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Phytochemistry of *Aloe vera*: A Catalyst for Environment-Friendly Diverse Nanoparticles with Sustained Biomedical Benefits

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ABSTRACT

Nanotechnology has become one of the most active fields in the research area and is getting more attention toward nanoparticle synthesis. Green synthesis methods using various plants, fungi, bacteria, and algae were used to synthesize nanoparticles with proper requirements and maintain sterile conditions to get the desired products. *Aloe vera*, a bio-medicinal plant, contains a wide range of phytochemicals such as phenolic, hydroxyl groups, alkaloids, polyols, polysaccharides, etc, which act as reducing and capping agents with high efficiency. This review revealed that aloe vera-derived nanoparticles are safe, stable, cost-effective, and eco-friendly, and they also possess significant applications for drug targeting, disease resistance, tissue engineering, wound healing, anticancer, antibacterial, and cosmetic industries. Synthesized metal nanoparticles are characterized through UV-visible spectroscopy, X-ray diffraction, scanning electron and transmission electron microscopy, photoluminescence, and the Well-diffusion method. It is highly interesting to note that aloe vera-mediated silver and zinc nanoparticles possess high potency against multi-drug resistant pathogens. Here, anticancer, antioxidant, anti-inflammatory, and photocatalytic activity separately showed by aloe vera peel, gel, and leaf, along with possible challenging situations faced during plant extract-based nanoparticle synthesis, are highlighted. Additionally, the introduction of GMOs is subjected to play an important role in advancing green methods. However, more research is required to estimate the dose's safety, degradation, and synergistic mechanism inside the human body for better use of the green method for the treatment of microbial infections.

INTRODUCTION

With the reasons for the advances in science and technology research, nanotechnology has become 1 of the most active fields in every research area. They are significantly used in electronic devices and are seeking attention for the synthesis of nanoparticles. Nanoparticles are characterized as of nano or minuscule dimensions as they lie within a range between 1-100 nanometres and possess a large surface-volume ratio and high reactivity with their ideal synthesis route. Nanoparticles display unique properties like magnetic, optical, electrical, chemical, and other various biological properties (Zharov et al. 2005). Top-down & bottom-up approaches synthesize nanoparticles with the involvement of physical and chemical methods for the synthesis of NPs. Chemical synthesis occurs through methods including co-precipitation, sol-gel, hydrothermal, etc. Methods require excessive energy with the release of toxic, carcinogenic by-products (Ying et al. 2022). At present, green chemistry approaches are being used to develop nanoparticles using Phyto-fabrication of plant extracts (precursor) and microbes (Koratala et al. 2023).

An ecologically friendly way to form a stable and novel nanoparticle with the requirement of little energy and chemicals and also eliminating fewer wastes is pointed as “green synthesis”. This method is more advantageous as natural sources, nontoxic, and cost-effective (Behravan et al. 2019). Plant extracts, which contain components like alkaloids, polyphenols, vitamins, and steroids, act as reducing and capping agents and result in the formation of stable metal nanoparticles (Sargazi et al. 2022). Metal NPs produced by plant extracts or green methods are more stable. Phenolic groups in plant extracts have a higher capacity to reduce the metal ions for nanoparticle synthesis in comparison to fungi and bacteria. Plants are getting more attention in synthesizing metal nanoparticles like Cu, Au, Ag, Zn, CO, etc. They exhibit a high composition of biomolecules like proteins, enzymes, flavonoids, and terpenoids. These phytochemicals have great medicinal value and act as reducing and stabilizing agents (Akbar et al. 2020). The extent of metal ions reduction to synthesize specific metal NPs directly depends on the type and concentration of phytoconstituent present in plant extracts (Iravani 2011). With the use of NPs, Antibiotic-resistant bacteria exhibit increased antibacterial activity. The green route reduces the risk of contamination and helps to maintain the cell structure. Plant-mediated nanoparticles have various antimicrobial, anti-inflammatory, drug delivery anticancer, antioxidant, etc properties (Muthu et al. 2021). Its biological production recycles the expensive metals such as gold and silver in the waste stream. With the increment in alkaline conditions, metal ions will get reduced to attain a petite size of the nanoparticle, whereas, with the increment in temperature, there is an increment in the absorption spectra (profound effect), which results in the rapid formation of nanoparticles (Song et al. 2009). Due to the reason of having nano size and the high surface-volume ratio of nanoparticles, they have great application in agricultural fields in the formation of pesticides and fertilizers to resist damage to crops from diseases, drug delivery, and diagnosis in tissue engineering (Altammar 2023). Several different types of nanoparticles varying in size and shape are synthesized with their biological applications. Using biological methods like plant extracts, bacteria, fungi, and other pathogens, green synthesis has emerged as an ideal option over conventional methods for NP synthesis (Behravan et al. 2019).

From ancient times medicinal plants have been seeking more attention in the fields of medicinal drugs and disease treatment. Active components in natural sources play a vital therapeutic role in health benefits. Various plants such as *Medicago sativa, A. indica, Aloe vera, Tamarind, Alfa Alfa, Hydrilla* sp., *Mangifera indica, Cassia fistula, Piper betel,* and many more medicinal plants have been used for metal NP's synthesis. Among various plants, aloe vera is proposed to be chosen for metal nanoparticles due to its cheap, eco-friendly, non-toxic nature and numerous therapeutic properties as anticancer, anti-inflammation, antioxidant, antifungal, etc. *Aloe barbadensis* Miller, commonly called aloe vera, is the oldest plant species with the highest medicinal properties ever known. Aloe vera is one of the most common succulent xerophyte plants of the family *Liliaceae* and is grown in hot and dry climates in India, Japan, and China (Baruah et al. 2016). Aloe plants can grow up to a height of 60-120cm. It can survive as below as 40°C temperature and freezing (Grindlay & Reynolds 1986). This green plant has a high water-storing capacity in leaves to survive in harsh conditions. Aloe leaves are covered with a thick epithelium layer containing colorless, viscous, and bitter gel with parenchymatous cells. Among 420 kinds of *Aloe* species, *Aloe vera* is one of the most effective and active plants with medicinal properties, commercially used (Ahlawat & Khatkar 2011). Several researchers have attempted to identify the active component responsible for the medicinal properties of aloe vera in wound healing in case of burns and inflammation (Rao Kandregula et al. 2015). It contains 200 active components, including enzymes, minerals, polysaccharides, and amino acids, present in different layers or parts of the aloe leaf. Some chemical compounds include anthraquinones, glycoside sterols, lipids, etc. (Gao et al. 2019). These chemical components have different advantages as antiviral, anti-inflammatory, antidiabetic, antioxidative, and anticancer properties. It is widely used in products related to the pharmaceutical, food, and cosmetics industries. Thus, this review provides a detailed analysis of aloe vera-mediated synthesis of nanoparticles (Table 1) through ongoing research related to it with their potential antibacterial, anticancer, and photodegradation applications for a safe future by eco-friendly or green approach.

How is a Flora-Derived Green Synthesis of Metal Nanoparticles Utilized in Comparison to Conventional Methods?

The trend of synthesis of safe, novel, and less harmful nanoparticles is exploited all over. Different methods like physical, chemical, and biosynthesis methods are used for the synthesis of nanoparticles. Despite using physio-chemical methods for producing metal nanoparticles, green synthesis approaches are now exploited in the research sector due to their eco-friendly nature and several clinical and nutraceutical properties. Physical methods for synthesis require high energy and release harmful chemicals and waste products. Chemical methods face many problems, like using toxic and expensive solvents (Kundu et al. 2014) and heating the chemicals at high temp, with low pressure, which leads to increased risk to human health and surroundings (Li et al. 2011). These methods decline the biological applications and desired mass production. To overcome this problem, the global market transitioned towards environment-friendly methods. Different green methods or biological systems are used for nanoparticle synthesis. Biosynthesis methods are quite safe, Harmless, and novel approaches, including plants and microorganisms for medicinal applications (Rabiee et al. 2020). Microbial systems are cost-effective and nontoxic for the environment, including bacteria, fungi, algae, yeast, etc, for nano-size particles. These work to reduce and stabilize the particular metal nanoparticle (Gericke Mariekie & Pinches Anthony 2006). Among these biological systems, fungi have better quality in production due to low expenses for downstream processing, highly efficient for extracellular enzymes used for large mass production, good metal reduction, and utilization of biomass (Sarkar et al. 2014). It is quite challenging for researchers because of the complexity of toxic metals for the synthesis of nanoscale materials. Microbes-mediated nanoparticles are not completely viable to form the desired product, they require a proper sterile condition and high maintenance. No control for nanoparticle size, structure, and time for microbial screening are some major drawbacks of microbial systems for nanoparticle synthesis (Kundu et al. 2014). Researchers investigated to reveal that plant parts and their extracts are the most ideal and cost-effective, nontoxic method of nanoparticle synthesis with deficient maintenance of requirements in the system. Plant extracts contain numerous active phytocomponents like flavonoids, amino acids, minerals, enzymes, polysaccharides (Gao et al. 2019), polyols, and polyphenols (Ovais et al. 2018). Phytochemicals in plant extracts act as stabilizing agents as compared to microbial systems for nanoparticle synthesis to reduce toxic heavy metals. Any parts like the root, stem, leaf, or flower of a plant containing phytochemicals can be used for synthesizing various nanoparticles like gold, silver, copper, zinc, etc (Iravani 2011). Plant-mediated nanoparticle synthesis is cheap, accelerated, and doesn’t require specific conditions and screening of microbial cultures as microbial systems do, and was easily synthesized in a controlled condition at room temperature (Rajakumar et al. 2012) with quite stirring and heating (Acharyulu et al. 2014). This is done by simply mixing the reducing agents present in plant extracts in an aqueous solution of the respective metal of the nanoparticle to be synthesized (Fig. 1). Synthesis of nanomaterial comprises three phases: (a) activation phase; metal ion gets reduced, (b) growth phase; aggregation of small particles to form large nanoparticles via Ostwald ripening, (c) termination phase; concluded the shape of a nanoparticle. The formation of nanoparticles is characterized by a visual change in the color of the solution or by UV-Vis Spectroscopy. Finally, nanoparticles are collected by washing before drying at low temperatures. The capacity of certain metal ions to get reduced depends on the presence and concentration of specific functional groups such as hydroxyl, phenol, aldehyde, ketones, carboxylic acid, and amines, as well as phytochemicals like polyols, polyphenols, and enzymes present in plant extract (Iravani 2011). Plant-mediated synthesis of nanoparticles is stable for getting higher yield, which makes it a highly preferred method over other biosynthesis methods. Plant-extracted nanoparticles have various diagnostic and therapeutic applications in biotechnology. Several nanomaterials synthesized by this method have unique properties. Ex- Gold and silver nanoparticles synthesized by plant extracts have anti-microbial, anticancer, and antiviral properties. Whereas Zinc oxide nanoparticles are efficient for the production of

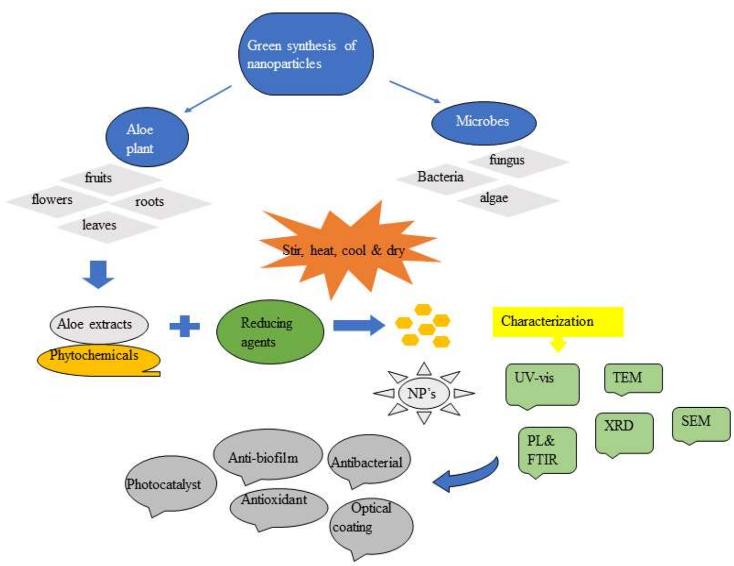

Fig. 1: Plant-facilitated NP synthesis with its biomedical applications.

cosmetic products and for coating purposes (Mittal et al. 2013). Therefore, plant extracts proposed an efficient method for fast, safe, convenient, and stable way of nanoparticle synthesis.

An Overview of the Plant, *Aloe barbadensis* Miller (Aloe vera)

The scientific name of Aloe vera is *Aloe barbadensis* Miller, commonly called 'Gwar path' or simply 'Aloe vera'. It is a green shrub that belongs to the family Liliaceae. It is a xerophytic, succulent plant that grows in dry and hot climates. Triangular leaves of aloe vera are enveloped with a thick epidermis layer and cuticles at the edges. Thick, fleshy leaves contain a bitter and viscous gel with parenchymatous cells. High water-holding capacity makes them able to survive in variable temperatures (Grindlay & Reynolds 1986). It is widely known for its healing and medicinal applications in burns, inflammation, gastric problems, stress, cosmetics, and many more. It contains 200 biologically active aloe components such as proteins, carbohydrates, acemannan, polyphenols, anthraquinones, etc (Talukdar et al. 2023). These secondary metabolites in gel provide anticancer, antidiabetic, antioxidant, antimicrobial, and anti-fungal benefits. Aloe vera consists of three layers. A thick outermost layer or rind produces proteins and carbohydrates. The middle layer contains yellow bitter latex rich in anthraquinones and glycosides (Baruah et al. 2016). The innermost layer contains mainly 98 percent water, and the rest are vitamins, sterols, and glucomannans (Chelu et al. 2023).

It has a unique, fast mechanism to heal damaged tissue by its active secondary metabolites. Mannose-6-phosphate (Hashemi et al. 2015), gibberellin, acemannan (Jettanacheawchankit et al. 2009a), saponin (Baruah et al. 2016), and polysaccharides (Tabandeh et al. 2014) are responsible for repairing damaged tissues. Wound healing is done by activating collagen production to increase blood supply in damaged areas. Also, it induces re-epithelialization by the proliferation of fibroblasts. Some constituents like lupeol (Das et al. 2011), aloe resin Es (Das et al. 2011), bradykinesia, alkaline phosphatase, peroxidase, cinnamic acid (Das et al. 2011), aloin, and aloe emodin, have anti-inflammatory properties. They act by blocking their nitric oxide synthase and cyclooxygenase pathway at the site of infection. Aloe vera extracts have an anticancer effect in lymphoma cells, and murine T-cell lymphoma in a dose-dependent manner was reported. Anthraquinones, emodin, aloin, and acemannan show active anticancer effects by inhibiting tumor growth and promoting apoptosis (Pradhan 2023). Aloe-emodin has antimicrobial properties and inhibits biofilm formation in microbes like *Mycobacterium tuberculosis, Staphylococcus aureus,* and *Enterococcus* (Xiang et al. 2017). By reducing oxidative stress, lowering blood glucose levels, increasing insulin levels, and improving islets in the pancreas, aloe polysaccharides (Kim et al. 2018) and aloe-emodin (Alshatwi & Subash-Babu 2016) act as antidiabetic agents by inhibiting apoptosis and oxidative stress signaling. Aloe vera extracts can improve skin health by promoting collagen formation in fibroblast cells and maintaining skin hydration. Aloe sterols (Misawa et al. 2008), acemannan (Jettanacheawchankitet al. 2009b), aloesin (Wu et al. 2012), and aloin (Jettanacheawchankit et al. 2009b) are active components useful in treating hyperpigmentation, pimples, wrinkles, and other skin-related problems that are yet investigated. Acemannan is the most active phytochemical in reducing oral ulcers, gum diseases like gingivitis and plaque, and neurodegenerative diseases. Processing methods of these compounds can change the concentration of their laxative property. Aloe vera extracts can create toxic effects like kidney issues, allergies, and abdomen pain in some cases if taken in high concentration without prescription. Aloin is mainly responsible for allergy reactions (Fujii 2003). To avoid any toxic effects, a safe dose is necessary for benefits. Aloe extracts are assessed to prevent the generation of ROS and also increase the release of Ca^{2+} ions inside cells to treat neurodegenerative disorders such as Parkinson's, Amyotrophic lateral sclerosis, Alzheimer's, and Huntington's diseases. Researchers found aloe vera wastes to be used as fertilizer, biofuels, drug delivery systems, and in the pharma industry. Evaluating all of the therapeutic properties of this plant, it is a crucial element in green nanoparticle synthesis with various pharmacological effects.

Diverse Forms of Aloe vera-Facilitated Nanoparticles

Aloe vera-derived Ag-nanoparticles: Aloe vera is significantly used for silver nanoparticle synthesis (Ag NPs). Silver nanoparticles gained the most attention for their different properties and applications in various fields of study. Plant extracts containing phytoconstituents are helpful in the reduction of silver ions to form safe, non-toxic, and enhanced therapeutic effects of AV-Ag NPs. Various crucial parameters affecting Ag NP synthesis are pH, the concentration of reducing agent and aloe extracts, and temp. pH can change the size and morphology of NPs (basic pH elevates the synthesis of NPs) (Singh & Dhaliwal 2019). Concentration and reaction time should be optimum for reducing silver ions to form nanoparticles (Devaraj et al. 2013).

Arshad et al. (2022) synthesized AV-Ag NPs against multi-drug resistant pathogens and observed NP synthesis by simply mixing silver nitrate solution and aloe extract solution in 4-6 hrs of incubation at 65°C. Characterization of particles is done by UV-visible spectroscopy, X-ray diffraction, and scanning electron microscopy, resulting in spherical shape nanoparticles in the range of 30-80nm (Arshad et al. 2022).

Begum et al. (2020) demonstrated the synthesis of AV-Ag NPs to measure antibacterial activity against gram-positive and gram-negative bacteria by disc diffusion method. Synthesis of AV-Ag NPs was carried out by taking a 5:95 ratio of aloe vera extract to silver nitrate solution at optimum pH 8 for a day. Characterization of synthesized NPs by SEM shows spherical particles with a size of 20-24 nm (Begum et al. 2020).

Begum & Mahboob (2019) evaluated the antioxidant properties of aloe extracts and aloe-mediated silver nanoparticles in vitro and in vivo studies. A preliminary identification test was conducted to detect the presence and antioxidant properties of phytochemicals present in the aloe extracts for the synthesis of AV-Ag NPs. AV-Ag NP synthesis was confirmed by UV-vis spectroscopy. A reddish-brown color of the solution was observed due to the excitation of surface plasmon resonance of synthesized silver nanoparticles in the reaction mixture. It resulted in the synthesis of spherical shape AV-Ag NPs with maximum absorption at 400 nm and size in the range of 20 to 24 nm. In Vitro, the antioxidant property was determined by some methods like lipid peroxidation inhibition (LPOI), DPPH, i.e.,1,1-Diphenyl-2-picrylhydrazyl, and reducing power assay based on the concentration of aloe vera extract and AV-Ag NPs. It resulted in high LPOI in aloe vera extract, high DPPH activity, and reduced power activity in AV-Ag NPs. On the other hand, an in vivo study of AV-Ag NPs was performed in rats for 28 days (10 $mg.kg^{-1}$ of body weight). It showed the reno-protective effect by reducing the level of MDA and increasing in level of catalase, SOD, and GSH level. Antioxidant potential and nontoxic effect of AV-Ag NPs based on their conc., size, and exposure period were estimated by this study (Begum & Mahboob 2019).

Nalini & Kay (2020) synthesized spherical AV-Ag NPs, which were 12-40 nm in size measured by SEM and at a temperature of 32°C. They analyzed the antimicrobial properties of these synthesized AV-Ag NPs on cotton fabric against the bacteria E. coli and Staphylococcus aureus. The analysis was carried out in the Well diffusion method and streak plate method to measure the zone of inhibition, with an absorbance at 420 nm, and resulted in bactericidal effects.

Mohamed & El-Masry (2020) prepared AV-Ag NPs with exposure to sunlight to increase the reducing efficiency. NPs were characterized through TEM, FTIS (Fourier transform infrared spectroscopy), and dynamic light scattering. Formation of colloidal spherical AV-Ag NPs, with size in the range of 94 nm, absorption peak noted at 400 nm. The resulting AV-Ag NPs have significantly high antibacterial effects to stop the growth of Gram-positive *Staphylococcus aureus*, Gram-negative *Pseudomonas aeruginosa*, and yeast (*Candida albicans*). Besides, it has high therapeutic or anticancer effects on breast cancer cells (Mohamed & El-Masry 2020).

Vélez et al. (2018) synthesized silver nanoparticles using aqueous and ethanolic extracts of aloe vera as reducing agents. High-resolution TEM was used to identify nanoparticle Sizes and was found to be 2-7 nm by aqueous extracts and 3-14 nm by ethanolic extracts. Researchers reported that even a small concentration of aqueous and ethanolic aloe extracts mediated silver nanoparticles show results for effective removal of harmful mercury detected by atomic absorption spectroscopy and antibacterial activity for mesophilic pathogen *Kocuria variants* (Vélez et al. 2018).

Dinesh et al. (2015) showed that a very low dose of AV-Ag NPs is required to show a mosquitocidal effect against *Anopheles stephensi* and to stop the growth of *Bacillus subtilis* and *Salmonella typhi* in water. They used SEM, XRD, and FTIR techniques for the characterization of synthesized AV-Ag NPs (Dinesh et al. 2015).

Basak et al. (2018) produced spherical aloe-mediated Ag NPs. Evidence of exp. Conclude anticancer activity against MCF-7 and T47D (breast cancer cells) and antimicrobial properties against bacterial species (Basak et al. 2018). In this study, an experiment was performed to compare the antibacterial properties of *Aloe vera, Portulaca oleracea*, and *Cynodon dactylon,* mediated silver nanoparticles through the disc diffusion method, which calculates their MIC (minimum inhibitory concentration) values. Size and shape were determined by technique, SEM, and UV-vis Spectroscopy. They found that aloe vera-mediated NPs exhibit high bactericidal 50µg/mL concentration against various species of bacteria (Abalkhil et al. 2017).

A group of Researchers experimented on 30 male mice weighing between 50 to 70 g. They aim to determine the efficiency of recovering epithelial cells on ulcers due to irradiation. Mice were classified into five groups and exposed to harmful radiation, which resulted in the induction of ulcers in each mouse. After irradiation, the first group received no treatment to function as a control, whereas the Second group was ulcer-induced but no treatment was received for it. The third group was treated with aloe extracts, the fourth group was treated with Ag NPs, and the fifth group was treated with a combination of both, i.e., AV-Ag NPs, respectively. The team identified that AV-Ag NPs treated mice have elevated collagen synthesis due to an increase in IL-10 level when compared to individual AV and Ag NPs. This restoration efficiency of epithelial tissues helps in reducing the adverse effects of inflammatory reactions and re-epithelialization in case of ulcer formation (El-Batal & Ahmed 2018).

Aloe vera-derived Au-nanoparticles: Gold is effectively being used in the synthesis of nanoparticles due to its high physical, chemical, electric, thermal, and optical properties and exhibits great applications in electronic devices, biomedicines, drug delivery, and sensing devices. Various shapes of gold nanoparticles were synthesized, like spherical, triangles, etc, based on the concentration of aloe extracts used for agglomeration.

Nalini & Kay (2020) synthesized spherical AV-AuNPs (aloe-mediated gold nanoparticles) below 15 nm in size and at a temperature of 34°C measured by SEM after 16 hrs of incubation. They identified the antimicrobial properties of synthesized AV-AuNPs on cotton fabric against E. coli and Staphylococcus aureus. The test was carried out in the Well diffusion method and streak plate method and exhibited an absorbance of 530 nm (Nalini SP & K 2020).

In a study conducted by (Malik et al. 2023) where, they synthesized gold nanoparticles using Aloe vera, *Gymnema sylvestre*, and honey. They aimed to study the toxicity of gold nanoparticles. When chloroauric acid ($HAuCl_4.3H_2O$) was mixed with aloe extracts, it led to a change in color of the mixture from brownish to purple then it was centrifuged at around 150 rpm in a dark room. Characterization of synthesized AuNPs via XRD, UV-vis, FTIR, and SEM. They discovered (AV-AuNPs) of size 30-45 nm, and an absorbance peak was noted at 540 nm. The yield and absorbance of gold NPs directly depend on the elevation of temperature. Furthermore, they examine the cytotoxic effects of AuNPs by conjugating them with anticancer drugs to treat MCF-7 and MDA-MB231 breast cells (Malik et al. 2023).

Chandran et al. (2006) reported the biological synthesis of gold nanotriangles and spherical-shaped silver nanoparticles using aloe vera extracts. When they mixed the chloroauric acid solution and aloe extracts it resulted in a brownish-red color solution after 5 h of incubation. The presence of crystalline gold nanotriangles was detected with size ranges between 50-350 nm and was confirmed by UV- -vis -NIR absorption spectroscopy. It exhibits two absorption bands. TEM analyses that MTP (multiple twinned particles) of varying shapes direct the formation of crystalline gold triangular nanoparticles. Strong NIR absorption is widely used to treat cancer and in optical coating (Chandran et al. 2006).

Aloe vera-derived CuO-nanoparticles: Due to the unique properties of copper oxide nanoparticles, they are highly used in the synthesis of gas sensors and resistant materials. Multiple applications of copper oxide nanoparticles synthesized by varying concentrations of aloe extracts exhibit antibacterial, antifungal, and antifouling activities. From all works of literature, copper has higher antibacterial properties as compared to Ag, Au, and Zn metals.

A study of the synthesis of CuO NPs was carried out by (Narayanan et al. 2023) and his team using aloe extract. 5 g of aloe leaf was mixed with 200 ml of distilled water, heated, cooled, and filtered out. 0.56 g copper acetate monohydrate dissolved in distilled water with magnetic stirring to make a solution. When aloe extract is added to copper sulfate solution, the solution turns out to be green from blue. Brown precipitates of copper oxide particles appeared—characterization of synthesized spherical CuO nanoparticles through UV-vis, FTIR, SEM, and TEM. More than 80 percent of the efficiency of photocatalytic properties of AV-Cu NPs was reported by researchers (Narayanan et al. 2023).

This study aimed to determine the electrocatalyst activity of copper-cobalt oxide-based electrodes on Ni-substrate. In this hydrothermal process, aloe vera extracts are used as surfactants to induce the growth of NPs. Copper & and cobalt oxide-based electrocatalysts exhibit applications in oxygen-evolving processes. In this exp (Sarkar et al. 2023), Ni substrate was prepared by first treating it with acetone, followed by a bath in HCl, distilled water, and ethanol, and drying at the end. On the other side, an aloe vera extract sol. was also prepared by boiling, stirring, and cooling. The reaction was conducted in different mineral mediums (HCl, CA, DEA, NaOH, and H_2NCONH_2) containing an equal ratio of both copper & and cobalt metal oxide on the Ni-substrate. The solution was heated at 130°C, cooled at RT, and dried to separate the catalysts from the Ni substrate. Characterization was successfully carried out by XRD, EDS (energy dispersive spectrum), Field Emission SEM, and testing oxygen evolving performance. This study showed that an acidic mineral medium influences the growth of copper oxide, whereas basic minerals promote the growth of cobalt oxide. Besides this, aloe vera-based metal oxide with urea mineral medium is anticipated to have high electro-catalytic potential on Ni-substrate (Sarkar et al. 2023).

Rehman & Shahid Minhas (2021) experimented by mixing 6 g of copper nitrate solution and aloe extracts at 120°C by stirring for 7 h. Finally, after several hours, black-colored precipitates appeared, confirming 60 nm spherical-shaped CuO NPs. These synthesized nanoparticles are characterized by SEM and XRD. The potency of CuO NPs was discovered to kill MCF-7 cell lines of breast cancer (Rehman & Shahid Minhas 2021).

Researchers successfully synthesize CuO NPs using aloe extracts and copper chloride or copper sulfate as precursors and changing the type and quantity of copper precursor results in the formation of rod, spherical, and platelet-like shapes of pure copper oxide nanoparticles varying in size from 9-23 nm. Rod and platelet-shaped CuO NPs have high resistance to bacteria due to their increased surface area compared to spherical-shaped particles analyzed by (Tavakoli et al. 2019).

Kumar et al. (2015) studied the synthesis of copper oxide nanoparticles using 5 mL of aloe vera extracts added to 10 mM of copper nitrate. The mixture was heated at 120°C on vigorous magnetic stirring for a day, resulting in a dark red color. Finally, a black ppt of CuO NPs appeared with a size of 22 nm obtained by XRD and TEM techniques. They found efficient antibacterial activity against fish pathogens like *Aeromonas hydrophila, Flavobacterium branchiophilum,* and *Pseudomonas fluorescens,* causing infection in fishes. The bactericidal effects of synthesized nanoparticles were analyzed via the micro-dilution broth technique (Kumar et al. 2015).

Gunalan et al. (2012) reported the synthesis of monodisperse copper oxide nanoparticles by chemical and biological methods. They dissolve copper sulfate and aloe extract solution by continuing magnetic stirring of the mixture. Keeping the mixture under vigorous stirring for 7 hrs at 130°C, a black precipitated solution of copper oxide was observed. After two times centrifugation of the mixture at 3500 rpm, the crushed dry product was collected for its optical property analysis. Maximum particles were observed to be 20 nm, and characterization of CuO NPs was done via UV-vis, photoluminescence, XRD, and SEM (Gunalan et al. 2012).

Aloe vera-derived ZnO-nanoparticles: Zinc oxide has low toxic effects and is under-listed as GRAS (Generally Recognised as Safe) by the US Food and Drug Administration. It has many applications in cosmetics, plastic, paints, pharmacy, and microelectronic devices and is widely used to synthesize efficient nanoparticles against pathogens. At present, further research is going on zinc oxide nanoparticles which are highly used due to their high efficiency as an antimicrobial agent.

To compare inhibitory effects against *Klebsiella pneumonia* isolated from patient samples, Hammood et al. (2022) compared zinc oxide nanoparticles synthesized by aloe vera with chemically synthesized zinc nanoparticles. In this study, 1 mM of ZnO solution was mixed in 10 mL of aloe extracts keeping it for around 30-35 min on a magnetic stirrer, maintaining a neutral pH. The resulting White ZnO nanoparticles underwent centrifugation at 1000 rpm for nearly 10 min before drying and characterization—maximum absorption between 360 to 380 nm depicted by UV-vis spectrum. Scanning electron microscope indicates spherical-shaped Zn nanoparticles of 20 to 40 nm. Other properties of particles were studied via atomic force microscopy, X-ray diffraction, and infrared spectroscopy. This study identified that aloe-mediated zinc nanoparticles exhibit greater inhibition against *K. pneumonia* as compared to commercially prepared zinc nanoparticles (Hammood et al. 2022).

Khatana et al. (2021) synthesized aloe-mediated zinc oxide nanoparticles to examine their antibacterial properties

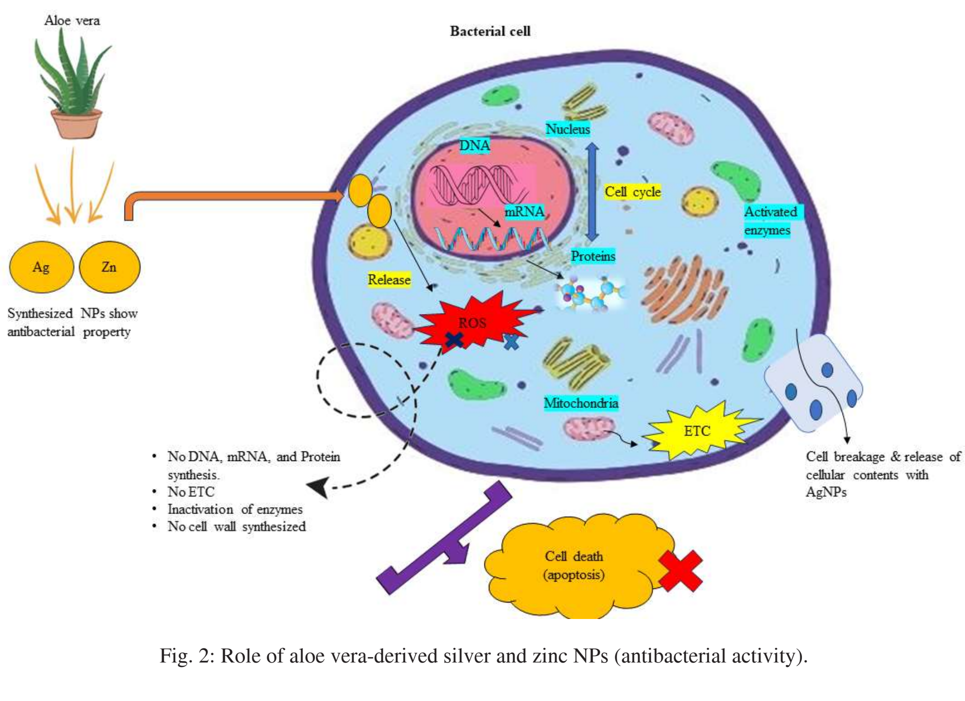

Fig. 2: Role of aloe vera-derived silver and zinc NPs (antibacterial activity).

against different bacterial strains. 100 g of aloe leaves were washed, chopped, and boiled in 100 ml of distilled water and filtered to get a fresh aloe solution. 0.50 g zinc acetate solution was dissolved in freshly prepared aloe extracts solution to 12 pH, and colored zinc oxide nanoparticles were formed. L-ascorbic acid and other components are responsible for ZnO NP synthesis. A flower-like shaped Zn O NP was observed under SEM, showing 0.126 nm of interplanar space. Studied results show high antibacterial efficiency (Fig. 2) against *S. aureus, E. coli,* and *Pseudomonas aeruginosa* (Khatana et al. 2021).

Zinc oxide-nanocomposites (ZnO-BAV, ZnO-WAV, and ZnO-N) were prepared using dried powder of black and white aloe vera and dried powder of Terminalia arjuna nuts by Dar et al. to explore their antibacterial efficiency. At the start of this study, 5 g of dried plant contents of both plants were taken separately in 100 mL of distilled water. Stir each solution at nearly 100 rpm on a hot plate maintaining its temperature at 70°C for 15 min. On the other side, prepare a solution of zinc acetate by adding 2.9 g in 50 ml of distilled water at room temperature for one hour. After preparing both solutions, mix 50 mL of aloe extract in zinc acetate solution and leave at 100 rpm on an orbital shaker for at least 3 hours. After all this procedure researchers centrifuged yellow ZnO nanocomposites settled at the bottom and dried them at 80˚C. Synthesized ZnO-nanocomposites were characterized by UV-visible, SEM, and FTIR techniques, respectively. SEM revealed the morphology of ZnO-BAV (zinc oxide-black Aloe vera) appeared as fibrous-wired of size 27-71 nm, ZnO-WAV (zinc oxide-white aloe vera) as octahedral of size 29-75 nm, and ZnO-N (zinc oxide-nuts) as scattered particles of size 32-83 nm. The disc diffusion method showed a larger zone of inhibition by ZnO-BAV when tested *against E. coli* and *B. stabilis*. ZnO-WAV and Zno-N both showed efficient antimicrobial properties only against E. coli. However, no response showed against *B. stabilis* (Dar et al. 2021).

Sharma et al. (2020) successfully conducted a study on the antimicrobial and photodegradation of dye depending on different sizes and shapes of zinc oxide nanoparticles synthesized. The procedure involved the preparation of zinc acetate dihydrate, Zn $(CH_3CO_2)_2{\cdot}2H_2O$ solution, and aloe leaves were washed, chopped, boiled, and filtered to extract aloe juice. With continued stirring, dropwise addition of aloe extract to different concentrations of 5, 10, and 50 mmol. kg^{-1} of zinc acetate solution at 70°C with pH 11.5. After regular heating for 4 hours, yellow-whitish-colored zinc oxide nanoparticles were synthesized, collected, and dried. UV-visible spectrum analyzes the optical properties of AV-ZnO NPs between 200 to 800 nm with a sharp absorption peak around 370 nm, and the band gap was calculated to be 3.4 eV. SEM, TEM, or EDS (SEM-energy dispersive X-ray spectroscopy) examined the size and shape of ZnO NPs at varying concentrations of Zn $(CH_3CO_2)_2{\cdot}2H_2O$. They obtained hexagonal NPs with a size of 63 nm at 5 $mmol.kg^{-1}$, spherical and hexagonal NPs with a size of 60 to 180 nm at 10 $mmol.kg^{-1}$, and cuboidal or rod-shaped nanoparticles with a size of 40 to 45 nm at 50 $mmol.kg^{-1}$. It has been noticed that 50 mg of the catalytic load is enough for degrading dye for spherical and hexagonal shape nanoparticles. However, there is an increase in degradation efficiency that led to an increase in the concentration of catalytic load for cuboid-shaped zinc oxide nanoparticles. Results also show that synthesized ZnO NPs are effective against pathogens such as *S. aureus, B. subtilis,* and *E. coli* (Sharma et al. 2020).

Aloe peel extract was used by Chaudhary et al. (2019) to synthesize zinc-oxide nanoparticles to depict its efficiency against bacterial and fungal pathogens. Synthesized Zinc oxide nanoparticles were hexagonally confirmed by TEM and with a size range between 50-220 nm UV-vis spectra. Hydroxyl, amine, aromatic, and carbonate groups are responsible for ZnO NP synthesis tested through FTIR. This study results in ZnO NPs having efficient bactericidal and antifungal effects against E. coli and A. niger (Chaudhary et al. 2019). Another similar study on aloe vera peel was performed to form nanovesicles for analyzing active healing mechanisms. Researchers discovered the anti-inflammatory effects of aloe vera peel-mediated nanovesicles (NV's) in macrophages and keratinocytes in case of burn wounds. Synthesized NV's prevent stimulation, contraction, and differentiation of both myofibroblast and fibroblast cells *in vitro* (Ramírez et al. 2024).

Ali et al. (2016) with the help of a simple, safe, and eco-friendly 1-pot biosynthesis method to synthesize Aloe vera functionalized zinc oxide NPs (AV-ZnO NPs) using aloe vera leaf extracts and zinc sulfate. They synthesized these AV-ZnO nanoparticles by heating at 60°C for three hours and with pH-8. It's a simple procedure of synthesis of NPs that doesn't require much temperature, pressure, or any toxic chemical. Characterization of NPs by XRD, SEM, UV-visible spectrum, and SEM-EDX was done to analyze nanoparticles within a range of 13 to 18 nm. The results of this experiment showed that aloe vera functionalized ZnO-NPs (AV-ZnONPs) used as nano antibiotics exhibit great antibacterial and anti-biofilm effects against S. aureus, a gram-positive, and E. coli, a gram-negative bacterium (Ali et al. 2016).

A group of researchers synthesized ZnO nanoparticles by using 60 mL of aloe vera leaf extracts and 5 g of zinc nitrate, a precursor. The mixture was collected in a ceramic crucible and heated at 400°C for two hours in a furnace. The resulting light-yellow particles were collected, dried, and ground in powder form. ZnO nanoparticles were characterized by a UV-vis spectrum with an absorption peak of 360 nm. SEM and XRD analyze oval zinc oxide nanoparticles with a size range between 70 and 74 nm. It has been found that increasing the concentration of zinc-oxide-nanoparticles resulted in an increment in the growth, hydrogen peroxide, and lipid peroxidation contents of soybean(Hashemi et al. 2016).

Synthesis of ZnO NPs by utilizing precursor (zinc nitrate), cold and hot aloe leaf extracts (biosynthetic process), and sodium hydroxide used for a chemical method to estimate and compare their antibacterial efficiency against various strains of bacteria. Characterization of ZnO-AVH (hot aloe extract), ZnO-AVC (cold aloe extract), and ZnO-C (chemical) through X-RD, SEM, and calculating MIC values. SEM images assessed the morphology of nanoparticles: rod shape of ZnO-AVH &ZnO-AVC and spherical shape: ZnO-C. ZnO-AVC and ZnO-C resulted in small particle size as compared to ZnO-AVH and significantly showed high anti-bacterial effects against strains such as *Bacillus subtilis, Staphylococcus aureus, Pseudomonas aeruginosa,* and *Escherichia coli* (Laxshmi et al. 2012).

In this study, Sangeetha et al. (2011) reported the synthesis of AV-ZnO NPs and compared it to the ZnO-NPs synthesized by chemical method. They examined the morphology and optical properties of both methods. For the chemical method, zinc oxide NPs were produced with the dissolution of zinc nitrate in a sodium hydroxide (NaOH) solution. It formed white precipitates of nanoparticles after ten minutes of centrifugation at 3000 rpm and was dried. On the other hand, side, zinc nitrate was added in different concentrations of aloe leaf and aloe gel solution, and yellow-whitish precipitates appeared in the case of aloe-mediated nanoparticles. They centrifuged it two times at 4500 rpm for 10 to 15 min before drying at 80°C. Characterization of NPs by UV-visible spectra, TEM, and XRD analyze their average size. Aloe leaf (34 nm), aloe gel (35 nm), and approximately 60 nm of average size were analyzed by the chemical process. FTIR predicted the functional group responsible for Zn-NPs formation. Researchers highlighted that aloe-mediated NPs have many applications in the industrial field (Sangeetha et al. 2011).

Aloe vera-derived indium oxide nanoparticles: A semiconductor, indium oxide has a variety of applications in LED (light emitting diodes), solar cells, gas sensors, nanotubes, nanowires, and nanoparticles, etc. indium oxide has the property of great transparency for visible lights and strongly interacts with toxic gas molecules on any surface. Indium oxide nanoparticles are synthesized by chemical methods but they can also be synthesized by green methods by using cost-effective, eco-friendly, non-time-consuming aloe vera extracts.

Synthesis of indium oxide (In_2O_3) nanoparticles was discussed by (Maensiri et al. 2008) using indium acetylacetonate, a precursor, and prepared aloe extracts by boiling. This was prepared by directly dissolving indium acetylacetonate in aloe vera solution by constant stirring and drying at 60°C. calcination of dried indium oxide nanoparticles (In_2O_3 NPs) in box furnaces at different temperatures (400°C, 500°C, and 600°C) for at least two hours. Characterization of calcinated nanoparticles was done through XRD, PL, and TEM. Strong PL was shown by In_2O_3 nanoparticles because of the generation of oxygen vacancy during calcination. TEM discovered cubic In_2O_3 NPs with an average size of 5 to 50 nm depending on calcinated temperature Phokha et al. 2008).

Aloe vera-derived titanium dioxide nanoparticles: Titanium dioxide nanoparticles (TiO_2 NPs) are inflammable, white colored, nontoxic, with surface-reactivity, high thermal stability, and photocatalyst. These are highly used in cosmetic products, drug delivery, implants, and bioimaging. These are considered as effective bactericidal agents against a range of pathogens.

Ahmed et al. (2023) synthesized aloe-mediated titanium dioxide (AV-TiO_2) nanoparticles. They synthesized TiO_2 NPs by simply dissolving titanium isopropoxide (TTIP) as a precursor in a drop-by-drop manner in different concentrations of aloe extract solution (10 mL, 20 mL, and 30 mL) with continued vigorous stirring for two hours. Samples were washed with ethanol and distilled water and dried before their calcination at 450°C. XRD, FTIR, and RAMAN techniques confirmed a small optical band gap and high photocatalytic property of green synthesized spherical TiO_2 when compared to chemically or water-synthesized titanium dioxide nanoparticles. This study showed that aloe vera-mediated titanium dioxide nanoparticles with dose-dependent exhibit high radio-sensitization activity (Ahmed et al. 2023).

Hanafy et al. (2020) focused on the synthesis and characterization of titanium dioxide nanoparticles using aloe vera extract at varied pH (acidic, neutral, and basic) levels. TiO_2NPs involved a procedure, the addition of aloe extract solution drop by drop to titanium tetrachloride ($TiCl_4$) solution at (RT) room temperature. Finally, the mixture was then maintained at three varying pHs with the help of ammonium hydroxide and hydrochloric acid. White suspended nanoparticles were washed and followed by drying at 500°C. Spherical-shaped TiO_2 nanoparticles were characterized through XRD, UV-visible, and TEM. Maximum absorption of TiO_2 NPs under acidic, neutral,

Table 1: A concise summary of parameters for aloe vera-facilitated various nanoparticles.

Type of nanoparticle synthesized	Precursor or reducing agent	Incubation at (temperature)	Morphology and dimensions (in nanoscale)	Estimated property	References
Ag	Silver nitrate soln.	65℃	Spherical 30-80 nm	Antimicrobial	(Arshad et al. 2022)
Ag	Silver nitrate sol.	N/A	Spherical 20-24 nm	Antibacterial	(Begum et al. 2020)
Ag	Silver nitrate sol.	RT	Spherical 20-24 nm	Antioxidant	(Begum & Mahboob 2019)
Ag	Silver nitrate sol.	32℃	Spherical 12-40 nm	Antibacterial	(Nalini & Kay 2020)
Ag	Silver nitrate sol.	Sunlight exposure	Colloidal-spherical 94 nm	Antibacterial, Anticancer	(Mohamed & El-Masry 2020)
Ag	Silver nitrate sol.	57-80℃	2-24 nm	Antibacterial, Elimination of mercury	(Vélez et al. 2018)
Ag	Silver nitrate sol.	N/A	Spherical, cubic 30-57 nm	Mosquitocidal effects	(Dinesh et al. 2015)
Ag	Silver nitrate sol.	N/A	Spherical 10-30 nm	Anticancer	(Basak et al. 2018)
Ag	Silver nitrate and polyvinylpyrrolidone (PVP)	N/A	Spherical 10-17 nm	Anti-inflammatory, Re-epithelialization	(El-Batal & Ahmed 2018)
Au	Chloroauric acid	34℃	Spherical Below 15nm	Antimicrobial	(Nalini & Kay 2020)
Au	Chloroauric acid	30-50℃	Spherical 30-45 nm	Against Cytotoxic effects	(Malik et al. 2023)
Au	Chloroauric acid	N/A	Triangles 50-350 nm	Anticancer, optical coating	(Chandran et al. 2006)
CuO	Copper acetate monohydrate	N/A	Spherical	Photocatalyst	(Narayanan et al. 2023)
CuO	Copper nitrate sol.	120℃	Spherical 60 nm	Anticancer	(Rehman & Shahid Minhas 2021)
CuO	Copper chloride or copper sulfate	N/A	Rod, spherical, platelet. 9-23 nm	Antibacterial	(Tavakoli et al. 2019)
CuO	Copper nitrate sol.	120℃	22 nm	Antibacterial	(Kumar et al. 2015)
CuO	Copper sulfate	130℃	20 nm	Optical property	(Gunalan et al. 2012)
Zn	Zinc oxide	N/A	Spherical 20-40 nm	Antibacterial (Klebsiella pneumonia)	(Hammood et al. 2022)
ZnO	Zinc acetate sol.	N/A	Flower-like 0.126 nm	Antibacterial	(Khatana et al. 2021)
ZnO	Zinc acetate	RT	Fibrous, octahedral 27-75 nm	Antimicrobial	(Dar et al. 2021)
ZnO	Zinc acetate dihydrate	70℃	Hexagonal and spherical 60-180 nm, Cuboid and rod shape 40-45 nm	Antimicrobial Photocatalyst	(Sharma et al. 2020)
ZnO	Zinc sulfate and sodium hydroxide	N/A	Hexagonal 50-220 nm	Antibacterial Antifungal	(Chaudhary et al. 2019)
ZnO	Zinc sulfate	N/A	13-18 nm	Antibacterial Anti-biofilm	(Ali et al. 2016)
In_2O_3	Indium acetylacetonate	400-600℃	Cubic 5-50 nm	Optical property	(Maensiri et al. 2008)

Table Cont....

Type of nanoparticle synthesized	Precursor or reducing agent	Incubation at (temperature)	Morphology and dimensions (in nanoscale)	Estimated property	References
TiO_2	Titanium isopropoxide	450°C	Spherical	Photocatalyst, Radio-sensitizer	(Ahmed et al. 2023)
TiO_2	Titanium tetrachloride	N/A	Spherical 13-22 nm	N/A	(Hanafy et al. 2020)
TiO_2	Titanium oxyhydroxide	N/A	80-90 nm	Photocatalyst	(Nithya et al. 2013)
NiO	Nickel nitrate hexahydrate	300-500°C	Cubic crystals	Antibacterial Antifungal	(Ahmad et al. 2022)
CeO_2	Cerium nitrate hexahydrate	600°C	Spherical 42-50 nm	Antibacterial Antifungal	(Shetty et al. 2022)
CeO_2	Cerium nitrate sol.	N/A	Irregular 13-15 nm	Antibacterial Photocatalyst	(N et al. 2021)
CeO_2	Cerium nitrate hexahydrate	600°C	Spherical, With a diameter of 63.6 nm	Optical property	(Kanneganti et al. 2014)

and basic pH was examined to be 318, 326, and 320 nm, respectively. The average size of TiO_2 NPs was estimated to be 22.86±0.85, 15.83±0.902, and 13.3±0.68 nm. The researchers pointed out that for the formation of small-sized, pure, and crystalline forms of TiO_2, basic pH would be preferred (Hanafy et al. 2020).

The biosynthesis of titanium dioxide NPs was successfully carried out to study and analyze their photocatalytic properties for Rh B dye (Rhodamine B dye). A mixture was prepared by adding titanium oxyhydroxide to aloe vera gel extracts and was stirred for a day. The light green appearance of the solution indicates the synthesis of TiO_2 nanoparticles. Particles were then dried at 120°C. AFM (atomic force microscopy) confirmed the average size of 80 to 90 nm of titanium dioxide nanoparticles. When the photocatalytic efficiency was tested for Rh B dye, it showed that TiO_2 synthesized by aloe vera had high efficiency (41%) of decolorization for dye, whereas chemically synthesized TiO_2 showed less efficiency with 24% (Nithya et al. 2013).

Aloe vera-derived nickel oxide nanoparticles: Nickel oxide nanoparticles possess ideal catalytic, magnetic, biocompatible, antifungal, and antibacterial properties. They are highly used in solar cell batteries, fuel cells, gas sensors, and various biomedical areas.

An experiment was performed by Ahmad et al. (2022) to synthesize nickel oxide nanoparticles using nontoxic, cost-effective, and eco-friendly aloe vera leaves. In this procedure, Ni $(NO_3)2{\cdot}6H_2O$ was added to the aloe vera extract solution and continued stirring on a hot plate for nearly one hour, from 72°C to 80°C. The collected samples of nickel oxide nanoparticles were washed three times with deionized water and then dried at 80°C. After doing this finally, dried particles were collected in a ceramic crucible and kept at 300°C, 400°C, and 500°C for 1-2 h. XRD characterization estimated that pure and stable cubic crystals of NiO are obtained at 500°C, and if temperature exceeds 500°C to 600°C then the crystallinity of NiO NPs declined. The results revealed that NiO NPs annealed at 500°C exhibited high antibacterial activity against both gram-positive and gram-negative strains of pathogens and had less antifungal activity (Ahmad et al. 2022).

Aloe vera-derived cerium oxide nanoparticles: Cerium oxide NPs have a range of applications in nano-pharmacy, solar cells, fuel cells, gas sensors, and other polishing objects. CeO_2 is considered an intelligent photosensitizer, helpful in detecting and targeting cancer.

Shetty et al. (2022) synthesized cerium oxide nanoparticles by "low-temperature combustion process" by mixing 4.3 g of cerium nitrate hexahydrate (Ce $(NO_3)_2$ $6H_2O$) to 9 to 10 ml of aloe vera gel solution acting as fuel. Keep the homogenized solution in a furnace at 600°C, which led to yellow dried particles of CeO_2 nanoparticles. SEM and TEM showed the spherical CeO_2 nanoparticles of size about 42 to 50 nm with crystalline structure depicted through the PXRD (powder X-ray diffraction) technique. The author estimated higher antibacterial properties (MIC-2 to 5 $\mu g.mL^{-1}$) in order of *S. aureus* > *E. aerogenes* > *E. coli* by agar diffusion assay. Whereas antifungal effects (MIC-15 $\mu g.mL^{-1}$) are shown in order of *A flavus* > *A. clavatus* > *A. niger* (Shetty et al. 2022).

Present experimentation analyses the effectiveness of photodegradation and bactericidal properties of CeO_2-NPs. Purushotham et al. (2021) mixed cerium nitrate to aloe gel extract solution on a magnetic stirrer resulting in the synthesis of cerium oxide NPs. PXRD and UV-vis spectroscopy obtained irregular shapes of particles with sizes of about 13 to 15 nm. The increasing order of antibacterial properties was estimated as P. aeruginosa > E. coli > K. pneumonia. Up to 97% degradation of Indigo Carmine was recorded with UV radiation in one hour. 85% to 89% degradation showed with Blue 4 dye in one hour thirty minutes.

Kanneganti et al. (2014) Reported the same as earlier: synthesized cerium oxide nanoparticles by forming a homogenized mixture of cerium nitrate hexahydrate solution and aloe vera gel broth solution. Calcinate particles for two hours to obtain a fine, pure, and dried powder of particles at around 600°C. Resulted particles were characterized through XRD, FTIR, SEM, and TEM analyzers, and the size of cerium oxide NPs was determined as spherical with an average diameter of 63.6 nm through dynamic scattering assay (Kanneganti et al. 2014).

CHALLENGES AND UPCOMING PROSPECTS

Nanotechnology has enormous benefits through nanoparticle synthesis due to the reasons of their targeted drug delivery, reduced toxic effects, high biocompatibility, and safety. Aloe-assisted NPs are modified by conjugation, functionalization, and control of size to enhance their biomedical applications. Here, in this review article, the roles and the various biological benefits of aloe vera-mediated nanoparticles are highlighted. Some challenging situations are faced with plant extracts during dry or hot climates, as there is a reduction in phytochemicals due to the shedding of leaves. This led to low productivity and no control over shape & size. In the future, the demand for products that are aloe-based silver and zinc NPs is expected to elevate. Also, nowadays, Aloe vera-based Ag NPs are highly used for edible product packaging. So, there's a proper need for assessment of the quality, degradation, and other PK (pharmacokinetic) mechanisms inside the human body. Furthermore, the introduction of GMOs for enhancement in proteins, molecules, and other enzymes will be the key future in green synthesis.

CONCLUSIONS

This review article summarizes a quick study of several nanoparticles, such as silver, gold, zinc oxide, copper oxide, indium oxide, titanium dioxide, nickel oxide, and cerium oxide. Production of these metals or metal oxide nanoparticles using *Aloe vera* extract follows a green method. This one-step process is fast, simple, safe, non-hazardous, low-cost, high-yield approach. Synthesized AV-MNPs (Aloe vera mediated metal nanoparticles) concluded with various biomedical properties, including antifungal, antibacterial, anti-inflammatory, anticancer, antidiabetic, and antioxidant. AV-MNPs are characterized by multiple techniques such as UV-visible spectroscopy, scanning and transmission electron microscopy, X-ray diffraction, photoluminescence, and Fourier transform IR spectroscopy. The average size of nanoparticles synthesized varies with the quantity of aloe vera extract used at different temperatures, deduced by cited references. The conclusion from this review highly prefers to use of aloe-mediated nanoparticles, mostly silver and zinc, against bactericidal effects. It also prohibits using too much dose of AV-MNPs as it may cause harmful issues. More research is needed to better understand its safety and clinical use. Besides this, long-time stability, and overcoming barriers to improve the delivery of aloe-mediated NPs to targeted sites must be addressed for further research in this area. There is much research literature available on silver, zinc, and nanoparticles, but insufficient works of literature are available on gold, nickel, cerium, and indium nanoparticles synthesized by the aloe vera plant. So, more focus should be required on less explored aloe-mediated nanoparticles and the reason for their restriction towards using their application must be analyzed. In addition to this, there is also a need to investigate the synergistic potency of aloe vera towards various diseases and other microbial infection treatments.

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