



Synthesis of Silver and Copper oxide nanoparticles using *Ficus racemosa* leaf extract: characterization, anticancer potential, and dye degradation efficacy

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Abstract

Due to their economic and eco-friendly attributes, there has recently been a growing interest in phytochemicals as catalysts for synthesizing nanoparticles (NPs). The present study describes the synthesis of nanoparticles (NPs) via green chemistry by utilizing *Ficus racemosa* (*F. racemosa*) leaf extract without using any harsh chemical reagents. Silver (Ag) NPs were synthesized through conventional and microwave-irradiation routes, while the NPs of Copper oxide (CuO) were synthesized through traditional synthetic routes. The average crystallite size was around 26 and 38 nm for Ag and CuO NPs, respectively, with highly crystalline properties. The peak of around 450 nm for Ag and 551 nm for CuO, respectively, provided evidence of their formation. The NPs synthesized via the conventional route had spherical morphology with sizes between 40–80 nm and 95–250 nm for Ag and CuO NPs, respectively. With a size range of 80–300 nm, Ag NPs synthesized via microwave irradiation had triangular, polygonal, and almost spherical shapes. Ag NPs synthesized via microwave irradiation had triangular, polygonal, and nearly spherical morphology with a size range of 80–300 nm. The cytotoxicity of NPs was assessed on the human lung cancer cell line (A549). With an IC₅₀ value of 75 µg/mL, the studies revealed that both NPs displayed comparable activities. The catalytic dye degradation activity of Ag NPs was investigated using Bromophenol blue (BB), Methylene blue (MB), and Methyl orange (MO). Therefore, using green synthesis, the current pathway facilitates the environmentally favorable synthesis of NPs for anti-cancer and dye degradation applications.

Keywords Anti-cancer activity · Copper oxide nanoparticles · Dye degradation · *Ficus racemosa* · Green synthesis · Material characterization · Silver nanoparticles

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1 Introduction

Nanotechnology involves the manipulation of particles at with a typical dimension of less than 100 nm [1]. This process involves the synthesis of metal-based nanoparticles (NPs) such as zinc, iron, gold, silver, etc. [2–4]. The use of metallic NPs in treating cancer, bacterial infections, and fungal infections has been the subject of substantial research. Various biological, chemical, and physical techniques are available to synthesize these NPs, amongst which the biogenic route, also known as the “Green Chemistry,” is adopted because of its economical nature, non-poisonous, and environmentally friendly properties [5, 6]. In contrast to bulk materials, nanomaterials have miniaturized dimensions and unique attributes, contributing to their increased physicochemical properties. Therefore, their ability to respond and exceptional physio-chemical, electrical, opto-magnetic, and mechanical characteristics are observed [7, 8]. Ag and CuO are two metallic NPs extensively researched for their wide applications. These include catalysts, sensors [9], signal enhancers [10], optical receptors, polarizing filters [11], intercalating materials in batteries [12], drug delivery systems [13, 14], anti-cancer agents [15–17], anti-inflammatory agents [18–20], bio-labeling [21], antioxidants, and antimicrobial agents [22–25]. They are also utilized in catalysis, optics, and sensor-based technology [26]. The synthesis of Ag and CuO NPs via a biogenic route using fungi [27], bacteria [28], algae [29], and plants such as *Cleome viscosa* [30], *Ulva lactuca* [31], *Taraxacum officinale* [32], *Murraya koenigii* [33], *Acalypha indica* [34], *Punica granatum* [35], *Ficus religiosa* [16], *Aegle Marcello Correa* [19], *Citrus medica* Linn. [23], etc., are well-documented in several published works of literature. Green synthesis is preferable due to its versatility, health and safety concerns, and efficiency of resources as compared to conventional chemical synthetic pathways, and it is more cost-effective [36]. It can produce significant quantities of NPs, which are generally contamination-free and possess a clearly defined size and morphology [37].

Moreover, green nanotechnology substantially advances regenerative medicine by creating nanomaterials that enhance tissue regeneration and facilitate wound healing [38]. Through the utilization of renewable resources and the reduction of waste output, green synthesis helps to promote ecological sustainability. The traditionally employed chemical synthetic routes involve potentially harmful substances that could harm both humans and the environment [6, 39–41]. Furthermore, NPs derived from plant extracts have intrinsic antimicrobial characteristics, rendering them highly useful in the fight against infections and developing antimicrobial coatings for medical equipment.

Green nanotechnology in cancer therapy employs novel approaches, such as NPs modified with ligands capable of selectively attaching to cancer cells for targeted medication delivery. Selectively targeting specific areas minimizes unintended effects, improving the effectiveness of anticancer medications. In addition, nanomaterials can be employed for photothermal treatment and photodynamic therapy, in which light-absorbing NPs produce heat or reactive oxygen species to eliminate cancer cells.

On the other hand, the incorporation of different parts of plants for synthesis has been greatly reduced in recent years due to the rapid development of synthetically obtained medicines. Nonetheless, the emergence of unfavorable side effects from synthetic compounds and their incompatibility with human nature has again drawn the focus toward plant-based phytochemistry [37]. Cancer, the uncontrolled proliferation of abnormal cells, is primarily caused by significant metabolic alterations in the genetic and cellular composition of an organism. It is common practice to employ therapeutic approaches such as surgery, radiotherapy, and chemotherapy in cancer treatment. However, these approaches are costly and associated with many adverse effects [42]. For this reason, there is a significant urge to develop innovative and efficient anticancer treatments. These treatments should include pharmaceuticals and medications that are not only cost-effective but also non-poisonous and have a limited number of adverse effects. The ramifications of cancer are not confined solely to physical well-being but also encompass emotional, social, and economic dimensions, rendering it a multifaceted and pressing field of research. Researching cancer not only adds to our scientific understanding but also plays a crucial part in shaping public health policies and efforts focused on preventing and managing cancer. Chemotherapeutic-based research against tumor demands for novel/ new anticancer drugs has stimulated the use of metal oxide NPs as potential anticancerous drugs [43–45]. Nanotechnology has enabled the development of medicines at the nanoscale (nanomedicine), significantly contributing to cancer treatment globally. Ag NPs [46–49] and CuO NPs [50] play a significant role in nanomedicine for cancer treatment.

Ficus racemosa (*F. racemosa*) is sometimes referred to as the cluster fig tree. It is recognized for its significant role in the eco-friendly synthesis of NPs, owing to its abundant phytochemical composition. *F. racemosa* leaf extract includes bioactive components, including flavonoids, phenolics, and tannins. These chemicals serve as reducing and stabilizing agents when synthesizing metallic NPs. This ecologically sensitive approach seeks to reduce the amount of toxic substances used and the impact exerted on the environment [3]. The leaf extract of *F. racemosa* is a biocompatible material obtained from plants. There is a reduced probability of introducing harmful components into the synthesized

nanomaterials, particularly when utilized in biological or medical contexts such as inhibiting bacterial growth. Recent research has shown that *F. racemosa* leaf extract effectively synthesizes copper and silver NPs. The NPs synthesized via the green chemistry approach have notable effectiveness in combating cancer, specifically targeting lung cancer cells. This is because of their capacity to produce a greater quantity of reactive oxygen species (ROS), resulting in apoptosis, which is the process by which cancer cells undergo programmed cell death [51, 52]. Moreover, these NPs exhibit exceptional efficacy in breaking down organic dyes [53, 54], underscoring their promise in wastewater treatment [55, 56].

The present work is centered on the eco-friendly synthesis of Ag and CuO NPs utilizing an extract derived from the leaves of *F. racemosa*. The aim is to examine the influence of these NPs on the A549 human lung cancer cell line, expanding on previous studies [57, 58]. Traditionally, *F. racemosa* extracts are used in India to treat several diseases [59, 60]. In Ayurveda, fruits treat sore throat, dry cough, kidney and spleen-related diseases. Leaves have also been used as astringent in Unani medicine, while buds have been used to improve skin complexion [61]. The plant extract contains phytochemicals, including alkaloids, flavonoids, phytosterols, phenolics, etc. Using *F. racemosa* in green synthesis technique provides a sustainable substitute for traditional chemical processes and improves the biomedical and environmental applications of NPs. Biogenically synthesized NPs possess biocompatibility, cost-effectiveness, and scalability, making them appropriate for many industrial applications [62]. The present approach is characterized by its simplicity, ease of execution, cost-effectiveness, and environmentally friendly nature.

2 Materials and methodology

2.1 Materials

The leaf extract of *F. racemosa*, Silver nitrate (AgNO_3 , 99.5% assay), Copper sulfate pentahydrate ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, 99.5% assay), Dimethyl sulfoxide (DMSO, 99.5% assay), and Ethanol ($\text{C}_2\text{H}_5\text{OH}$, 99.5% assay) were used to synthesize the NPs and were used without any additional purification. These high-purity reagents were purchased from Sigma Aldrich and Co. Human lung cancer cell lines (A549) and Roswell Park Memorial Institute (RPMI) 1640 media for culturing and were also procured from Sigma Aldrich and Co.

2.2 Synthesis of nanoparticles

The salt of silver, i.e., AgNO_3 in the aqueous medium, is the precursor of Ag^+ ions. As per the previously adopted

protocol, 5 mL of leaf extract was added to 50 mL of 0.05 M of AgNO_3 solution. On the other hand, in the conventional heating route, the reaction mixture consisting of plant extract and AgNO_3 was heated to 40 °C and under vigorous stirring for 40 min to ensure the reaction was completed. After some time, the liquid went from yellow to light brown, indicating the formation of Ag NPs. In the case of microwave-based heating, after 30 s, the mixture underwent a color shift from light to dark brown in color. This change indicates the synthesis of Ag NPs at the end of the reaction. For the synthesis of NPs via reduction, the Ag and Cu ions transform into Ag^0 and Cu^0 atoms, respectively. The possible reduction of Ag^+ to Ag^0 was accomplished due to the optimal concentration of phytoconstituents of *F. racemosa* leaf extract. The presence of unreacted AgNO_3 was confirmed in this case by conducting an effective AgNO_3 test. Specifically, NaCl (0.5 M) helped to maintain the pH of supernatant aqueous salt solutions. Ultimately, no precipitation due to AgCl or CuCl_2 was observed as per the procedure adopted by Yalappa et al. [63]. The plant extract derived from *F. racemosa* is crucial in synthesizing NPs as it effectively facilitates the reduction reaction, owing to its notable reduction potential.

The reduction potential of a plant extract directly affects its ability to donate electrons and facilitate the reduction process. *F. racemosa* is recognized for its bioactive components, including flavonoids, phenolics, tannins, and alkaloids. These phytochemicals can donate electrons and convert metal ions into their zero-valent state, resulting in NP formation. The reducing potential of *F. racemosa* extract is contingent upon the quantity and composition of its bioactive components. The reduction reaction occurs when metal ions are exposed to the extract at a specified pH and temperature. Moreover, these extracts frequently include stabilizing chemicals that aid in preventing the agglomeration of NPs and enhancing their stability. Figure 1 shows the schematic diagram underlying the proposed mechanism for synthesizing NPs [64, 65].

Figure 2a displays the flowchart illustrating the synthesis of Ag NPs using two distinct routes. $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ is the primary source of Cu^{2+} ions in the aqueous medium. The plant extract and a 0.05 M solution of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ were mixed in a ratio of approximately 1:2. The heating of the mixture was carried out up to 80 °C under continuous agitation for an hour until the reaction was terminated. After 5 min, the mixture changed to light greenish yellow from light blue, which is an indicator of the formation of NPs. Figure 2b depicts the flowchart for CuO NPs synthesis via green chemistry.

2.3 In-vitro anti-lung cancer activity

The toxicity of NPs is governed by several aspects, and the selection of the plant extract and process are crucial parameters. Plant extracts contain a range of phytochemicals,

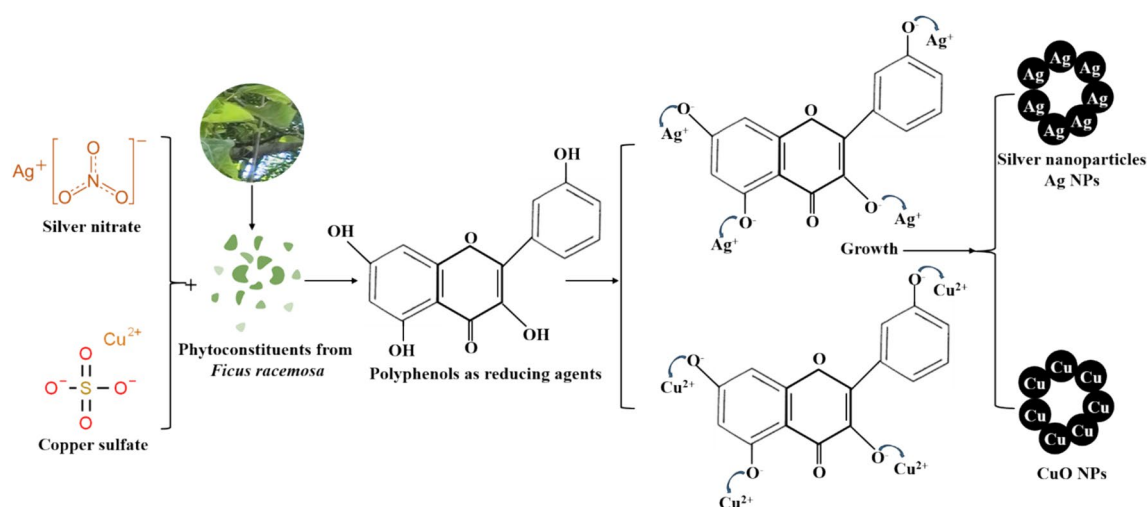
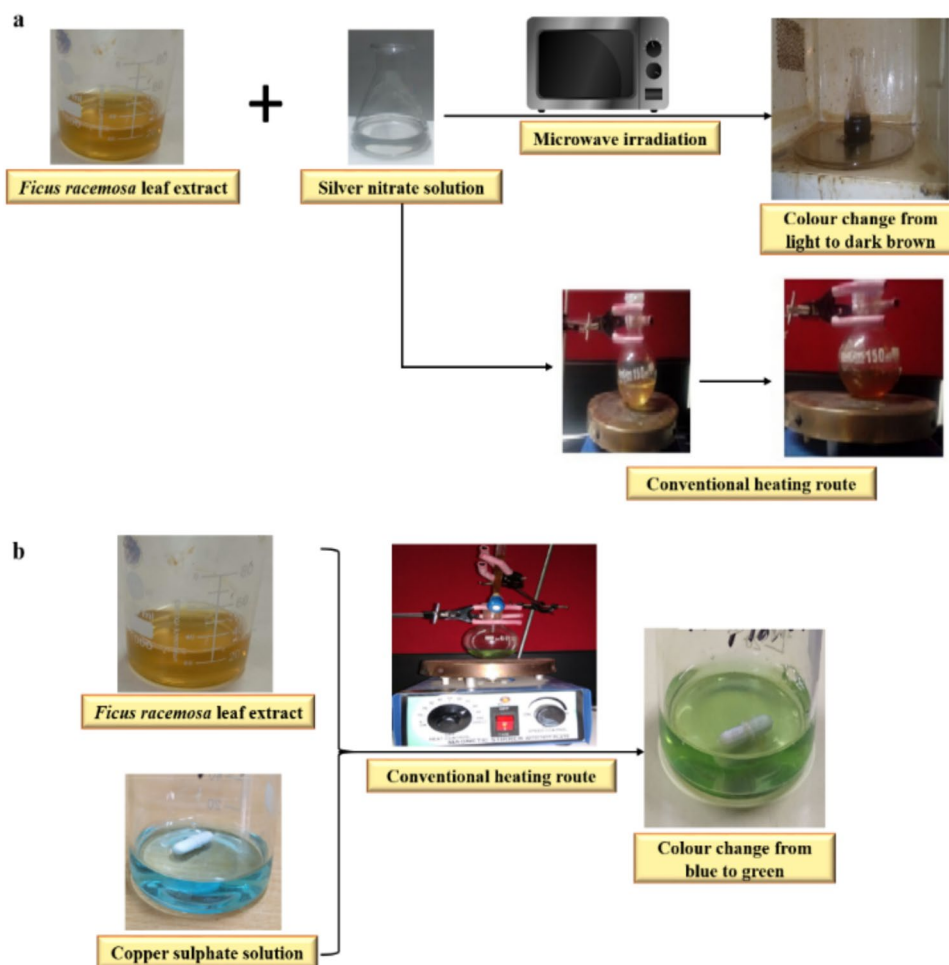


Fig. 1 Mechanism for the formation of nanoparticles via green synthesis

Fig. 2 Synthesis of Silver nanoparticles via **a** conventional route at 40 °C and microwave irradiation route, and **b** Copper oxide nanoparticles via conventional route



including flavonoids, terpenoids, and phenolic compounds [66]. These phytochemicals can affect the cytotoxicity of NPs [67]. For instance, extracts that are abundant in

antioxidants may result in a lower presence of harmful NPs than extracts that include high quantities of chemicals that induce reactive oxygen species [68]. Green synthesis

techniques can synthesize NPs with different morphologies and surface charges, affecting their interaction with biological cells [69]. Smaller NPs have a higher tendency to enter into the cells, which can result in more cytotoxic effects. Green synthesis enables the production of NPs of diverse compositions, including metal oxides of copper and silver, metallic NPs such as silver and gold, and carbon-based NPs like graphene oxide [70]. Due to its physicochemical features and interactions with biological systems, every composition can display distinct cytotoxicity profiles. Various cell viability assays (e.g., 3-[4,5-dimethylthiazol-2-yl]-2,5 diphenyl tetrazolium bromide (MTT) assay), evaluation of cellular anatomy and tests for cellular apoptosis are employed to quantify cytotoxicity. These assays offer valuable information about the interactions between green synthesized NPs and cells, their ability to kill cells and induce negative impacts on cellular activities [71]. Understanding the cytotoxicity of NPs is crucial to guarantee their effective utilization in biomedical and environmental contexts.

The A549 cell line was cultured in RPMI 1640 media supplemented with gentamycin (30 µg/mL) and Amphotericin B (25 µg/mL), as well as Minimum Essential media (MEM) non-essential amino acid and fetal bovine serum (FBS, 10%). The culture incubation was conducted in a controlled environment with high humidity and 5% CO₂ for 24 h at 37 °C. The cytotoxicity of CuO and Ag NPs was evaluated against the A549 cell line. The cells were individually allocated into 96-well plates, each containing a concentration of 1×10^5 cells. The trials were replicated and incubated for 24 h at 37 °C with a CO₂ concentration of 5%. After a day, the medium was removed and treated with 0.1 mL of CuO and Ag NPs at 15, 30, 50, 75, and 100 µg/mL concentrations in separate wells, excluding the cell control (DMSO). The specimen was incubated for 48 h. Following incubation, a 0.01 mL MTT reagent (5 mg/mL) was introduced into each well, including the control. The samples were thereafter placed in an incubator and kept at 37 °C for 2–3 h. The incubator was set to maintain a CO₂ concentration of 5%. Following the incubation period, a volume of 0.1 mL of formazan solution was introduced. Cellular viability was evaluated at a wavelength of 570 nm. The cell viability (%) was determined using the following formula:

% viability of cells

$$= \frac{\text{Optical density of cell line treated with NPs}}{\text{Optical density of control}} \times 100 \quad (1)$$

2.4 Dyes adsorption and degradation

Approximately 10 mL of 0.01% and 0.001% aqueous solutions of MB, BB, and MO containing 2 mg of Ag NPs were added as catalysts for dye degradation. After adding Ag NPs

to the solution of dyes, the UV–Vis absorption was examined at different intervals to determine the MB, BB, and MO concentrations.

3 Results and discussion

3.1 X-ray diffraction analysis

The Rigaku Smart lab 3 kW model acquired X-ray diffraction (XRD) patterns for Ag and CuO NPs. The tests were conducted using Cu K α radiation at 40 kV. The intensity of diffraction was measured at a wavelength of 1.541 Å, with the angle of diffraction (2 θ) spanning from 20° to 80° for Ag NPs and from 30° to 70° for CuO NPs at 1°/min scanning rate. The average size of the crystallite (nm) was determined using the Debye–Scherrer equation:

$$D = \frac{K\lambda}{\beta \cos \theta} \quad (2)$$

The variables in the equation are defined as follows: D represents the average size of the crystallite in nm, K is a dimensionless constant with a value of 0.90, λ represents the wavelength of X-ray (1.5406 Å), β represents the whole width at half maximum in radians, and θ represents the Bragg's diffraction angle. XRD ascertained the structure and phase of the synthesized NPs. The X'Pert HighScore Plus software helped to identify the phases in synthesized samples. The average crystallite size for Ag and CuO NPs was around 26 and 38 nm, respectively, as determined using Debye Scherrer's formula. The diffraction patterns indicate distinct intensity peaks being highly crystalline in the case of the synthesized NPs. The diffraction patterns of Ag and CuO NPs, respectively, are shown in Figs. 3a and b.

The peaks corresponding to Ag NPs were detected at 2 θ values of 26.62°, 32.76°, 38.09°, 47.02°, 54.84°, 58.47°, 61.97°, and 64.36° for Miller indices (011), (111), (020), (121), (022), (122), (031), and (131), respectively. The results are in accordance with the observations of Gauri et al. [72], Vanaja et al. [73], Asif et al. [74], and Dhoondia et al. [75]. The lattice parameters for Ag NPs are observed to be $a = b = c = 4.7310$ Å (Reference Code: 96-431-8189) with a cubic crystal geometry. Further, it can be observed that contaminant-free Ag NPs were synthesized as diffraction patterns other than those of Ag were absent. The peaks corresponding to CuO NPs were detected at 2 θ values corresponding to 32.15°, 32.80°, 38.26°, 38.91°, 50.88°, 52.53°, 55.81°, 57.84°, 64.98°, 66.23°, 67.26°, and 67.41° with miller indices (110), (002), (111), (200), (112), (020), (021), (202), (022), (310), (220), and (113), respectively (Reference Code: 96-901-5715). The lattice parameters of CuO NPs were determined as $a = 4.6790$ Å, $b = 3.4810$ Å,

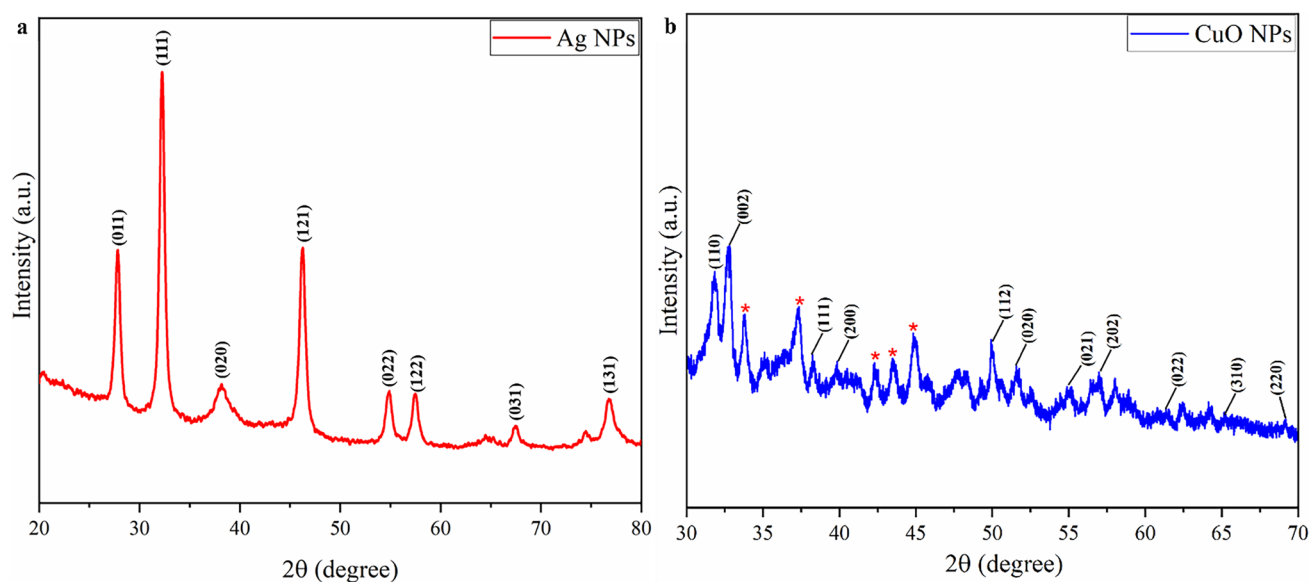


Fig. 3 Diffraction patterns of **a** Silver and **b** Copper oxide nanoparticles

and $c = 5.118 \text{ \AA}$ with a monoclinic crystal geometry. The results align with Roguai et al. [76], Subashini et al. [77], and Awwad et al. [78]. However, some unidentified peaks were also observed in the XRD pattern of CuO nanoparticles, as previously reported in several published studies [79, 80]. These peaks can be due to the phytoconstituents in the *F. racemosa* leaf extract. The average crystallite size is within the nanoscale range. Furthermore, no unknown phases were detected in the XRD analysis.

3.2 Ultraviolet–visible spectroscopic analysis

The interaction between metallic salts and leaf extract of *F. racemosa* is a unidirectional process. The change to a reddish-brown color reflected the reduction of Ag ions. Conversely, the change from pale blue to greenish yellow color indicates the conversion of Cu ions to CuO. The color formation is contingent upon stimulating surface plasmon oscillation of metallic NPs. The presence of Ag NPs was verified by the peak observed at 450 nm, as depicted in Fig. 4a and b. This aligns with the observation reported by Yallappa et al. [63] and He et al. [81]. However, for CuO NPs, a peak at 551 nm can be observed, which is in line with Sriramulu et al. [82]. The UV–Vis spectroscopy investigation illustrates the transformation of the phenolic chromophore to the excited from the ground state. In this process, the chromophore decreases AgNO_3 and CuSO_4 in the surrounding media, forming metallic NPs. The absorbance of synthesized silver NPs, through conventional and microwave-assisted methods, and synthesized CuO NPs were taken by varying the time intervals and amount of leaf extract used in the synthesis process.

Absorbance in both NPs increases when the time and concentration of leaf extract are increased during the synthesis, as shown in Figs. 4a–c.

3.3 Scanning electron microscopy and energy dispersive X-ray spectroscopic analysis

The morphological examination of NPs was carried out using SEM to identify their dimension and shape. The SEM examination showed that the dimensions and shape of Ag and CuO NPs synthesized by traditional and microwave-irradiation routes are distinct. The Ag and CuO NPs, synthesized using the traditional method, were spherical, with diameters ranging from 40 to 80 nm and 95 to 250 nm, respectively. On the other hand, the microwave-assisted synthesized Ag NPs exhibited a diverse range of morphologies, such as triangular, polygonal, and almost spherical. The size of these particles ranged from 80 to 300 nm, as shown in Figs. 5 (a–c). The quantitative elemental composition was determined using energy-dispersive X-ray spectroscopy (EDAX). It provides vital information about the quantitative assessment and distribution of elements within the present sample. It also facilitates spatial data analysis, allowing the creation of maps of the distribution of elements. Figures 6a and b display the EDAX spectra of Ag and CuO NPs synthesized using different methods.

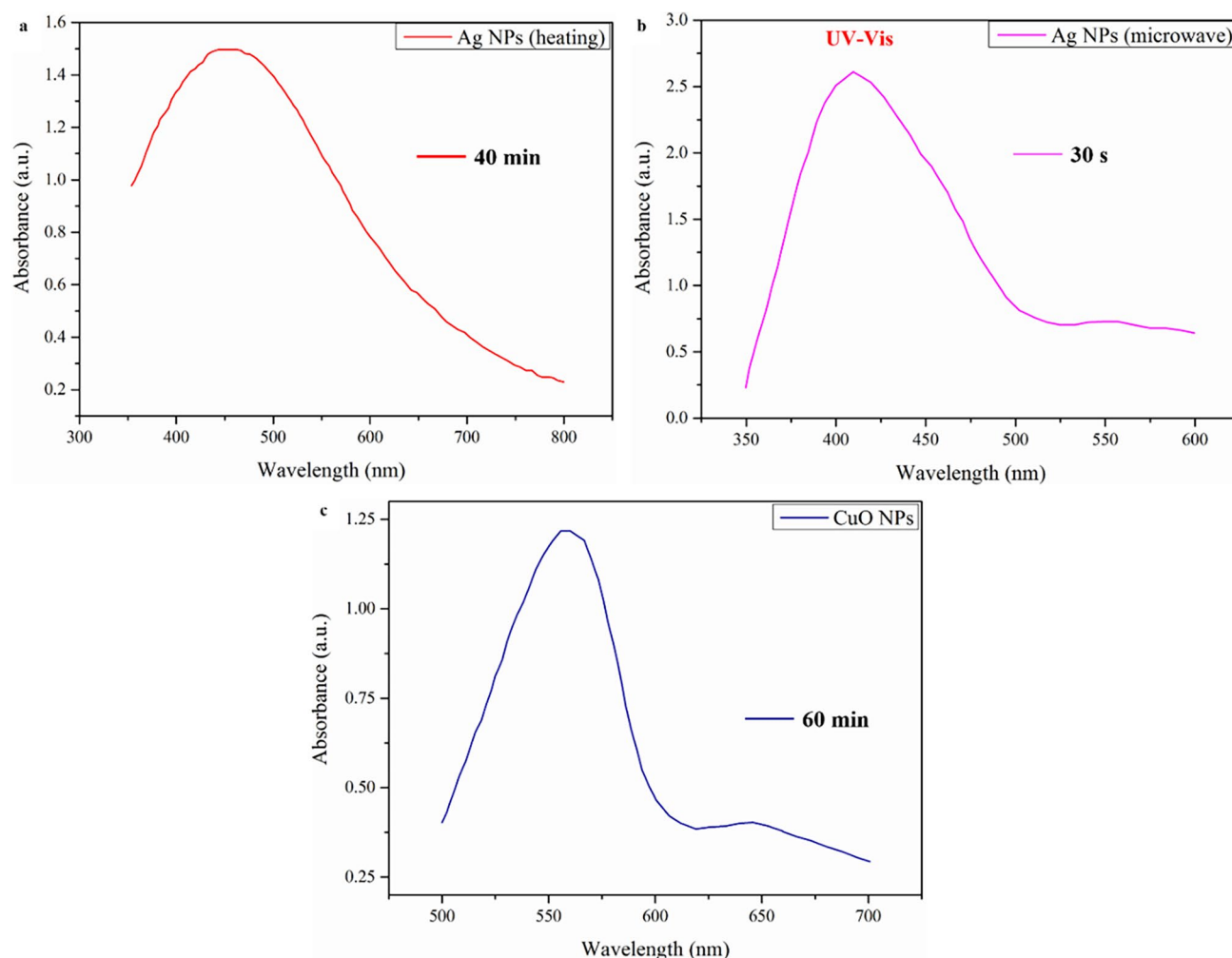


Fig. 4 Ultraviolet–visible analysis of Silver nanoparticles **a** via conventional route, **b** via microwave irradiation route respectively, and **c** Copper oxide nanoparticles

3.4 Transmission electron microscopy

The transmission electron microscope (TEM) utilizes an electron beam to inspect a sample visually. It can capture detailed information on a very small scale, even smaller than a light microscope. The computation of Ag NPs average particle was conducted using TEM (Model: Tecnai G2 20 S-TWIN) at 100 kV. The TEM images of AgO NPs are presented in Fig. 7a and histogram of the average size of particles is depicted in Fig. 7b. Some Ag NPs are spherical, while some are irregularly shaped. The average particle size for Ag NPs, as determined from Fig. 7b, is around 40 nm, which is aligned with the results of SEM.

3.5 Cytotoxicity analysis

Ag NPs are widely recognized for their exceptional anti-bacterial activity against bacteria, fungi, and viruses.

Nevertheless, a comprehensive understanding of the exact mechanisms responsible for the bactericidal impact of Ag NPs is still needed. There is a current discussion over the potential inhibitory effects of Ag NPs or silver ions on bacterial growth. The bactericidal activity of Ag NPs is assumed to be associated with the direct interaction between NPs and the bacterial cell wall, followed by their penetration into the cytoplasm. The uninterrupted contact between Ag NPs and the extensive bacterial cell wall surfaces can disrupt the cell membrane, releasing cellular components and ultimately causing cellular apoptosis [83–85]. Table 1 presents a comparative summary of the analysis of cytotoxicity of NPs.

The cell morphology before and after treatment with NPs is shown in Figs. 8a & b, whereas the concentration-dependent cytotoxicity plots against A549 are shown in Figs. 8c–e. From Fig. 8a, different morphology of Ag NPs can be observed.

Fig. 5 Scanning electron micrographs of **a** Silver nanoparticles via conventional route, **b** microwave irradiation route respectively, and **c** Copper oxide nanoparticles

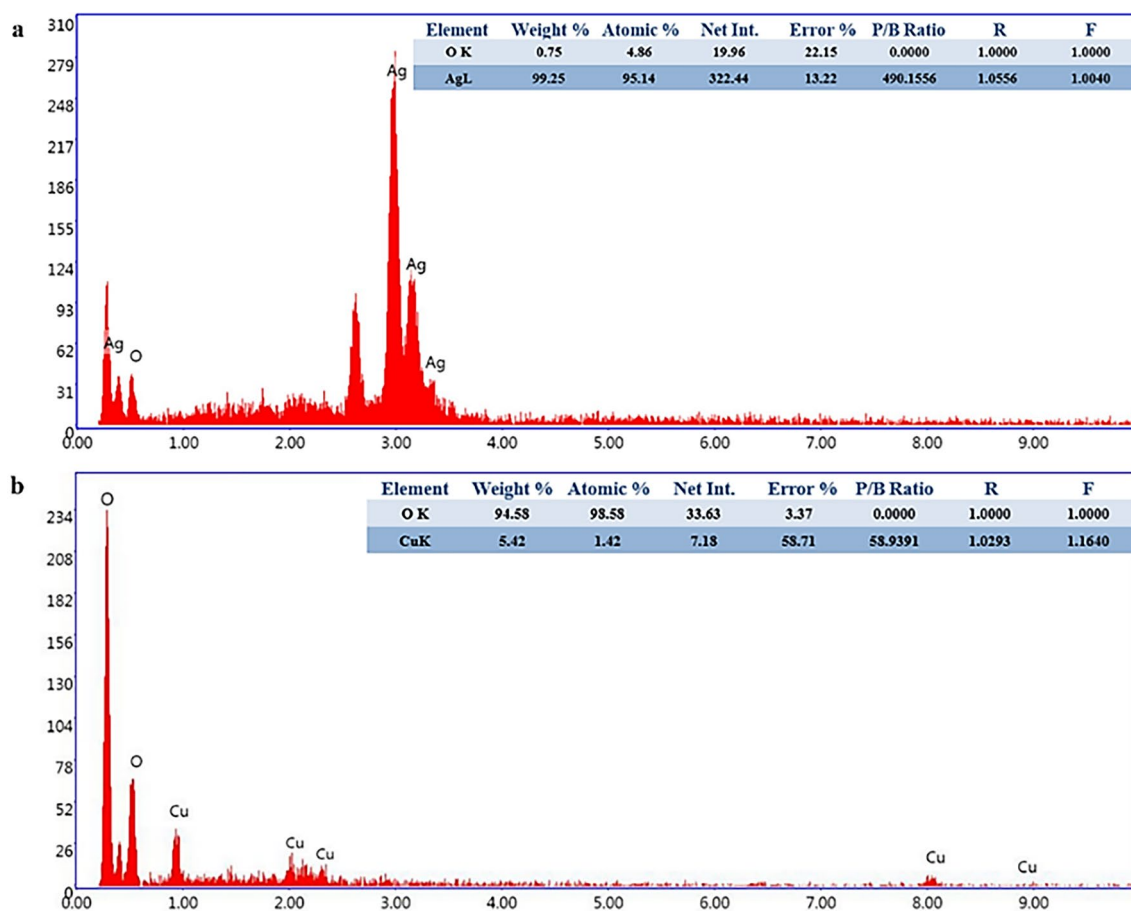
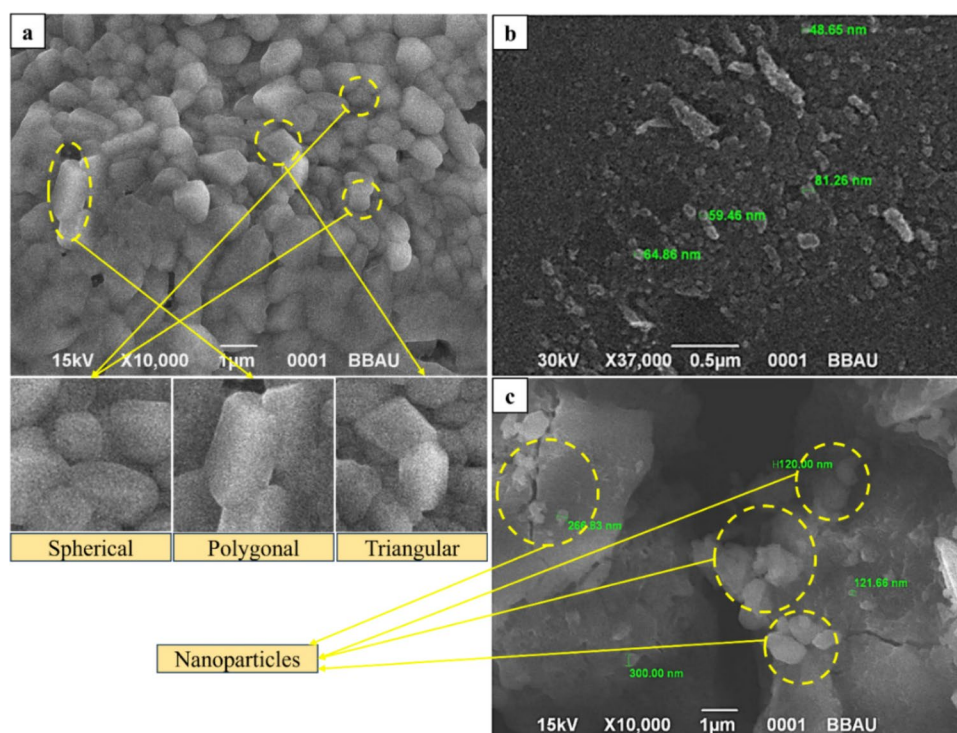


Fig. 6 Elemental composition of **a** silver and **b** copper oxide nanoparticles

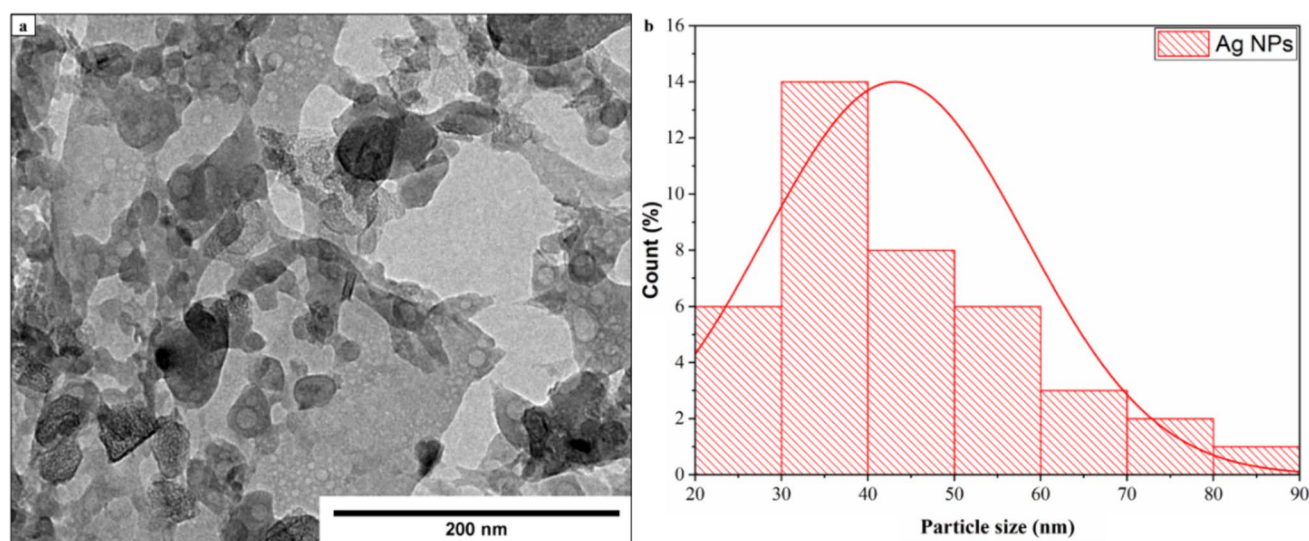


Fig. 7 **a** Transmission electron micrographs of Silver nanoparticles and **b** average particle size distribution histogram

Table 1 Comparative summary of the cytotoxic analysis of nanoparticles

Source	Nanoparticles	Physio-chemical characteristic	Remark	References
<i>Artemisia deserti</i>	CuO	Spherical, 9.72 ± 7.80 nm	A2780-CP cells showed minimal cytotoxicity on normal healthy human foreskin fibroblast cells	[86]
<i>Pterocladia capillacea</i>	CuO	Spherical, 62 nm	Compared to nedaplatin, higher toxicity towards cell lines of liver cancer, breast cancer, and ovarian cancer 0.40 ± 0.08 , 1.50 ± 0.12 , and 0.70 ± 0.09 $\mu\text{g}/\text{mL}$ as IC_{50} values	[87]
<i>Bacillus paramycoides</i>	Ag_2O	Spherical, 25–70 nm diameter	$\text{IC}_{50} = 50$ $\mu\text{g}/\text{mL}$ against A549	[88]
<i>Malus domestica</i>	Ag-CuO and CuO	Spherical, 18–20 nm	CuO had a larger ZOI than Ag–CuO NPs, and Cu^+ ions killed bacteria by enzyme binding action	[89]
<i>F. racemosa</i>	Ag and CuO	Spherical	IC_{50} values as 15, 30, 50, 75, and 100 $\mu\text{g}/\text{mL}$	Present work

The cytotoxicity of Ag and CuO NPs was assessed using the A549 cell line by the MTT test. These NPs exhibited anticancer effects on A549 cells that varied depending on their concentration. After 48 h of incubation, alterations in cell viability were detected in the cell lines treated with Ag and CuO NPs at various doses of 15 $\mu\text{g}/\text{mL}$, 30 $\mu\text{g}/\text{mL}$, 50 $\mu\text{g}/\text{mL}$, 75 $\mu\text{g}/\text{mL}$, and 100 $\mu\text{g}/\text{mL}$. DMSO exhibited 100% of normally functioning and actively dividing cells when used as a negative control. The IC_{50} value of CuO and Ag NPs was computed to be around 75 $\mu\text{g}/\text{mL}$ when compared with negative control. Thus, CuO and Ag NPs have shown anti-cancerous activity against A549 cell lines.

3.6 Dye degradation activity

The investigation of Methylene blue (MB) dye degradation at different time intervals was carried out using Ag NPs. The peak absorbance of MB was determined at 669 nm. The maximum absorbance of MB was measured at a wavelength

of 669 nm. The absorbance of MB dye rises proportionally with the increase in incubation time of the Ag NPs and MB aqueous mixture. The optical density of a 0.01% solution and a 0.001% solution of MB at 669 nm are 2.364 and 1.434, respectively. The absorbance was determined within a time frame of 0 to 30 min after the addition of Ag NPs. The data indicates a significant rise in absorbance, implying the decrease of the concentration of MB over time with no alteration in color during the degradation process. The absorbance for MB is shown in Fig. 9.

The 0.01% and 0.001% Methyl orange (MO) dye solutions absorb 2.889 and 0.382 at 464 nm, respectively. The MO solution was exposed to Ag NPs, and the absorbance was measured from 0 to 30 min. The degradation of MO was verified by the progressive rise in absorbance over time. Following complete degradation, the rate of absorbance increases diminished. There is no color change during degradation. The absorbance in the case of MO is shown in Fig. 10.

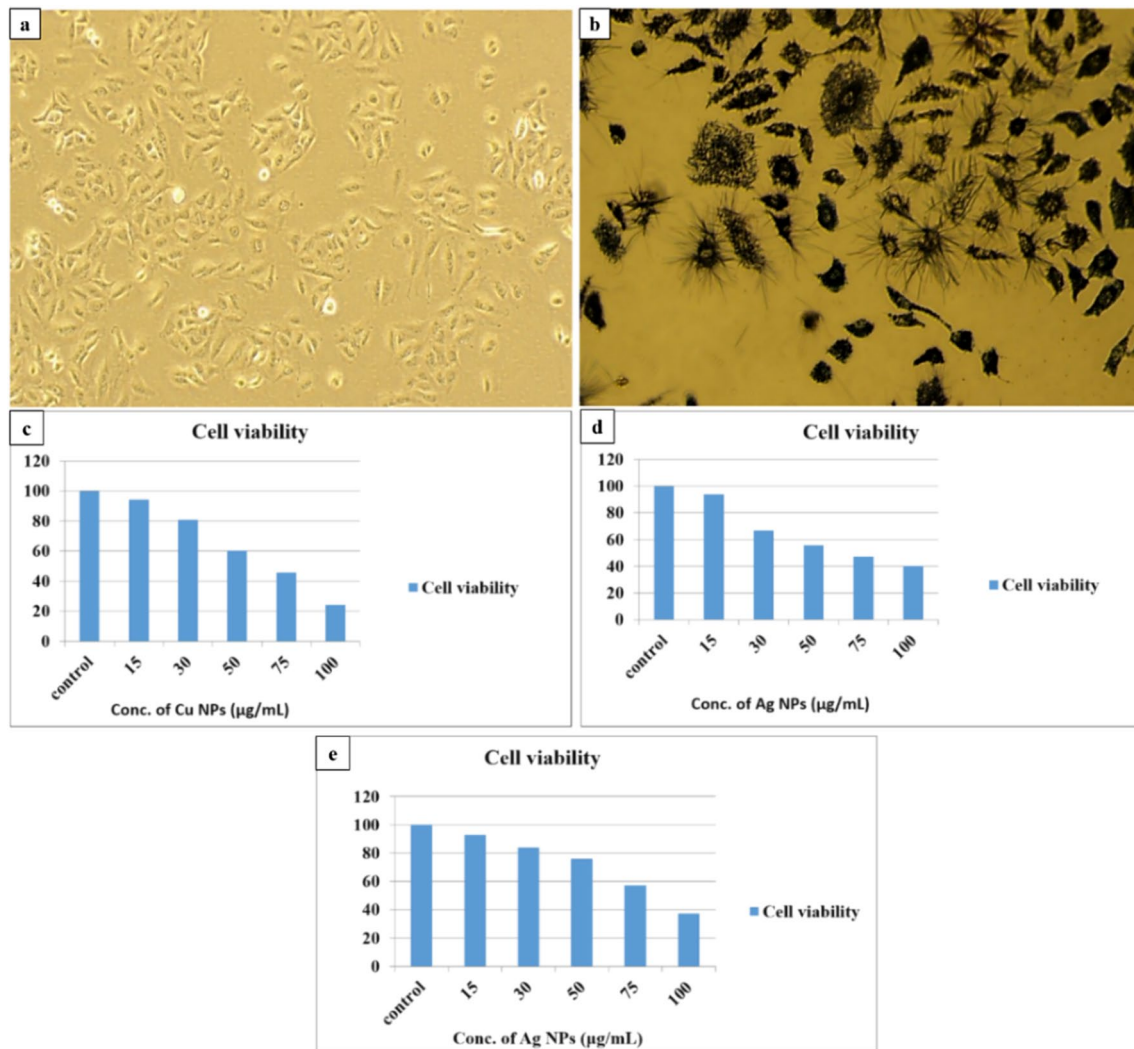


Fig. 8 Lung cancer cell line **a** before treatment, **b** after treatment with nanoparticles showing the anti-lung cancer activity, concentration-dependent cytotoxicity against A549 for **c** Copper oxide nanopar-

ticles, **d** Silver nanoparticles synthesized via conventional heating **e** silver nanoparticles synthesized via microwave-irradiation

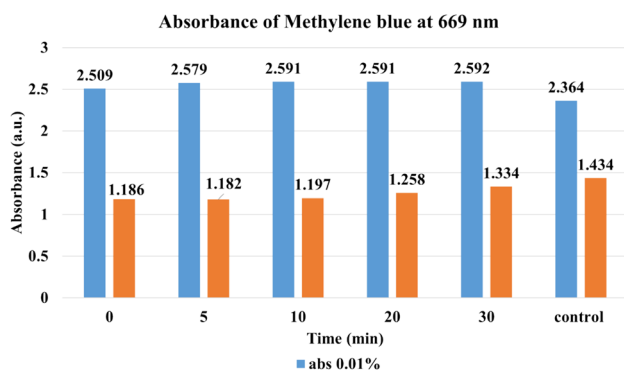


Fig. 9 An increase in the absorbance for Methylene blue corresponding to 669 nm at 0.01% and 0.001%

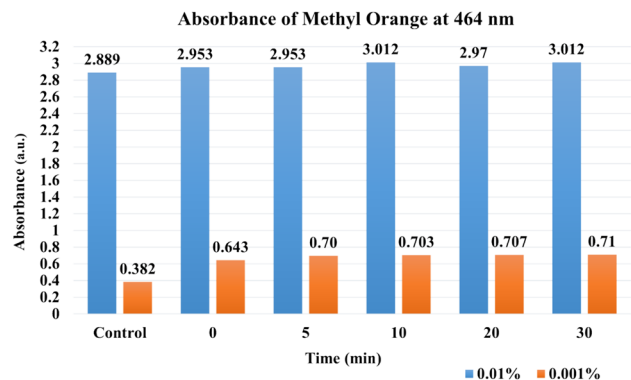


Fig. 10 An increase in the absorbance for Methyl orange corresponding to 464 nm at 0.01% and 0.001%

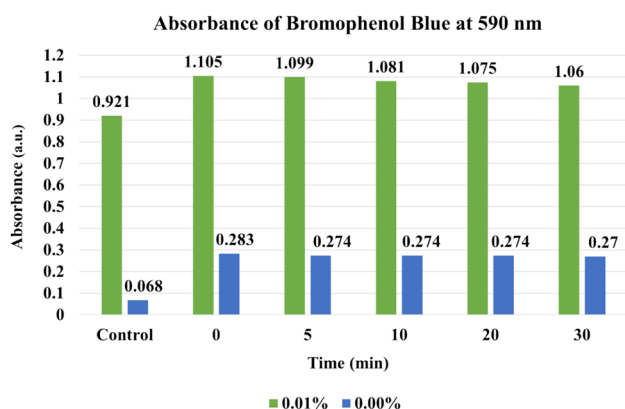


Fig. 11 A decrease in the absorbance for Bromophenol blue corresponding to 590 nm at 0.01% and 0.001%

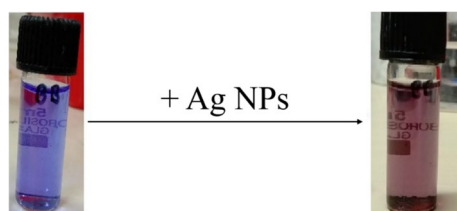


Fig. 12 Color change of Bromophenol blue and Ag NPs mixture from blue to light magenta

The absorbance of a 0.01% solution and a 0.001% solution of Bromophenol blue (BB) dye at 590 nm is 0.735 and 0.068, respectively. Following the application of Ag NPs, the SRP of the combination rises from 0.735 and 0.067 to 1.105 and 0.283, respectively, within 0 min. Nevertheless, as the incubation time increases, the absorbance peak diminishes, signifying the breakdown of BB dye. There is a visible change in color during the degradation of BB from blue to light magenta. The degradation of BB is visible through color change; therefore, the BB is more degradable than the MB and MO. Degradation of these dyes occurs without any reducing agent, so it reduces cost and is eco-friendly. The absorbance in the case of Bromophenol blue is shown in Fig. 11.

As seen in Fig. 12, the transformation of BB from blue to bright magenta in the presence of Ag NPs can be observed.

4 Conclusions

The water-based extract of *F. racemosa* leaves was effectively used to synthesize Ag and CuO NPs. The present method is simple, inexpensive, eco-friendly, and does not rely on harsh chemical reagents. The XRD analysis reveals that the synthesized samples comprise a single phase of Ag

and CuO NPs. The average size of the crystallites is 26 nm for Ag and 38 nm for CuO, respectively. The crystal structure of Ag is cubic, while CuO is monoclinic. The presence of Ag and CuO NPs was confirmed by a peak around 450 nm and 551 nm for Ag and CuO, respectively. The SEM images revealed that Ag and CuO NPs, synthesized via the traditional method, displayed a spherical shape, with diameters ranging from 40 to 80 nm and 95 to 250 nm, respectively. In contrast, the Ag NPs synthesized under microwave irradiation exhibited diverse morphologies, including triangular, polygonal, and almost spherical. The particles exhibited a size distribution that varied between 80 and 300 nm. The EDAX spectra showed no extra peaks besides Ag, Cu, and O in the synthesized samples. The present study successfully explored the potential of biogenically synthesized NPs and their effect on the A549 cell line. Ag and CuO NPs have shown an enhanced cytotoxic effect on the A549 cell line. The results suggest that metallic NPs may serve a broader range of chemotherapeutics while directly targeting the tumor cells. The present study also gives a clear idea of the potential biomedical applications of Ag NPs against cancer treatment. Thus, these NPs can effectively treat cancer through less costly invasive methods. The cost of dye degradation using the synthesized NPs may be significantly reduced using the green synthesis route. In the future, the *in-vivo* animal model analysis will provide a clear picture of anti-lung cancer activity on a much broader level. NPs synthesized via the green synthesis route can be utilized in environmental and biomedical fields. The present work also presents a hopeful resolution to the issue of dye pollution in aquatic environments, substantially contributing to improving cleaner and safer ecosystems.

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Declarations

Conflict of interest It is declared by the authors that they do not have any known conflicting financial interests or personal ties that may have seemed to affect the work that is disclosed in this publication.

Ethical approval This manuscript does not report on or involve the use of any animal or human data or tissue. So the ethical approval is not applicable.

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