticles.**(Munteanu & Apetrei, 2021).**

Percent (%) inhibition of DPPH activity = [(A-B)/A] x 100.

Where A and B – absorbance values of blank and sample, respectively. A curve of concentration versus percentage inhibition was plotted and concentration required for 50% inhibition was determined.

2.8. Selection of finishing techniques

The application of nanomaterials onto textile substrates can be achieved through several finishing techniques depending on the desired functionality and the type of fabric used. Common nanoscale finishing methods include chemical vapor deposition (CVD), electrospinning, and dip coating, which facilitate the deposition of nanoparticles onto textile surfaces. Additional finishing processes such as heat treatment, plasma treatment, and surface functionalization are often applied to enhance the durability and functionality of the treated fabric. These techniques can impart various properties to textiles, including water repellency, antimicrobial activity, improved conductivity, and enhanced durability. The selection of an appropriate finishing method depends on the intended application and the characteristics of the fabric material.

2.8.1. Spray coating method

Spray coating is a widely used technique for applying nanomaterials onto textile surfaces due to its simplicity and ability to produce uniform coatings. In this study, the nanosynthesized extract derived from Azadirachta indica (Neem) and Ocimum basilicum (Sweet Basil) was sprayed evenly onto the cotton fabric surface. This process enables the uniform distribution of herbal nanoparticles across the fabric. After the spraying process, the treated fabric was subjected to a drying stage to ensure proper adhesion and stability of the nanoparticles on the textile surface. The spray coating technique provides controlled and homogeneous coverage, allowing the fabric to exhibit improved functionalities such as antimicrobial activity, enhanced durability, and possible water-resistant properties.

2.9. Analyzation of sample

The analysis of the treated fabric samples involves evaluating several important textile parameters such as material composition, weave structure, thread count, and fabric weight. These factors influence the mechanical performance, durability, breathability, and comfort of the textile material. Fabrics treated with antimicrobial agents or nanoparticles are also assessed for their ability to inhibit

Journal of Chemical Health Risks
www.jchr.org
JCHR (2026) 16(2), 895-908 | ISSN:2251-6727

microbial growth, which is particularly important for medical textile applications.

2.9.1. Antibacterial test

The antibacterial performance of the treated fabric was evaluated using standard testing methods such as AATCC Test Method 100. The cotton fabric treated with herbal nanoparticles was tested against bacterial strains including *Staphylococcus aureus* and *Streptococcus pyogenes*. Antibacterial activity was determined using the disc diffusion method. Muller–Hinton agar medium was prepared in sterile Petri dishes (60 mm diameter) and inoculated with the test microorganisms. Sterile fabric samples were cut into rectangular pieces measuring approximately 10 × 10 mm, and discs with a diameter of 6 mm were prepared. These discs were impregnated with 20 µL and 40 µL of the sample extract. The prepared discs were placed on the surface of the agar plates and allowed to stand at room temperature for approximately 30 minutes to permit diffusion of the active compounds into the medium. A control sample containing amoxicillin was used as the standard reference. The plates were incubated at 37 °C for 24 hours, after which the zone of inhibition around the discs was measured in millimeters to determine antibacterial effectiveness. The experiment was conducted in duplicate to ensure reliability of the results.

2.9.2. Physical testing of fabric

2.9.2.1. Stiffness test

The stiffness test was conducted to evaluate the bending rigidity or drape characteristics of the fabric. Fabric samples were cut into standardized dimensions and ensured to be free from wrinkles before testing. Each sample was placed in the stiffness testing apparatus, and the fabric was gradually moved along the measuring scale. The stiffness value obtained from the instrument was recorded. This test follows standard procedures similar to ASTM D4032.

2.9.2.2. Crease recovery test

The crease recovery test determines the ability of a fabric to return to its original shape after being folded or creased. Fabric samples measuring 2 inches in length and 1 inch in width were prepared and placed in the crease recovery tester. A standard load was applied to the fabric to create a crease and maintained for a specific period. After removing the load, the fabric was allowed to recover naturally. The crease recovery angle was measured to evaluate the fabric's recovery ability according to ASTM D1296 standards.

2.9.2.3. Quadrant balance

The quadrant balance method is used to determine the yarn count of textile materials such as yarn, roving, or sliver. In this procedure, cotton fabric samples were cut according to the template measurement and folded to form a compact mass. The weighed yarn sample was then suspended from the hook of the quadrant balance, and the yarn count was directly read from the quadrant scale.

2.9.2.4. Abrasion tester

The abrasion resistance of the fabric was evaluated using an abrasion testing machine. Fabric samples were cut into identical dimensions of 2 × 2 inches and mounted securely onto the specimen holders of the testing apparatus. The machine parameters, including load, speed, and number of cycles, were adjusted according to standard testing requirements. The test was conducted until the predetermined number of cycles was reached. The performance of the fabric was then assessed based on factors such as surface wear, colourfastness, and pilling resistance.

2.9.2.5. Thickness tester

The thickness of the fabric was measured using a thickness tester. The fabric sample was first cleaned and cut into a standard size to ensure accurate measurement. The sample was placed between the anvil and circular pressure foot of the thickness tester. When the pressure lever was released, the thickness value was displayed on the dial indicator and recorded in micrometers (µm).

3. Results

The results of the present study demonstrated the successful development of nanosynthesized herbal-treated cotton fabric using extracts of Azadirachta indica (Neem) and Ocimum basilicum (Sweet Basil). The phytochemical screening of the ethanolic extract confirmed the presence of several bioactive compounds such as flavonoids, phenols, tannins, alkaloids, glycosides, and terpenoids, which are known for their antioxidant and antimicrobial properties. The synthesis of silver nanoparticles using the plant extracts was indicated by a visible color change in the

Journal of Chemical Health Risks
www.jchr.org
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reaction mixture, suggesting the reduction of silver ions and the formation of stable nanoparticles. Subsequent characterization analyses, including UV–Visible spectroscopy, FT-IR, XRD, SEM, and EDX, further confirmed the formation, structural properties, and elemental composition of the synthesized nanoparticles. The treated cotton fabric exhibited improved functional properties compared to untreated fabric, indicating the effectiveness of the herbal nanosynthesis treatment for potential medical textile applications.

3.1. Qualitative Phytochemical Analysis

Phytochemical screening of the extracts obtained from *Azadirachta indica* (Neem) and *Ocimum basilicum* (Sweet Basil) was carried out to identify the presence of bioactive compounds. The analysis revealed that the herbal extracts contained a wide range of phytochemical constituents. The results indicated a strong presence of phenols, terpenoids, xanthoproteins, flavonoids, cardiac glycosides, saponins, leucoanthocyanins, tannins, carbohydrates, alkaloids, anthocyanins, steroids, proteins, glycosides, coumarins, and anthraquinones. These phytochemicals are known to contribute to the biological activities of the plant extracts, including antioxidant and antimicrobial properties.

Table 1: Phytochemical analysis of plant extracts

SL.No	Test for	Observation	Result
1	Terpenoid	Reddish brown	+++
2	Flavonoids	Yellow colour	+++
3	Saponins	Formation of froth	+++
4	Tannin	Green precipitate	+++
5	Alkaloids	Yellow colour precipitate	+++
6	Steroids	Reddish brown ring	+++
7	Glycosides	Violet into blue into Green colour	+++
8	Phlobatanins	Red precipitate	+++
9	Proteins	White precipitate	+++
10	Coumarin	Yellow precipitate	+++
11	Emodin	Red colour	+++
12	Anthroquinon e	Pink, Violet, Red Colour	+++
13	Anthocyanin	Pinkish red to Bluish Violet colour	+++
14	Carbohydrate	Reddish violet ring Formation	+++
15	Leucoanthocyanin	Organic layer into Red	A
16	Cardiac glycosides	Formation of Violet Browning	+++
17	Xanthoprotein	Blue black colour	+++
18	Phenols	Reddish orange Colour	+++

(Where (+) represent Trace, (++) represent Moderate, (+++) represent Strong and A represents Absent).

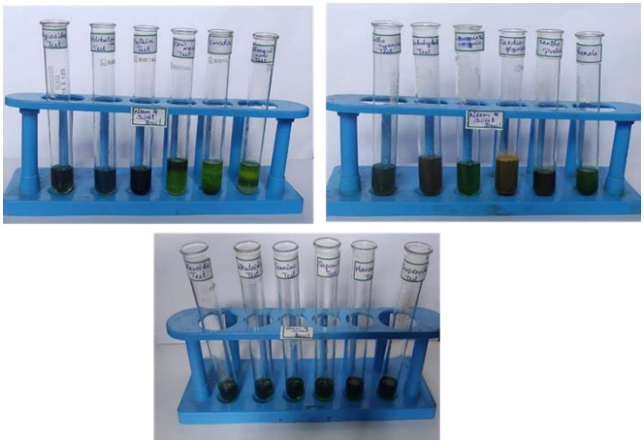

Figure 4: Phytochemical analysis of the plant extracts

3.2. NANO RESULTS

3.2.1. VISUAL COLOUR CHANGE AND UV-Vis's SPECTROSCOPY

In this experiment, the addition of ethanolic plant extract to the glass vial containing silver nitrate ($AgNO_3$) resulted in a noticeable color change from colorless to reddish-brown, indicating the formation of silver nanoparticles. This color transformation confirms the reduction of silver ions by the bioactive compounds present in the plant extract. Furthermore, the synthesis of silver nanoparticles was confirmed through UV–Visible spectroscopic analysis, where a characteristic surface plasmon resonance (SPR) peak was observed at 470.9 nm, indicating the presence of silver nanoparticles in the reaction mixture.

Journal of Chemical Health Risks
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JCHR (2026) 16(2), 895-908 | ISSN:2251-6727

Figure 5: Nanoparticle synthesis from plant leaf extracts

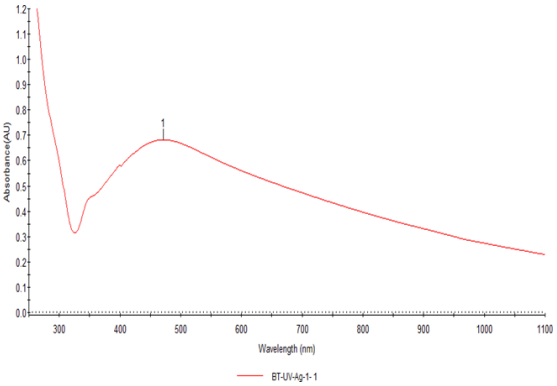

Figure 6: UV-Visible spectroscopy of AgNPs-leaves extract

3.2.2. FUNCTIONAL GROUP DETERMINATION USING FT-IR SPECTROSCOPY

The Fourier Transform Infrared (FT-IR) analysis was performed to identify the functional groups present in the plant extract that are responsible for the reduction and stabilization of silver nanoparticles. The FT-IR spectrum of the synthesized AgNPs showed several characteristic absorption bands indicating the presence of different biomolecules. A medium absorption band observed at 3447.36 cm^{-1} corresponds to N–H stretching vibrations of primary amines, suggesting the presence of protein or amino compounds that may participate in the stabilization of nanoparticles. A strong band detected at 2078.27 cm^{-1} is attributed to N=C=S stretching vibrations of isothiocyanate groups. The peak at 1637.70 cm^{-1} represents C=C stretching vibrations of alkenes, which may be associated with plant-derived organic compounds involved in the reduction of silver ions.

Another medium band observed at 1055.50 cm^{-1} corresponds to C–N stretching vibrations of amines, indicating the presence of nitrogen-containing biomolecules. Additionally, a strong absorption band at 680.05 cm^{-1} corresponds to C–Br stretching vibrations of halo compounds. These functional groups confirm that various phytochemicals present in the leaf extracts of Azadirachta indica and Ocimum basilicum play an important role in the reduction, capping, and stabilization of the synthesized silver nanoparticles.

Table 2: FT-IR analysis of AgNPs-leaves extract

Functional group	Band	Frequency,cm^{-1}
Primary amine	Medium band	3447.36 cm^{-1} corresponds to N-H stretching vibrations
Isothiocyanate	Strong band	2078.27 cm^{-1} corresponds to N=C=S stretching vibrations
Alkene	Medium band	1637.70 cm^{-1} corresponds to C=C stretching vibrations
Amine	Medium band	1055.50 cm^{-1} corresponds to C-N stretching vibrations
Halo compound	Strong band	680.05 cm^{-1} corresponds to C-Br stretching vibrations

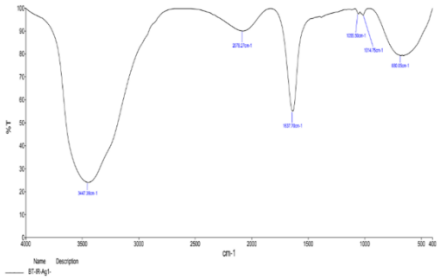

Figure 7: FT-IR analysis of AgNPs

Journal of Chemical Health Risks
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3.2.3. Scanning electron microscopy

The SEM image is employed to predict the size and morphology of resultant silver nanoparticles using sample. The size (diameter) of the nanoparticles lies between 86.93-126.7 nm region, the average size of the nanoparticles is ~ 200 nm, whereas the shapes were spherical and cubic.

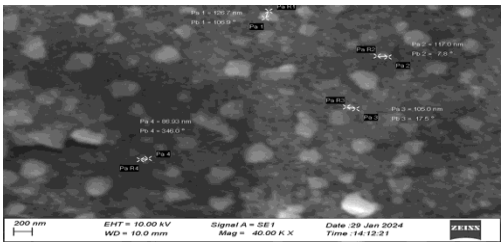

Figure 8: SEM images of AgNPs of leaf extracts

3.2.4. EDX analysis

Energy dispersive X-ray (EDX) spectrometer analysis confirmed the elemental signal of silver nanoparticles. The Y-axis (vertical) represents the number of X-ray counts while X-axis (horizontal) shows the energy in KeV. EDX spectrum of the silver nanoparticles was recorded with additional peak of oxygen because of biomolecules attached to the silver nanoparticles surface. From EDX spectra, it is found that silver nanoparticles are reduced by the sample of herbs *Azadirachta Indica* and *Ocimum Basilicum* have the silver weight percentage as 45.81%.

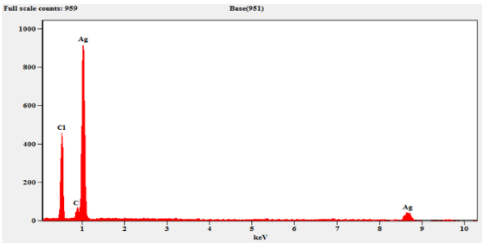

Figure 9: EDX analysis of the AgNPs

Table 3: EDX analysis of the AgNPs

Element Line	***Weight %***	***Weight % Error***	***Atom %***
Cl K	20.31	± 4.91	35.15
C K	22.53	± 3.26	44.53
Ag K	57.16	± 1.83	20.32
Ag L	---	---	---
Total	100.00		100.00

3.2.5. X-RAY DIFFRACTION (XRD)

The crystalline nature of silver nanoparticles was confirmed using X-ray crystallography. The X-ray diffractogram patterns of synthesized silver nanoparticles were represented below. The intense diffraction peak is obtained at 2Θ values, 38.3569, 45.634, 67.1435, 78.2872 corresponds to the following diffraction facets are (111), (200) respectively. This pattern shows the face centred cubic structure for silver according to (JCPDS, File No. 04-0783)). Unassigned peaks are also present in the graph this may be due to extract contains some phytochemicals which may be capping the nanoparticles surface.

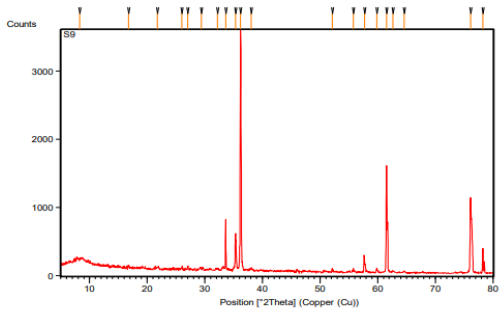

Figure 9: X-ray diffractogram patterns of synthesized silver nanoparticles

3.3. ANTI-OXIDANT ACTIVITY

The antioxidant activity of the AgNPs-leaves of Azadirachta Indica and Ocimum Basilicum was evaluated using the DPPH free radical scavenging assay and compared with the standard antioxidant, Ascorbic acid. The results demonstrated that the radical scavenging activity increased with increasing concentration of the samples. At a concentration of 20 µg/mL, the silver nanoparticles exhibited 46% inhibition, while the standard ascorbic acid showed 67% inhibition. As the concentration increased to 40 µg/mL, the antioxidant activity of the nanoparticles increased to 57%, whereas ascorbic acid showed 70% inhibition. At 60 µg/mL, the silver nanoparticles showed 60% radical scavenging activity, while the standard exhibited 73% inhibition. Further

Journal of Chemical Health Risks
www.jchr.org
JCHR (2026) 16(2), 895-908 | ISSN:2251-6727

increase in concentration to 80 µg/mL resulted in 67% inhibition for silver nanoparticles and 79% inhibition for ascorbic acid. The highest antioxidant activity was observed at 100 µg/mL, where the silver nanoparticles showed 72% inhibition, while ascorbic acid exhibited 82% inhibition. Overall, the results indicate that the synthesized silver nanoparticles exhibit significant antioxidant activity, albeit slightly lower than that of the standard antioxidant. The increasing inhibition percentage with higher concentrations suggests a concentration-dependent antioxidant potential of the nanoparticles.

Table 4: DPPH activity of AgNPs-leaves

S.NO	CONCENTRATION (µg/ml)	ANTIOXIDANT ACTIVITY DPPH%	
		SILVER NANOPARTICLE	ASCORBIC ACID
1	20	46	67
2	40	57	70
3	60	60	73
4	80	67	79
5	100	72	82

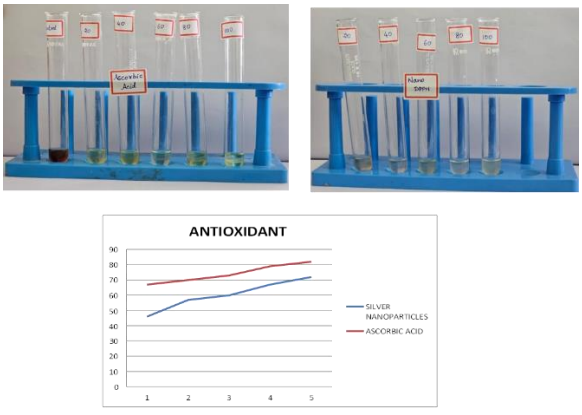

Figure 10: DPPH assay of AgNPs

3.4. ANTIBACTERIAL TEST

The antibacterial activity of fabric samples treated with extracts was analyses against pathogens are revealed. Fabric cotton samples showed a maximum inhibition was observed against *Staphylococcus aureus* (13 mm) and *Streptococcus pyogenes* at a concentration of 40 µg/ml.

Table 5: Antibacterial activity of AgNPs against *Streptococcus pyogenes* and *Staphylococcus aureus*

Sample	Concentration (µg/ml)	Organisms/Zone of inhibition (mm)	
		Streptococcus pyogenes	*Staphylococcus aureus*
Extracts coated fabric sample	20 µl	6	6
Extract coated fabric sample	40 µl	8	10
Control		0	0

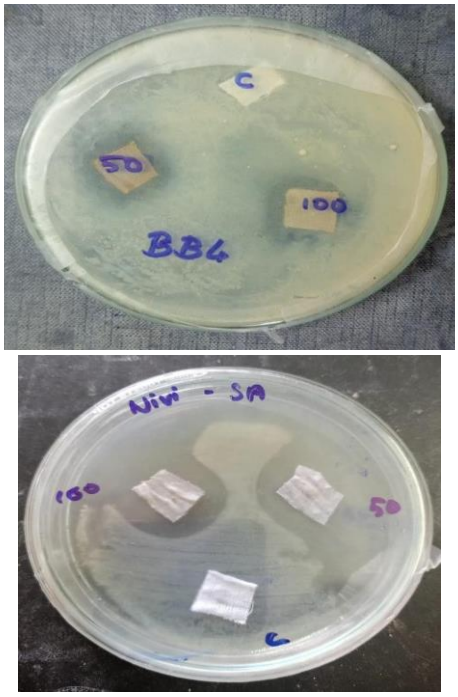

Figure 11: Antibacterial activity of AgNPs against cotton fabric

Journal of Chemical Health Risks
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JCHR (2026) 16(2), 895-908 | ISSN:2251-6727

3.5. Physical test

3.5.1. Stiffness test

The stiffness test was conducted to evaluate the bending rigidity of the cotton fabric in both warp and weft directions. The graph shows the stiffness values of untreated fabric samples (B1 and B2) and finished fabric samples (F1 and F2) treated with nanosynthesized extracts of Azadirachta indica and Ocimum basilicum. The results indicate variations in stiffness between treated and untreated fabrics, suggesting that the nanosynthesis treatment slightly influences the mechanical properties of the cotton fabric while maintaining its structural integrity.

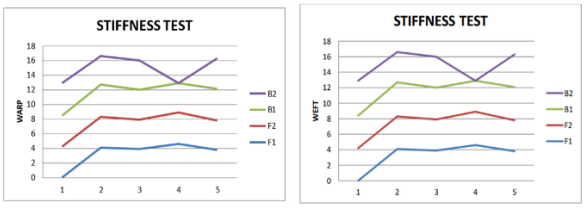

Figure 12: Stiffness Test of Treated and Untreated Fabric

3.5.2. Crease recovery test

The crease recovery test was performed to determine the ability of the cotton fabric to regain its original shape after being folded or creased. The graph illustrates the crease recovery angle measured in both warp and weft directions for the treated fabric samples. Higher crease recovery values indicate better resistance to creasing and improved fabric resilience. The results show variations in the recovery angles across different readings, demonstrating that the nanosynthesized treatment using extracts of Azadirachta indica and Ocimum basilicum maintains good crease recovery properties while slightly influencing the flexibility of the cotton fabric.

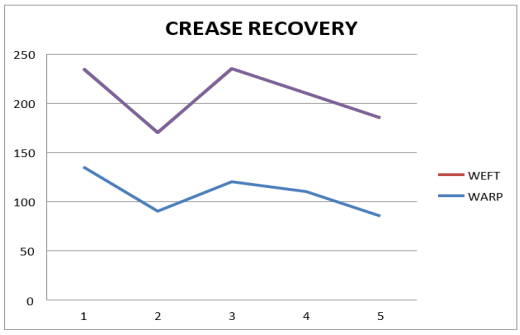

Figure 13: Crease Recovery Test of Treated Cotton Fabric

3.5.3. Quadrant balance

The nanosynthesized fabric sample was evaluated using the quadrant balance test to determine the yarn count of the fabric. This method allows the yarn count to be measured directly from the instrument scale. Based on the readings obtained during the test, the yarn count of the treated fabric was recorded and calculated. The results indicated that the yarn count of the fabric was 122, confirming the structural consistency of the cotton fabric after nanosynthesis treatment.

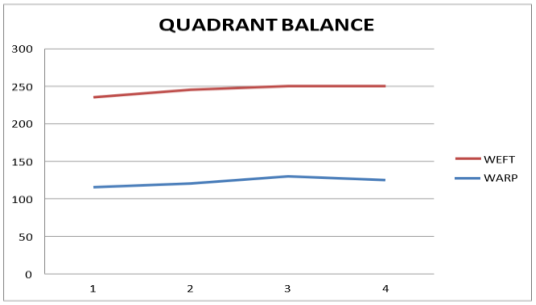

Figure 14: Quadrant Balance Test of Cotton Fabric

3.5.4. ABRASION TEST

The abrasion test performed on the nanosynthesized fabric treated with extracts of Azadirachta indica (Neem) and Ocimum basilicum (Sweet Basil) indicated a high resistance to abrasion. The results showed that there was no significant change in the fabric weight before and after the abrasion test, demonstrating good durability of the treated fabric. Additionally, the formation of pilling on the fabric surface was minimal, suggesting that the nanosynthesis treatment does not adversely affect the mechanical strength and surface stability of the cotton fabric.

Table 6: Abrasion Resistance Test of Cotton Fabric

SL. NO	BEFORE ABRASION	AFTER ABRASION
1	0.28	0.27
2	0.30	0.30
3	0.32	0.31
4	0.29	0.29

3.5.5. THICKNESS TEST

The thickness test conducted on the nanofabricated cotton fabric treated with extracts of Azadirachta indica

Journal of Chemical Health Risks
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(Neem) and Ocimum basilicum (Sweet Basil) showed that the fabric maintained a uniform thickness throughout its surface. The measurement obtained from the thickness tester indicated that the average thickness of the treated fabric was 0.25, demonstrating that the nanosynthesis process did not significantly alter the structural thickness of the cotton fabric.

Table 7: Thickness Measurement of Nanosynthesized Cotton Fabric

SL.NO	THICKNESS
1	0.25
2	0.24
3	0.26
4	0.27
5	0.25

4. Discussion

The present study successfully demonstrated the green synthesis of silver nanoparticles using leaf extracts of *Azadirachta indica* and *Ocimum basilicum* and their application on cotton fabric for the development of functional medical textiles. The results from phytochemical analysis, nanoparticle characterization, antioxidant assay, antibacterial evaluation, and physical fabric testing collectively confirm the potential of plant-mediated nanotechnology in the development of antimicrobial textiles.

The qualitative phytochemical analysis revealed the presence of important secondary metabolites such as phenols, flavonoids, tannins, alkaloids, terpenoids, glycosides, and saponins in the plant extracts. These phytochemicals are widely reported to act as natural reducing and stabilizing agents in the green synthesis of nanoparticles. Phenolic compounds and flavonoids possess strong redox potential, enabling them to convert silver ions into metallic nanoparticles while also preventing nanoparticle aggregation (Saxena et al., 2012). Previous studies have reported that plant-derived polyphenols significantly contribute to the synthesis and stabilization of nanoparticles and enhance their biological activities (Mittal et al., 2013; Prasad et al., 2017).

The formation of silver nanoparticles was initially confirmed by the color change from colorless to reddish brown, which is attributed to the excitation of surface plasmon resonance (SPR) in silver nanoparticles. The UV–Visible absorption peak observed at 470.9 nm falls within the characteristic range reported for biosynthesized silver nanoparticles (Song & Kim, 2009).

FT-IR analysis revealed several functional groups including amines, alkenes, and isothiocyanates, indicating that biomolecules such as proteins, flavonoids, and phenolic compounds present in the plant extracts are involved in nanoparticle reduction and stabilization. These biomolecules act as capping agents, which prevent nanoparticle aggregation and improve stability (Kharissova et al., 2013).

The SEM images confirmed that the nanoparticles were predominantly spherical and cubic in morphology, with particle sizes ranging from 86–126 nm. Similar nanoparticle shapes and size distributions have been reported in plant-mediated silver nanoparticle synthesis studies (Iravani et al., 2014).

The EDX analysis further confirmed the presence of silver as the major elemental component in the synthesized nanoparticles, with additional signals corresponding to carbon and oxygen derived from plant biomolecules. Such elemental compositions are typical in biosynthesized nanoparticles due to the presence of organic compounds attached to the nanoparticle surface (Kulkarni & Muddapur, 2014).

The XRD results showed distinct diffraction peaks corresponding to the face-centered cubic (FCC) structure of silver, which confirms the crystalline nature of the synthesized nanoparticles. Similar diffraction patterns have been reported in earlier studies on biologically synthesized silver nanoparticles (Thakkar et al., 2010; Rajeshkumar & Bharath, 2017).

The antioxidant activity evaluated using the DPPH radical scavenging assay indicated that the synthesized silver nanoparticles possess significant free radical scavenging potential. The radical inhibition increased with increasing concentration, reaching 72% inhibition at 100 µg/ml. Although the activity was slightly lower than that of the standard antioxidant ascorbic acid, the results indicate strong antioxidant potential. The antioxidant activity may be attributed to the presence of phytochemicals such as polyphenols and flavonoids bound to the nanoparticle surface (Gülçin, 2012). Previous studies have also reported that plant-mediated silver nanoparticles exhibit enhanced antioxidant activity due to phytochemical interactions (Altemimi et al., 2017).

The antibacterial assay demonstrated that the nanoparticle-coated cotton fabric exhibited inhibitory activity against Staphylococcus aureus and Streptococcus pyogenes, with higher inhibition observed at increased concentrations. Silver nanoparticles exhibit antimicrobial activity through multiple mechanisms including membrane disruption, generation of reactive oxygen species, and interaction with microbial DNA and proteins (Morones et al., 2005). The integration of silver nanoparticles into cotton textiles significantly enhances their antimicrobial performance, making them suitable for medical and healthcare applications (Simoncic & Tomsic, 2010).

The physical tests conducted in the study demonstrated that the nanosynthesis treatment did not significantly alter the structural properties of the cotton fabric. The stiffness and crease recovery tests indicated that the treated fabric retained adequate flexibility and mechanical stability. The yarn count measured using the quadrant balance method remained 122, indicating that the nanoparticle coating did not alter the fabric structure.

The abrasion test results revealed minimal differences in fabric weight before and after abrasion, indicating good resistance to mechanical wear. The thickness test also showed that the treated fabric maintained a uniform thickness of 0.25 mm, suggesting that the nanoparticle coating process did not significantly affect the fabric structure. Similar findings have been reported in nanoparticle-treated fabrics where antimicrobial finishing enhanced functional properties without compromising mechanical performance (Vigneshwaran et al., 2006; Dastjerdi & Montazer, 2010).

5. Conclusion

The present study successfully demonstrated the green synthesis of silver nanoparticles using leaf extracts of *Azadirachta indica* and *Ocimum basilicum* and their application in cotton fabric to develop functional medical textiles. Phytochemical screening confirmed the presence of several bioactive compounds responsible for the reduction and stabilization of nanoparticles. The successful formation of silver nanoparticles was confirmed through UV–Visible spectroscopy, FT-IR, SEM, EDX, and XRD analyses, which revealed their structural, morphological, and crystalline characteristics. The synthesized nanoparticles exhibited notable antioxidant activity and effective antibacterial activity against Staphylococcus aureus and Streptococcus pyogenes. Furthermore, the physical evaluation of the treated fabric indicated that nanosynthesis did not significantly affect important textile properties such as stiffness, thickness, abrasion resistance, and yarn count. Overall, the findings highlight the potential of plant-mediated silver nanoparticles as an eco-friendly and sustainable approach for developing antimicrobial and antioxidant textiles suitable for healthcare and biomedical applications.

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