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Bio-Inspired Synthesis Of Nanoparticles Using *Calotropis Gigantea*: A Mini-Review

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Abstract:
The bio-inspired synthesis of nanoparticles using *Calotropis gigantea* represents an eco-friendly and efficient approach to nanomaterial production. This mini-review focuses on the methods and applications of metallic nanoparticles synthesized from the plant extracts of *C. gigantea*, including silver (AgNPs), zinc oxide (ZnO NPs), magnesium oxide (MgO NPs), nickel (Ni/NiO NPs), titanium dioxide (TiO_2 NPs), and copper oxide (CuO NPs). Phytochemicals present in *C. gigantea*, such as flavonoids, terpenoids, and polyphenols, act as reducing and stabilizing agents during nanoparticle formation, eliminating the need for harsh chemicals. These nanoparticles exhibit remarkable properties, including antimicrobial, anticancer, antioxidant, and insecticidal activities, making them suitable for diverse applications in biomedicine, agriculture, and environmental remediation. This review highlights *C. gigantea* plant potential as a sustainable source for nanoparticle synthesis and emphasizes its future prospects in advancing green nanotechnology.

Keywords: Nanotechnology, Metallic nanoparticles, Green synthesis, *Calotropis gigantea*

1. INTRODUCTION:

Nanoscience and nanotechnology are rapidly evolving fields that focus on the study and manipulation of materials at the nanoscale, typically between 1 to 100 nanometres. The concept of nanotechnology was first articulated by Richard Feynman in 1959, and since then, it has evolved significantly [1]. At the nanoscale, materials exhibit unique physical and chemical properties due to quantum effects and increased surface area relative to volume [2]. For instance, nanoscale carbon materials can function as semiconductors, unlike bulk carbon, which is an insulator. This scale-dependent behaviour is a primary focus of scientific interest and investigation [3]. Metallic nanoparticles (MNPs) have emerged as a cornerstone in nanotechnology, offering a glut of applications across various fields due to their unique physicochemical properties. MNPs are extensively used in drug delivery systems to enhance the therapeutic index of medications [4]. They improve drug solubility, bioavailability, and targeted release, which is crucial for treating diseases like cancer and inflammation [5]. Their ability to encapsulate and release therapeutic substances at precise body regions makes them ideal for targeted therapy. MNPs serve as contrast agents in imaging techniques such as MRI, CT, and fluorescence imaging, improving disease identification and monitoring [6].

MNPs are broadly classified into three major categories:

a. **Noble Metal Nanoparticles**: These include gold (Au), silver (Ag), platinum (Pt), and palladium (Pd) nanoparticles. They are widely used due to their stability and unique optical properties, making them suitable for applications in drug delivery, cancer therapy, and biosensing [7].
b. **Magnetic Nanoparticles**: Comprising metals like iron (Fe), cobalt (Co), and nickel (Ni), these nanoparticles are primarily used in magnetic resonance imaging (MRI) and targeted drug delivery due to their magnetic properties [8].
c. **Metal Oxide Nanoparticles**: These include copper oxide (CuO) zinc oxide (ZnO), iron oxide (Fe_2O_3), and titanium dioxide (TiO_2) nanoparticles. They are used in electronics, catalysis, and as antibacterial agents due to their unique electronic and catalytic properties [9].

The bio-inspired synthesis of nanomaterials is an innovative approach that leverages natural processes and biological entities to create nanostructures with unique properties. This method is gaining attraction due to its environmentally friendly nature, cost-effectiveness, and ability to produce materials with complex structures and functionalities [9]. Bio-inspired synthesis often utilizes biological entities such as plant extracts, microbes, proteins, and other biomolecules as reducing agents and templates [10]. These natural materials facilitate the formation of nanomaterials under mild conditions, avoiding the need for harsh chemicals and high energy inputs [11]. The biocompatibility and biodegradability of bio-inspired nanomaterials make them suitable for biomedical applications, such as drug delivery and biosensing. Their environmentally friendly synthesis aligns with the goals of sustainable development [12].
Plant extracts contain a variety of phytochemicals such as terpenoids, alkaloids, phenols, tannins, and vitamins, which act as reducing and stabilizing agents in nanoparticle synthesis [12]. These compounds facilitate the reduction of metal ions to nanoparticles and stabilize them by capping, which prevents agglomeration [13]. The efficiency of nanoparticle

synthesis can be influenced by factors such as the concentration of plant extracts, reaction temperature, and pH, which affect the size and morphology of the nanoparticles [14]. Till date thousands of plants derived extracts are used in the synthesis of metallic nanoparticles. Out of which *Calotropis gigantea*, is one of the most studied plants in nanotechnology. *Calotropis gigantea*, commonly known as the giant milkweed, is a perennial shrub with significant ecological distribution and phytochemical diversity. This plant is native to India, Malaysia, and China, and is widely distributed across warm temperate regions and tropical wastelands [15]. It is renowned for its medicinal properties, which are attributed to a rich array of phytochemicals [16]. Therefore, the objective of the present study is to review the nanoparticle synthesis using extracts of *Calotropis gigantea* and to understand its future perspectives.

Calotropis gigantea:

Calotropis gigantea, commonly known as the Crown Flower or Giant Milkweed, is a perennial shrub belonging to the Apocynaceae family, specifically the Asclepiadaceae subfamily. This plant is Commonly referred to as "Aak" or "Madar" in Hindi, it is also known as "Akon" in Assamese and "Arka" in some other Indian languages. The plant is well-suited to arid climates and is often found in coastal regions, as evidenced by its collection from Alue Naga beach in Banda Aceh, Indonesia. Its ability to grow in such diverse environments emphasizes its ecological adaptability [17]. The plant exhibits a broad spectrum of pharmacological activities, including anti-inflammatory, antioxidant, antimicrobial, and anticancer properties. Its compounds have shown potential in treating conditions like asthma, diabetes, and various inflammatory diseases [18]. Bioactive compounds from *C. gigantea* have demonstrated anticancer activities through mechanisms such as apoptosis induction and inhibition of cell proliferation [15].

Silver Nanoparticles (AgNPs):

A successful synthesis of AgNPs was achieved using leaf and flower extracts of *Calotropis gigantea* as bio-reductants. These AgNPs exhibited antimicrobial activity on *Escherichia coli*, *Staphylococcus aureus*, *Cryptococcus neoformans*, and *Aspergillus* species. Beyond antimicrobial uses, AgNPs from *C. gigantea* have demonstrated insecticidal properties against pests like *Tribolium castaneum*, suggesting their potential in agricultural pest management [19–22].

Zinc oxide nanoparticles (ZnO NPs):

The synthesis of ZnO NPs using *C. gigantea* involves utilizing different parts of the plant, such as latex and leaves, to reduce zinc ions into nanoparticles. ZnO NPs synthesized from *C. gigantea* exhibit significant antibacterial and antifungal activities. They have been shown to inhibit the growth of various pathogenic bacteria and fungi, making them potential candidates for use in antimicrobial formulations. Studies have shown that ZnO NPs can induce cytotoxic effects in cancer cell lines, such as breast cancer cells, by triggering apoptosis. ZnO NPs derived from *C. gigantea* have been tested for their efficacy against agricultural pests, such as the tobacco cutworm, showing promising results as a biopesticide [23–26].

Magnesium oxide nanoparticles (MgO NPs):

MgO nanoparticles synthesized from *C. gigantea* exhibit significant antimicrobial properties. These nanoparticles are effective against a range of pathogenic microorganisms, making them suitable for applications in antimicrobial coatings and treatments. The antioxidant properties of MgO nanoparticles are attributed to their ability to scavenge free radicals, which is beneficial in reducing oxidative stress in biological systems. These nanoparticles have shown potential anticancer activities, making them promising candidates for cancer therapy. Beyond antimicrobial and anticancer applications, MgO nanoparticles are also explored for their potential in drug delivery systems, tissue engineering, and bioimaging due to their biocompatibility and stability [27,28].

Nickel (Ni) and Nickel oxide (NiO) nanoparticles:

Nickel nanoparticles synthesized using *C. gigantea* have shown promising results in antimalarial applications, providing a low-cost and efficient alternative for malaria diagnosis and treatment. NiO NPs also demonstrated significant anticancer activity against liver cancer cell lines, indicating their potential in biomedical applications. Both nickel and nickel oxide nanoparticles exhibit catalytic properties and suitable for various industrial applications. Their antimicrobial properties have been highlighted, with NiO NPs showing effectiveness against multidrug resistant gram-negative bacteria [29,30].

Titanium dioxide (TiO_2) nanoparticles:

TiO_2 nanoparticles are synthesized using extracts from different parts of *C. gigantea*, such as leaves, seeds, and flowers which further revealed promising anticancer properties on liver cancer cells (HepG2) with significant cytotoxic effects. The photocatalytic properties of these nanoparticles are quite important, with applications in degrading organic pollutants. For instance, TiO_2 nanoparticles have been used to degrade methylene blue and metformin, achieving high degradation efficiencies due to their enhanced photocatalytic activity [31–33].

Copper oxide (CuO) and its composite nanoparticles:

CuO NPs exhibit significant antimicrobial activity against various pathogens. The binary ZnO–CuO nanocomposites synthesized using *C. gigantea* show strong bactericidal effects against both non-MDR and MDR pathogens, making them promising agents for treating skin infections. CuO NPs have been applied in dye-sensitized solar cells and as catalysts for the degradation of organic pollutants. The cytotoxic effects of CuO NPs have been studied using embryonic zebrafish models, revealing their potential in biomedical applications. The nanoparticles influence the expression of genes related to oxidative stress and apoptosis, indicating their utility in cancer research and therapy. Copper oxide sulphate (CuS) NPs synthesized using *C. gigantea* leaf extract shows efficient photocatalytic degradation of dyes under sunlight, and their potential in environmental remediation [34–36].

Conclusion and Future Perspectives:

The use of *C. gigantea* in the synthesis of nanoparticles has shown promising results across various applications, particularly in the fields of biomedicine and environmental science. The plant extracts have been effectively utilized to produce different types of nanoparticles, including zinc oxide (ZnO), silver (Ag), titanium dioxide (TiO_2), copper oxide (CuO) and nickel nanoparticles, each exhibiting unique properties and potential applications. Future research should focus on optimizing the synthesis processes to enhance the yield and efficacy of nanoparticles. This includes exploring different parts of the plant, varying synthesis conditions, and employing advanced characterization techniques to better understand the properties of the nanoparticles. Detailed studies on the mechanisms of action of these nanoparticles, particularly their interaction with biological systems, are necessary to fully understand their potential and limitations. This will aid in the development of targeted applications in medicine and environmental science. The green synthesis approach using *C. gigantea* is eco-friendly and sustainable. Future research should continue to explore the use of plant-based methods for nanoparticle synthesis, reducing reliance on toxic chemicals and promoting environmental sustainability.

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The authors declare no competing interest

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