REVIEW ARTICLE

Exploring the Biomedical Applications of Plant-mediated Silver Nanoparticles and Eco-friendly Solutions

M. Maghimaa[1], Ethihas Reddy Mahasamudram[2]

[1]Phytomedicine, Natural Products and Cancer Biology Lab, Department of Pathology, Saveetha Medical College and Hospital, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamil Nadu, India, [2]Department of General Medicine, Saveetha Medical College and Hospital, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamil Nadu. India

Abstract

Cancer continues to be a major cause of death worldwide. Cancer is among the primary causes of mortality and illness, characterized by a complex pathophysiology. Conventional cancer treatments encompass chemotherapy, radiation, targeted, and immunotherapy. Still, challenges, such as a lack of specificity, cytotoxic effects, and multidrug resistance significantly hinder effective cancer management. The emergence of nanotechnology has transformed the field of cancer diagnosis and treatment. The exceptional optical, electrical, and catalytic characteristics of silver nanoparticles (AgNPs) have garnered the interest of researchers due to their small size. This review aims to investigate the biomedical applications of plant-assisted nanoparticles (NPs) as a strategy to address antimicrobial resistance, anticancer, antimicrobial, and wound-healing properties. This method presents a sustainable and eco-friendly alternative to antibiotics and traditional chemical synthesis techniques for generating AgNPs. Various analytical methods are utilized to assess the morphological, structural, and compositional properties of these NPs. AgNPs are evaluated for their effectiveness as anticancer agents against breast, prostate, and lung cancers. The environmentally friendly synthesis of AgNPs through greener methods offers several advantages over chemical and physical processes, including cost efficiency, the absence of toxic byproducts, sustainable environmental pathways, ease of regeneration, and the bio-reducing capabilities of plant-assisted NPs. This review delivers a comprehensive overview of the various biomedical applications of plant-assisted AgNPs, which demonstrate antimicrobial, antibiofilm, anticancer, and wound healing properties. In conclusion, we emphasize the importance of developing sustainable methods, expanding the range of biomedical applications, establishing safety protocols, promoting good health and well-being for the responsible use of AgNPs.

Key words: Anticancer, biomedical applications, good health and well-being, plant extracts, wound healing

INTRODUCTION

Cancer is a broad term that encompasses a variety of diseases marked by uncontrolled and random cell division, as well as invasiveness. Significant efforts have been dedicated over the years to identifying different risk factors associated with cancer. In certain types of cancer, the causes have been notably linked to specific environmental factors (acquired factors), such as radiation exposure and pollution. Nevertheless, an unhealthy lifestyle, including a poorly balanced diet, tobacco use, smoking, stress, and insufficient physical activity, has a profound effect on the assessment of cancer risk. While these external factors are acknowledged as primary contributors to cancer, the role of mutations in proto-oncogenes, the expression patterns of tumor suppressor genes, and the genes involved in DNA repair has proven challenging to quantify. Only about 5–10% of cancer cases are associated with inherited genetic factors. In addition, advancing age is a significant risk factor for cancer, as well as for many specific types of cancer.[1]

Address for correspondence:
M. Maghimaa, Phytomedicine, Natural Products and Cancer Biology Lab, Department of Pathology, Saveetha Medical College and Hospital, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai - 602 105, Tamil Nadu, India.
E-mail: maghimaamm@gmail.com

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The prevalence of antimicrobial resistance (AMR) is attributed to the appropriate and inappropriate use of antibiotics in humans and animals, in addition to the environmental contamination caused by antibiotic residues, *AMR* genes, and bacteria.[2] The misuse of drugs across various sectors of the healthcare system[3] accelerates the development of resistance an irreversible boost and renders clinically essential drugs ineffective.[4] In the United States, more than 2.8 million drug-resistant infections occur each year, leading to over 35,000 deaths.[5] A recent study indicates that worldwide, 1.27 million fatalities in 2019 were directly associated with AMR.[6] Jewell *et al.* investigated the significant variations in the proportion of resistant isolates across different sources, with humans-derived isolates exhibiting the maximum resistance, and environmental sources displaying the lowest resistance.[2] In recent years, significant research has been focused on the development of silver nanoparticles (AgNPs) using plant extracts from various parts, such as leaves, roots, flowers, barks, stems, and whole plant parts to combat drug resistance. Nanomaterials, defined by their size ranging from 1 to 100 nm, exhibit distinctive properties that render them highly sought after for a variety of applications, such as pharmaceuticals, catalysis, sensors, electronics, and the production of composites, among others.[7] Growing applications of nanoparticles (NPs) and nanomaterials are driven by their novel or enhanced properties based on morphology, size, and distribution.[8] In biomedicine, these NPs hold potential applications for cancer treatment, drug delivery, and diagnostic imaging. Various methods, including biological, chemical, and physical approaches, are utilized for the synthesis of NPs. A more environmentally friendly approach may be achieved by using resources, such as plant extracts, agricultural waste, enzymes, organisms, as well as ultrasound and microwave-assisted synthesis.[9] Nanomaterials produced through greener synthesis approaches provide an excellent eco-friendly alternative for generating recyclable and non-toxic nanomaterials with minimal waste byproducts. These techniques are in line with the increasing focus on sustainable practices for nanomaterial production. Especially, biological substrates, including plant extracts, bacterial components, and fungi, have attracted attention for the production of metal and metal oxide-based nanomaterials.[10] In particular, plant-assisted synthesis has received considerable interest due to the wide variety and abundance of plant species, which serve as a rich source of bioactive constituents for the synthesis of NPs.[11] However, this review explored plant-assisted NPs against antimicrobial, anticancer, antibiofilm and wound healing applications.

PLANT-ASSISTED AGNPS SYNTHESIS

Plants and their components harbor diverse substances, such as carbohydrates, pigments, alkaloids, alcohols, lipids, polysaccharides, vitamins, assorted secondary metabolites, and proteins. In the field of synthesizing NPs from metal salts, these materials serve various functions as reducing, capping, or stabilizing agents, resulting in the production of minimal to negligible harmful by-products.[12] Green synthesis utilizing plant extracts emerges as a preferred method for NPs production due to its cost-effectiveness, simplicity, and sustainability.[7,13] Using leaf extracts of *Ocimum basilicum*, *Beta vulgaris*, and *Raphanus sativus* as reducing agents, Garcidueñas-Piña *et al.* investigated the synthesis of AgNPs.[14] Ajaykumar *et al.* investigated the synthesis of AgNPs using leaf extracts from the therapeutic plant *Uvaria narum*, also known as narumpanal [Figure 1].[15]

CHARACTERIZATION OF AGNPS

Hemlata *et al.* investigated the *Cucumis prophaterum* leaf extract's Fourier-transform infrared spectroscopy spectra in relation to Cp-AgNPs and showed notable peak position alterations caused by the stabilization, capping, and reduction of the synthesized NPs' processes. These shifts indicate the involvement of various compounds, such as phenolic compounds, methylene group or aliphatic group, triterpenoid saponins; alkenyl or aromatic phenol or tertiary alcohols, phenol group, aliphatic chlorocompounds; and aromatic groups. The predominant peaks corresponded to phenolic groups present in triterpenoids, polyphenols, steroids, tannins and alkaloids sufficiently which exist in the leaf extract, and facilitate the Cp-AgNPs formation. The morphology of the formulated Cp-AgNPs was investigated through scanning electron microscopy (SEM) and revealed the polymorphic shapes; including ellipsoidal, irregularly granulated, and highly aggregated. Elemental analysis conducted through energy dispersive X-ray spectroscopy revealed a prominent absorption peak for silver at 3 keV, indicating that silver is the primary component. Microscopic (SEM) analysis further confirmed the uniform distribution and spherical shape of Cp-AgNPs.[16] AgNPs from leaf extracts of *Paliurus spina-christi*, *Juglans regia, Humulus lupulus*, and *Sambucus nigra* were shown in field emission-SEM microphotographs by Krkobabić *et al*. together with the associated size distribution [Figure 2a-h]. NPs, primarily spherical and solitary, with an average size of 63 ± 18 nm, were formed as a result of all plant extracts [Figure 2a]. The majority of NPs were found to be between 50 and 60 nm in size, according to Figure 2b. Furthermore, single and agglomerated AgNPs (66 ± 17 nm) were uniformly dispersed in Figure 2c.[17] AgNPs had a tetrahedral shape according to SEM analysis, however a crystalline size of 26.7 nm was found by X-ray diffraction.[18]

THERAPEUTIC APPLICATIONS OF PLANT-ASSISTED AGNPS

NPs have garnered significant attention in biomedical applications for several decades. Among them, AgNPs have emerged as potential antibacterial agents, suitable for incorporation into diverse nanostructured materials of different

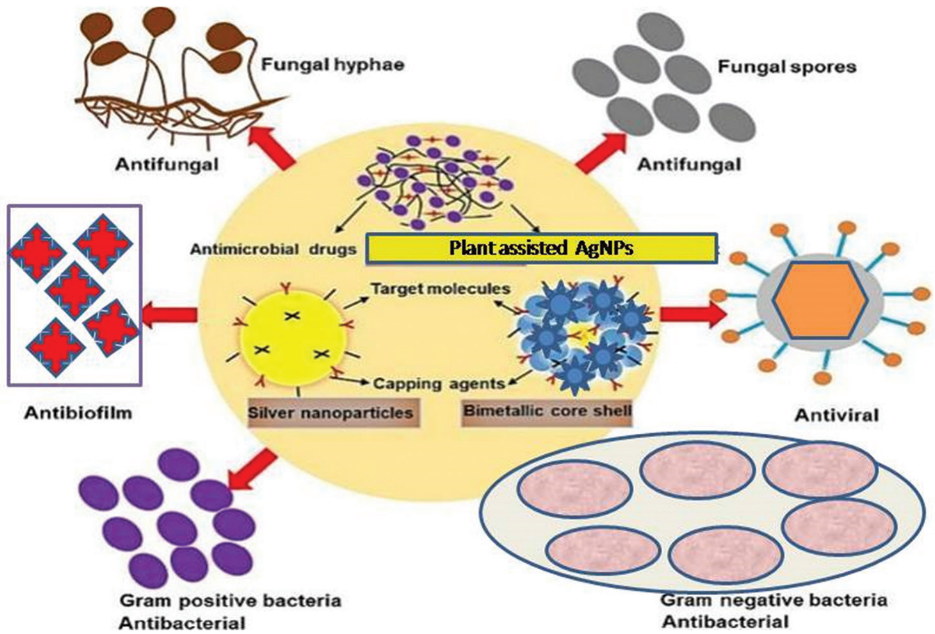

Figure 1: Plant-assisted silver nanoparticles for biomedical applications

shapes and sizes. AgNPs-based antimicrobial constituents are used in an extensive range of applications, including therapeutic uses, surface treatments, coatings, chemical and food industries, as well as agricultural productivity. The anticancer, antimicrobial, antibiofilm and wound healing properties of plant-assisted AgNPs have been addressed in this review.

ANTIMICROBIAL APPLICATIONS

The main source of treatments for all bacterial infections is antibiotics. Multidrug-resistant pathogens; however, represent a serious worldwide risk. Treatment for infections brought on by AMR bacteria is challenging and presents significant obstacles to present antibiotic regimens. Developing new antibiotics takes not only time but also a significant financial commitment.[19] Plant-assisted AgNPs are therefore becoming more and more popular as solutions to fight antibiotic resistance.

Yadav *et al.* conducted a study on the antibacterial properties of AgNPs derived from *Grewia tenax*, a locally cultivated berry recognized for its medicinal benefits, particularly against stomach disorders. The size of the AgNPs extracted from the leaf of the *Grewia* plant was measured at 109 nm through DLS analysis, demonstrating notable antimicrobial efficacy against several bacterial strains, including *Bacillus subtilis* (22.7 mm ± 1.52), *Escherichia coli* (18 mm ± 1), *Pseudomonas aeruginosa* (20 mm ± 1), and *Staphylococcus aureus* (17 mm ± 1).[20] In addition, AgNPs coated with *Ziziphus spina-christi* leaf extract showed effectiveness against *E. coli*, *S. aureus*, and *Candida albicans* (24.50 ± 1.50).[21] Furthermore, Aljeldah *et al*. detailed the antibacterial bioactivity of AgNPs sourced from *Hibiscus sabdariffa* flower extract, which were effective against *Enterobacter cloacae* (12.82 ± 0.36 mm), Methicillin-resistant *S. aureus* (14.54 ± 0.15 mm), *Klebsiella pneumoniae* (18.35 ± 0.24), and *E. coli* (21.69 ± 0.12).[22]

AgNPs work against bacteria by electrostatically interacting with their cell walls and membranes, which results in morphological alterations [Figure 3], membrane depolarization, and eventually cell death. Proteins, enzymes, DNA, ions, and metabolites are among the vital cellular components that are released into the environment as a result of the breakdown of bacterial cell walls and membranes.[22] Hemlata *et al.* demonstrated dosage-dependent inhibition activity of NPs *Cucumis prophetarum*, particularly effective against *Salmonella* Typhi compared to *S. aureus.*[16]

Krkobabić *et al.* showed strong antibacterial activity of AgNPs from leaf extracts of *J. regia*, *P. spina-christi*, *S. nigra* and *H. lupulus* against *S. aureus* than with varying efficacy against *E. coli.*[17] Similarly, Jamil *et al.* found significant antibacterial activity of AgNPs from *Aloe fleurentinorum* leaves against various bacterial pathogens including *B. subtilis*, *S. aureus*, *S. typhi* and *E. coli* with ZOI from 1 mm to 18 mm. Notably maximum zones of inhibition observed against *E. coli* (16–18 mm), maybe due to the thickness of the bacterial cell wall.[18] Ahmad *et al*. demonstrated significant antimicrobial efficacy of AgNPs against *E. coli*, *S. aureus,* and *Salmonella* Typhimurium[23] [Table 1].

ANTI-BIOFILM PROPERTY

"Biofilm" refers to the microbial community that adheres to a surface and is encased in a matrix of extracellular polymeric

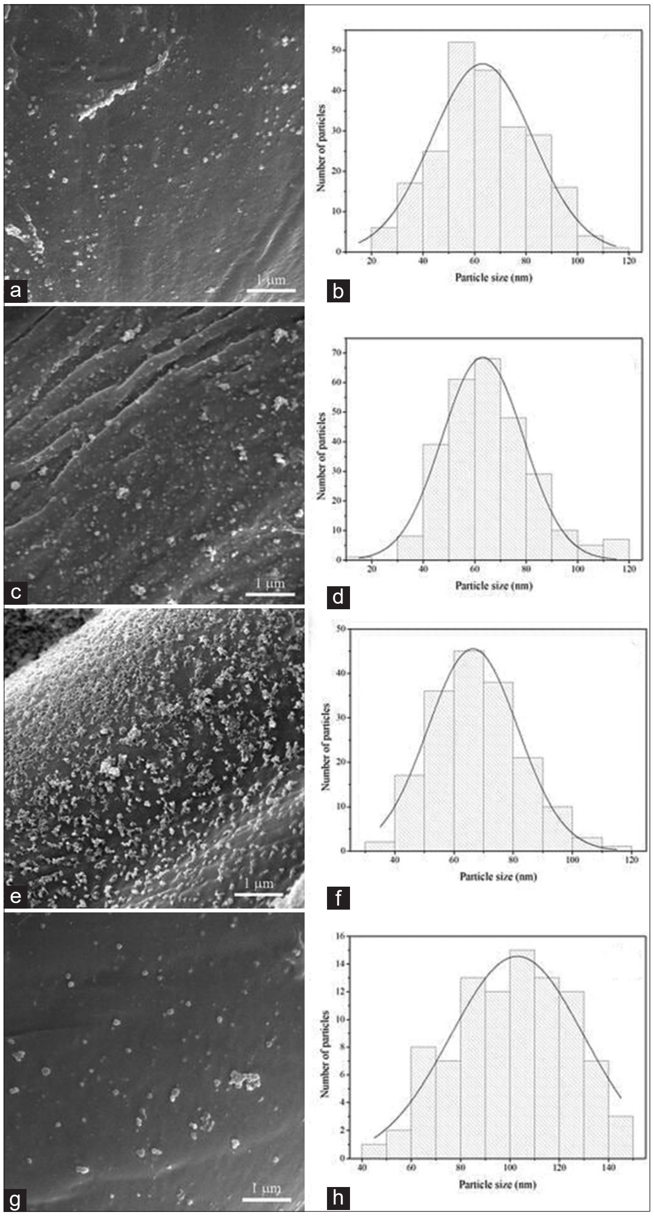

Figure 2: (a-h) Field emission scanning electron microscopy micrographs along with the size distribution represented by a Gaussian curve of silver nanoparticles[17]

molecules. These biofilms can cause significant financial losses and other problems in a variety of industries, including shipping, healthcare, and petroleum. The potential of NPs to fight biofilm by focusing on many phases of its production process has been clarified in recent years.[36] Pathogenic bacterial species often aggregate, adhere, reproduce, and form a complex three-dimensional structure on biotic or abiotic surfaces, termed biofilm.[37] Once they have matured, these biofilms can move to form new biofilms and hold onto dormant bacteria. Biofilms' extracellular components, including proteins, lipids, polysaccharides, and nucleic acids, function in concert with the network and the firmly established bacterial cells.[38] Adhesion, along with protection, nutritional supply, distribution of metabolites, resistance to environmental stressors, and defense against antimicrobial agents, represents the functions these elements serve. By preventing antibiotic penetration, encouraging enzymatic breakdown, and enabling the development of resistance in protected bacterial cells through genetic modification, biofilms offer a strong defense against antibiotics. Consequently, biofilm components are recognized as promising targets for antimicrobial therapy.[39] Yadav *et al.* showed the potent antibiofilm activity against the fungi *A. niger* and *C. albicans*.[20] Mostafa *et al.* explored the inhibition of biofilm formation percentage for S. aureus (79.48), E. coli (78.79), P. aeruginosa (77.50), and C. albicans (73.73).[27] Singhal *et al*. explored the leaf extract of *Punica granatum*-AgNPs was exhibited increased antibiofilm activity using Crystal violet staining and the Congo red test. The enhanced inhibition of biofilm formation occurs with elevated concentrations of AgNPs, ranging from 12.5 to 100 µg/mL.[28] While Barabadi *et al.* examined *Zataria multiflora*-AgNPs, they demonstrated biofilm inhibition activity at concentrations of 0.5, 1, 2, and 4. The minimum inhibitory concentration resulted in strong biofilm formation, weak biofilm formation, and no biofilm formation, respectively. Importantly, a concentration of ≥8 µg/mL of AgNPs exhibited biofilm inhibition, while at lower concentrations, the AgNPs confirmed maximum biofilm inhibition produced by *S. aureus*.[29] These findings underscore the potential of NP-based approaches in combating biofilm-associated issues.

ANTICANCER ACTIVITY

According to the US National Cancer Institute, cancer is defined as the unchecked proliferation of body cells that may have the ability to spread to other parts of the body. With around 10 million deaths in 2020, it remains the leading cause of death globally.[40] Of all the many types of cancer, breast cancer was the most common worldwide, accounting for 2.26 million new cases. Lung cancer came in second with 2.21 million new cases, which led to 1.80 million fatalities. About 22% of cancer-associated deaths are attributable to tobacco smoking, and 10% are related to other factors, such as excessive alcohol use, poor eating habits, and a lack of physical activity. 15% to bacterial and viral infections, including as human immunodeficiency virus, Epstein-Barr virus, human papillomavirus, and Hepatitis B and C contribute to 5–10% of inborn genetic abnormalities and 15% of cancer mortality.[41] Environmental factors, such as ultraviolet and ionizing radiation, as well as exposure to certain chemicals, such as asbestos and arsenic also play roles in cancer development in humans. Surgery, radiation therapy, chemotherapy, hormone therapy, targeted biological therapies, or combinations of these are commonly used as cancer treatment methods. However, these therapies often come with various side effects ranging from mild discomforts, such as weight loss and nausea, to more severe consequences, such as hair loss, cardiotoxicity, and even mortality. Numerous studies have examined AgNPs' cytotoxic effects on cancer cells in recent years, indicating their potential for use in cancer treatment.[36]

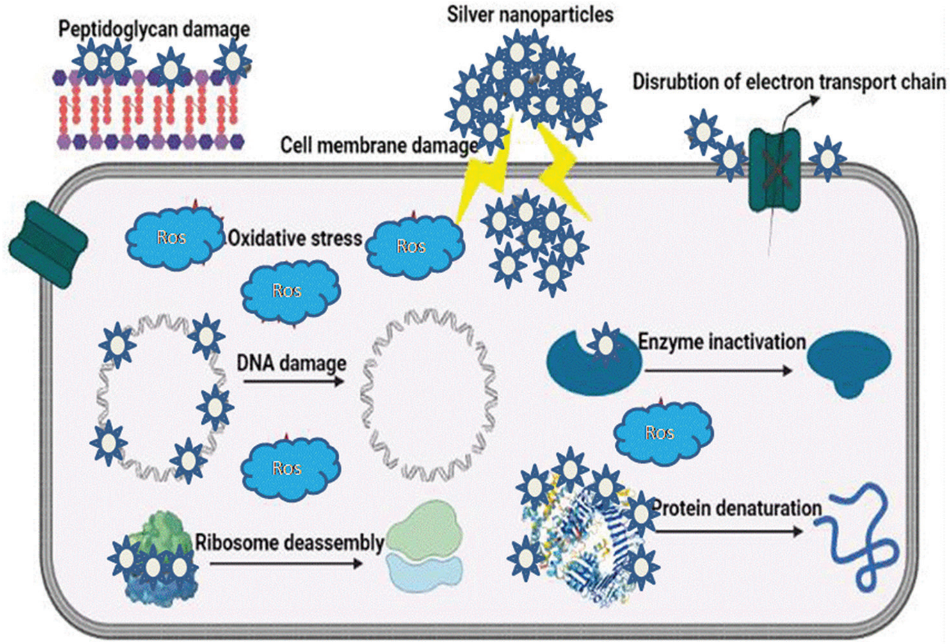

Figure 3: Mechanism of antibacterial property of plant-assisted nanoparticles against bacterial cells

Table 1: Plant-assisted silver nanoparticles for its biomedical applications

S. No.	Plant-assisted silver nanoparticles	Morphology and size (nm)	Biomedical applications	References
1	*Grewia tenax*	44 and Spherical	Antibiofilm	Yadav *et al*. (2024)[20]
2	*Grewia tenax*	44 and Spherical	Antibacterial	Yadav *et al*. (2024)[20]
3	*Ziziphus spina-christi*	34 and Spherical	Antibacterial and antifungal	Hussein *et al*. (2023)[21]
4	*Hibiscus sabdariffa*	58.682 and Spherical	Antibacterial	Aljeldah *et al*. (2023)[22]
5	*Cucumis prophetarum*	30–50 and Spherical	Antibacterial, Antiproliferative and anticancer	Hemlata *et al*. (2020)[16]
6	*Paliurus spina-christi*	57 and Spherical	Antibacterial and Anticancer	Krkobabić *et al*. (2024)[17]
7	*Juglans regia*	50 and 60 and Spherical	Antibacterial and Anticancer	Krkobabić *et al*. (2024)[17]
8	*Humulus lupulus*	66±17 and Spherical	Antibacterial and Anticancer	Krkobabić *et al*. (2024)[17]
9	*Sambucus nigra*	68±15 and Spherical	Antibacterial and Anticancer	Krkobabić *et al*. (2024)[17]
10	*Aloe fleurentinorum*	Tetrahedral	Antibacterial	Jamil *et al*. (2024)[18]
11	*Cinnamomum zeylancium*	45–65 and Spherical	Antibacterial	Ahmad *et al*. (2023)[23]
12	*Taxus wallichiana*	Spherical	Antibacterial and Anticancer	Yousaf *et al*. (2022)[24]
13	*Callisia fragrans*	48 and Spherical	Anticancer	Nguyen *et al*. (2023)[25]
14	*Tridax procumbens*	11.1 to 45.4 and Spherical	Antibacterial and Anticancer	Pungle *et al*. (2022)[26]
15	*Orobanche aegyptiaca*	30.58 andSpherical	Antimicrobial and Antibiofilm	Mostafa *et al*. (2023)[27]
16	*Punica granatum*	37.5 and Spherical	Antimicrobial and Antibiofilm	Singhal *et al*. (2021)[28]
17	*Zataria multiflora-*	25.5 and Spherical	Antimicrobial and Antibiofilm	Barabadi *et al*. (2021)[29]
18	*Achyranthes aspera*	Spherical	Wound healing	Shidramshettar *et al*. (2024)[30]
19	*Juglans regia L.*	Spherical	Antibiofilm	Al-Nadaf *et al*. (2024)[31]
20	*Curcuma longa*	Spherical	Antibacterial and wound healing	Maghimaa *et al*.(2020)[32]
21	*Alternanthera sessilis*	10.27 and Spherical	Biomedical applications	Kabeerdass *et al*. (2022)[33]
22	*Uvaria narum*	7.13 and Spherical	Antibacterial and Anticancer	Jamil *et al*. (2024)[18]
23	*Boerhaavia diffusa*	30 nm	Antibacterial and Anticancer	Sudhakar *et al*. (2025)[34]
24	*Solanum trilobatum*	50 nm	Antibacterial	Abareethan *et al*. (2024)[35]

Yousaf *et al*. inspected the considerable cytotoxic activity of Taxus wallichiana-AgNPs against U251 brain cancer cells and demonstrated potential glioblastoma treatment.[24] Hemlata *et al*. showcased the antiproliferative effects of *C. prophetarum* of AgNPs on diverse human cancer cell lines with IC_{50} values were MDA-MB-231 (81.1), A549 (105.8), MCF-7 (65.6 μg/mL) and HepG2 (94.2) in a dose-dependent way.[16] Alharbi and Alsubhi showed the high toxicity of *Azadirachta indica*-AgNPs against A549 lung cancer cells. To clarify the mechanism by which AgNPs prevent cell growth, morphological variations in A549 cells were inspected using an inverted microscope, and cell cycle spreading was evaluated using flow cytometry. In addition, a DNA fragment test was used to examine the DNA damage in cancer cells caused by AgNPs; the results showed that the cancer cells had undergone both DNA fragmentation and apoptosis.[42] Using many cancer cell lines, including MCF-7, HepG2, KB, LU-1, and MKN-7, Nguyen *et al*. (2023)[25] showed the anticancer activity of synthesized *Callisia fragrans*-AgNPs, with 50% inhibitory doses (IC_{50} values) of 2.41, 2.31, 2.65, 3.26, and 2.40 μg/mL, respectively. The synthesized AgNPs from Tridax procumbens exhibited anticancer activity against human lung carcinoma cells A459 (IC_{50} 42.70 μg/mL).[26] It was shown that *Artemisia bracteosum* significantly inhibited the growth of human NCI-H460 and HepG2 cancer cell lines. Notably, research on a recently discovered substance called 5,4'-dihydroxy-6,7,8,3'-tetramethoxyflavone revealed that it most likely triggers apoptosis through a mitochondrial mechanism controlled by reactive oxygen species, which in turn activates caspase-3 and encourages apoptotic cell death [Figure 4].[43] All investigated cell lines were cytotoxically affected by apple fucoxanthin, polyphenols, and plant-derivative tocotrienols. With an IC_{50} value of 4.3 μg/mL in bone cancer cells, tocotrienols showed the most potent and time-dependent lethal effect among them [Figures 5 and 6].[44]

WOUND HEALING ACTIVITY

A burn injury can result from exposure to heat, cold, electricity, synthetic substances, radiation, or friction. The severity and treatment complexity of burn wounds depends greatly on their extent. Such injuries can damage muscle, nerve, vascular, bone, epidermal, and dermal tissue, leading to traumatic consequences. Burn victims may face potentially life-threatening complications, such as infection, shock, respiratory failure, and electrolyte imbalances varying according to the burn location and the degree. In addition to clinical challenges, burns can also inflict severe psychological and emotional distress, prolonged hospital stays, scarring, and disfigurement.[45] By encouraging fibroblast differentiation into myofibroblasts, Shidramshettar *et al*. demonstrated that synthesized AgNPs have significant antibacterial and antioxidant properties in addition to aiding in the healing of burn wounds. In comparison to plant extract gel, this procedure improved wound contraction, improved

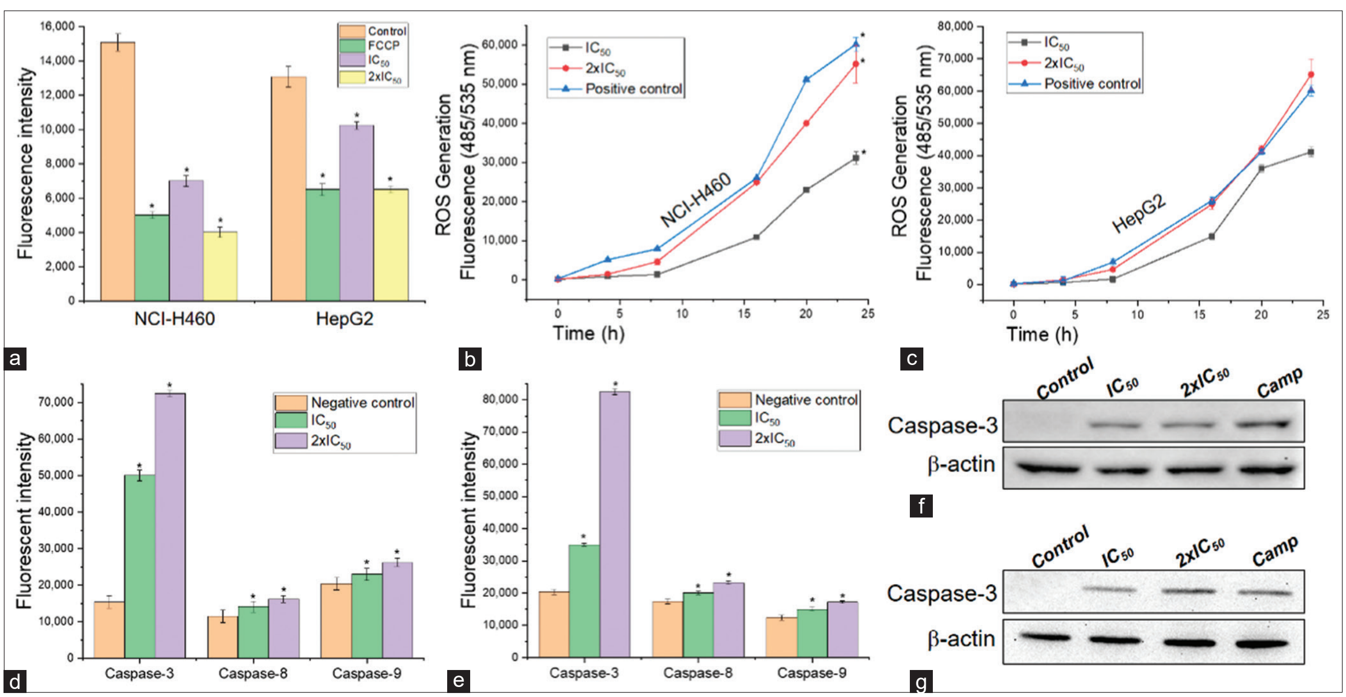

Figure 4: 5,4'-dihydroxy-6,7,8,3'-tetramethoxyflavone from *Adenosma bracteosum* and its possible mechanism of action on human lung and liver cancer cells. (a) The DCFH-DA assay was applied to measure the creation of reactive oxygen species and mitochondrial membrane potential in NCI-H460 (b) HepG2 (c) cells. Western blot analysis was used to confirm the expression of active caspase-3 protein in NCI-H460 (f) and HepG2 (g) cells, whereas caspase activity was assessed in NCI-H460 (d) HepG2 (e) cells treated with AB2 (f) HepG2 (g) cells, whereas caspase activity was assessed in NCI-H460[43]

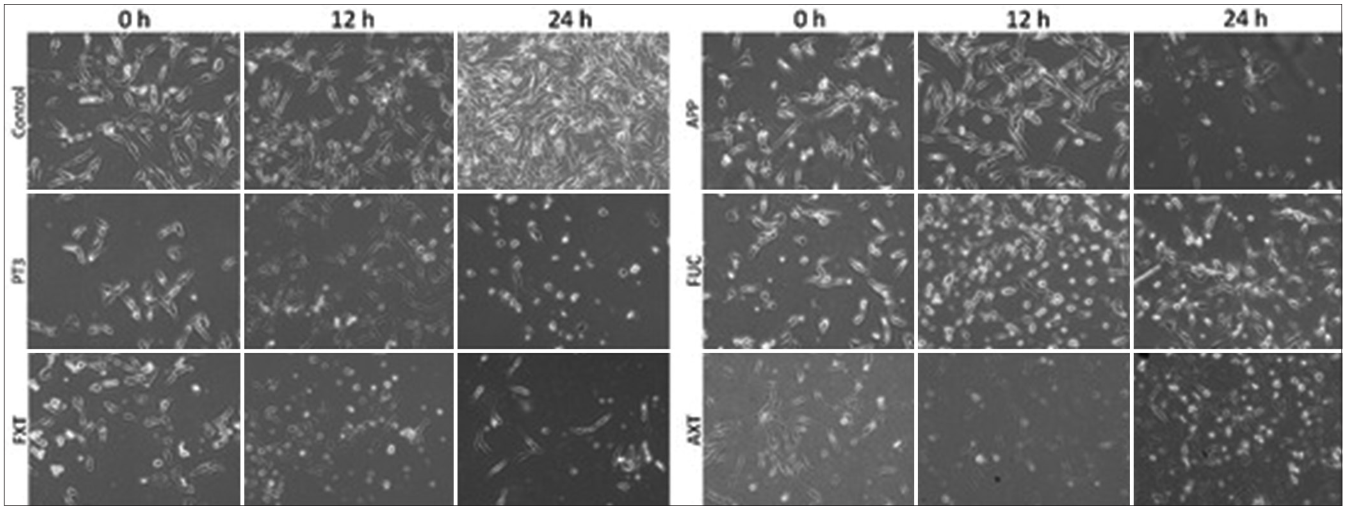

Figure 5: After being treated with several natural substances, morphological alterations have been observed in bone cancer cells (TIB-223). For either 12 or 24 h, the cells were exposed to each chemical at its corresponding IC_{50} concentration. Three separate experiments are represented by the representative photos that are displayed. Plant-derived tocotrienols (PT3), fucoxanthin (FXT), fucoidan (FUC), apple polyphenols (APP), astaxanthin (AXT), and untreated cells (control)[44]

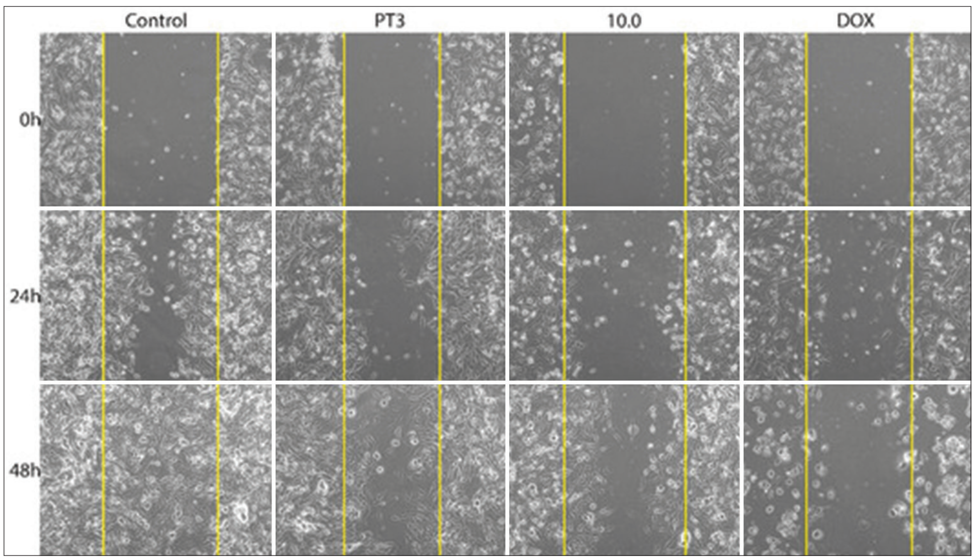

Figure 6: TIB-223 bone cancer cells were used in a wound-healing experiment. Following scratch induction and treatment with plant tocotrienols (PT3), supplement 10.0, and doxorubicin (DOX; utilized as a positive control), each at their respective IC_{50} concentrations, the photos show the cell monolayer. At 24 and 48 h, observations were made. The negative control consisted of untreated cells, and the initial wound borders at 0 h were indicated by yellow lines[44]

up healing, and promoted keratinocyte proliferation over the course of a 14-day trial period.[30] Green-synthesized AgNPs were shown to be effective in *in vivo* wound healing by Al-Nadaf *et al*.[31] Maghimaa and Alharbi explored that the synthesized *Curcuma longa*-AgNPs showed not able antimicrobial activities against pathogens causing skin infections. Furthermore, these NPs facilitated cell migration in normal fibroblast (L929) cells, supporting their potential in wound healing.[32,46] Nguyen *et al.* used a wound-healing experiment to assess the migration of TIB-223 bone cancer cells. Until the artificially generated gap was completely closed, the cancer cells' progress was tracked throughout time [Figure 6].[44] Therefore, by promoting antimicrobial activity, tissue regeneration, and rapid wound closure, plant extract-mediated NPs significantly enhance wound healing.[47]

CONCLUSION

This review focused on biomedical applications, AMR, its causes, and the associated mortality and morbidity. It particularly emphasized the adoption of environmentally friendly and cost-efficient biological methods employing plant extracts. As well as it explored the formulation and characterization of plant-assisted AgNPs along with their pharmacological applications, such as antimicrobial, antibiofilm, anticancer and wound healing properties. Despite the acknowledged biomedical potential, there remains a considerable gap in the widespread applications of NPs in healthcare. To address this, there is a need for extensive research into more potent biomolecules sourced from plant extracts and the development of stable AgNPs for commercial use. These developments have the potential to significantly improve human health and medicine, which makes the development of safety guidelines for the appropriate use of AgNPs and the extension of their uses in other biological domains.

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ETHICAL APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

CONSENT OF PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

The dataset generated and/or analyzed during the present study are available from the corresponding author, upon reasonable request.

AUTHORS' CONTRIBUTIONS

Maghimaa: Conceptualization, Writing – original draft, Data curation, Visualization, Formal analysis, Writing – review and editing. Ethihas Reddy Mahasamudram: Data curation, Formal analysis.

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