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REVIEW ON GREEN SYNTHESIS OF NANOPARTICLES FROM TRADITIONAL MEDICINAL PLANT- CROSSANDRA INFUNDIBULIFORMIS AND ITS APPLICATION

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ABSTRACT
This review explores the green synthesis of nanoparticles utilizing the traditional medicinal plant *Crossandra infundibuliformis*, commonly known as the Firecracker Flower, and highlights its various applications. It emphasizes an ecofriendly, sustainable approach that leverages plant extracts for nanoparticle creation, steering clear of harmful conventional chemical methods. The bioactive compounds in *Crossandra infundibuliformis*, such as alkaloids, flavonoids, and phenolic acids, act as natural reducing and stabilizing agents for eco-friendly nanoparticle synthesis, resulting in antibacterial and antioxidant properties with potential biomedical and environmental applications. This review also explores the prospective uses of these green synthesized nanoparticles in fields such as drug delivery and environmental remediation. By merging traditional medicinal practices with modern nanotechnology, this review offers a thorough understanding of the green synthesis method and its promising implications for future research and development in sustainable nanomaterials.

KEYWORDS: *Crossandra infundibuliformis*, green synthesis of nanoparticle, Antibacterial, Antioxidant, Anticancer, phytochemical.

INTRODUCTION

Nanotechnology is an emerging field that focuses on the synthesis and development of various nanomaterials. Nanoparticles, which range in size from 1-100 nm, often exhibit different properties compared to their bulk material counterparts due to their size. Currently, various metallic nanomaterials are being produced using elements such as copper, zinc, titanium, magnesium, gold, alginate, and silver. These nanoparticles have a wide range of applications, including medical treatments, industrial production like solar and oxide fuel batteries for energy storage, and incorporation into everyday materials such as cosmetics and clothing[1] Nanotechnology is revolutionizing daily life and agriculture, affecting animal feed, aquiculture, food processing, packaging, irrigation, and water filtering in various sectors over the past decade.[2] CuO, a p-type semiconductor with a narrow bandgap, is used in various fields like solar energy, electronics, agriculture, and medical applications, including antimicrobial coatings in the food sector.[3] Green synthesis is a method of creating materials from environmentally friendly sources using a reducing agent, solvent, and stabilizing ingredient. It is simple, economical, reliable, sustainable, and repeatable. CuNPs, produced using plant extracts, are used in various scientific contexts.[4] Green synthesis uses natural resources like plants, bacteria, and fungi to create nanoparticles.[5] Crossandra infundibuliformis, a classic plant with beneficial properties, includes antibacterial, anticancer, wound healing, insecticidal, antifungal, and anthelmintic properties. Its active ingredients include phytosterols, alkaloids, flavonoids, and phenolic substances. Commonly known as Firecracker flower.[6] The potential applications of green-synthesized nanoparticles are vast and varied. In biomedicine, they can be used for drug delivery, imaging, and as antimicrobial agents.[7] This review delves into how *Crossandra Infundibuliformis* aids in the synthesis of nanoparticles, focusing on the role of its bioactive compounds in reducing and stabilizing these particles. It also explores the potential applications of nanoparticles synthesized from *Crossandra Infundibuliformis* in various domains, such as biomedicine, environmental remediation, and agriculture.

PLANT DESCRIPTION

Crossandra infundibuliformis, a member of the Acanthaceae family, is often referred to as Firecracker flower or Unarmed orange nail dye. The crop is mostly cultivated in South India, particularly in the districts of Coimbatore, Madurai, Villupuram, Cuddalore, Pondicherry, Trichy, and Thiruvannamalai.[8] The word "Crossandra" comes from the Greek word krossoi, which means fringed and andre, which means anthers that are fringed.[6] *Crossandra Infundibuliformis* (L.) Nees is a flowering plant classified within the Kingdom Plantae and Division Tracheophyta, which includes vascular plants. It belongs to the Class Angiospermae, characterized by its production of flowers and seeds enclosed in fruit. This species is part of the Order Lamiales, known for its diverse group of flowering plants. Within the Family Acanthaceae, which comprises many tropical herbs and shrubs, *Crossandra* is the designated Genus. Commonly referred to as the firecracker flower, *Crossandra Infundibuliformis* is admired for its vibrant blooms and is often used in ornamental gardening.[9] *Crossandra infundibuliformis*, commonly known as the firecracker flower in English, is also referred to as unarmed orange nail dye due to its vibrant coloration. In India, it has various vernacular names across different languages: it is called "Abbolige" in Kannada, "Aboli" in Gujarati and Marathi, and "Krosendra" in Hindi. In Bengali, it is known as "Krasandra," while in Telugu, it is referred to as "Krassandra." Additionally, in Malayalam, this striking plant is called "Priyadarshini." These diverse names reflect the flower's cultural significance and popularity across different regions.[10] Among the plant's promising effects are its anticancer, antibacterial, antifungal, anthelmintic, insecticidal, and wound-healing qualities Fig: 1. The plant's active ingredients include phytosterols, alkaloids, flavonoids, and phenolic compounds.[8]

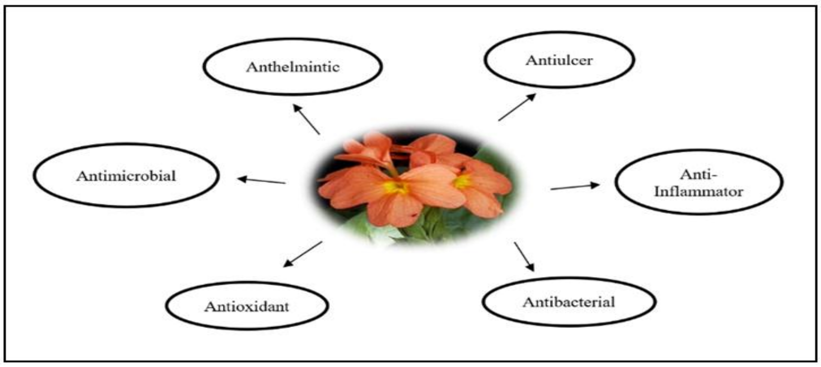

Figure 1: Pharmacological activities of Crossandra infundibuliformis.

TRADITIONAL USES

The Firecracker Flower, scientifically known as *Crossandra infundibuliformis*, has long been employed in Ayurvedic and Siddha medicine for addressing a variety of health issues.[9] The leaves of *Crossandra infundibuliformis* have been utilized for their anthelmintic, antibacterial, antioxidant, antiulcer, aphrodisiac, anti-inflammatory, antimicrobial, and wound-healing properties. They have also been employed to treat conditions such as fever, headache, and pain. Additionally, the plant is a traditional remedy for diabetes, leprosy, ulcers, conjunctivitis, and skin issues. Its anthelmintic activity was tested against Endrullus enguinae, Indian earthworms, and it also shows potential as a hepatoprotective agent. The root extract has been utilized for its anti- infective properties in treating infectious diseases. The stem extract has demonstrated antihyperlipidemic effects. Additionally, the flower extract has shown antisolar properties and has proven effective in wound healing.[8] The extract of the *Crossandra infundibuliformis* plant is rich in bioactive compounds that effectively combat various human pathogens.[10]

PHYTOCHEMICAL ANALYSIS

Madhumitha et al.[11] and Selvakumar et al.[12] analyzed crude extracts of various plants using different solvents, revealing distinct profiles of bioactive compounds. The petroleum ether extract contained carbohydrates, phenolics & tannins, flavonoids, oils & fats, phytosterols, and terpenoids. The ethyl acetate extract had phenolics & tannins, flavonoids, phytosterols, and terpenoids, while the methanol extract revealed alkaloids, phenolics & tannins, flavonoids, and terpenoids, with saponins unique to it and oils & fats and carbohydrates exclusive to petroleum ether extract expressed in table:1. *Crossandra Infundibuliformis* was also analyzed using aqueous, ethyl acetate, acetone, chloroform, and propane, showing diverse distribution of flavonoids, alkaloids, saponins, tannins, steroids, and cardiac glycosides, varying by solvent. These findings highlight the impact of solvent choice on the phytochemical composition, affecting biological activity and potential applications. Jency, S et al.[13] and Pulipati, S et al.[14] found that *Crossandra Infundibuliformis* flower extracts contained alkaloids, terpenoids, anthraquinone, flavonoids, tannins, and saponins in various solvents, with proteins, amino acids, steroids, and cardiac glycosides largely absent, except in specific cases, suggesting potential pharmacological activities influenced by solvent choice. Sharmila, N et al.[15] discovered multiple bioactive compounds in *C. infundibuliformis* leaf extracts, indicating a rich phytochemical profile with therapeutic or pharmacological potential. Elamathi, R et al.[16] identified carbohydrates, alkaloids, tannins, phenols, saponins, gums, mucilage, proteins, and flavonoids in both aqueous and methanol extracts of the plant, noting the absence of steroids and fixed oils, with alkaloids more concentrated in the methanol extract. These studies collectively highlight the diverse phytochemical composition of *C. infundibuliformis*, suggesting significant pharmacological potential varying with the extraction solvent.

Table 1: Phytochemical analysis of crude extracts.

Tests	A	B	C
Alkaloids	-	+	+
Carbohydrates	-	-	-
Saponins	-	+	-
Phenolics & Tannins	+	+	+
Flavonoids	+	+	+
Oils & Fats	-	-	-
Phytosterols	+	+	-
Terpenoids	+	-	-

A = Petroleum ether extract, B = Ethylacetate extract, C = Methanol extract. (+) = presence of compound, (-) = absence of compound.[11]

ANTIBACTERIAL ACTIVITY

Pulipati, S et al.[14] examined the in vitro antimicrobial activity of *Crossandra Infundibuliformis* against Gram-positive and Gram-negative UTI pathogens. The study found all extracts showed significant antibacterial activity, with the acetone extract being most effective, particularly against E. coli. Vishva, P.H. et al.[10] assessed the tannin content and antibacterial properties of *Crossandra Infundibuliformis* flower extracts, finding notable antibacterial activity, especially in the acetone extract. Jyothi et al.[17] found S. aureus to be the most susceptible strain among those tested. Elamathi, R et al.[16] evaluated the antibacterial activity of C. infundibuliformis leaf extracts, with the methanol extract showing effectiveness against S. aureus and S. typhi. Sharmila, N et al.[15] found that the ethanol extract showed antibacterial activity against all tested bacteria, with the highest activity against Pseudomonas aeruginosa. Madhumitha, G. et al.[11] assessed various bacterial strains, finding strong antibacterial effects from the petroleum ether extract against several strains and potential from ethyl acetate and methanol extracts against others. Overall, these studies highlight the significant antibacterial potential of C. infundibuliformis across various solvents and bacterial strains.

ANTIFUNGAL ACTIVITY

Madhumitha K et al.[11] evaluated the antifungal activity of *Crossandra infundibuliformis* extracts using petroleum ether (A), ethyl acetate (B), and methanol (C). The petroleum ether extract showed the strongest inhibition against various fungal species. The ethyl acetate extract was most effective against *Aspergillus niger* and *Penicillium chrysogenum*, with moderate effects on *Aspergillus flavus* and *Aspergillus fumigatus*. The methanol extract displayed weak inhibition, particularly against *Penicillium chrysogenum*. While all extracts showed moderate antifungal activity compared to standard agents, their potential for natural antifungal development was highlighted, with room for improvement in efficacy.

ANTICANCER ACTIVITY

Vadivel E et al.[18] studied the in-vitro anticancer activity of *Crossandra infundibuliformis* ethanolic leaf extract against the MCF-7 human breast cancer cell line using the MTT assay. The results demonstrated a dose-dependent cytotoxic effect, with the highest concentration of 60 µg/ml showing 11.76% cytotoxicity and 88.24% cell viability. The CTC50 (the concentration required for 50% cell death) was found to be 404.66µg/ml. The extract contained phytochemicals such as triterpenes, flavonoids, and tannins, which are known for their antimicrobial and anticancer properties. These active compounds may contribute to the observed anticancer activity of *Crossandra infundibuliformis.*

ANTIOXIDANT ACTIVITY

Patil, K. G et al.[19] investigated the antioxidant activity of *Crossandra Infundibuliformis* leaf extracts using various methods, finding that methanol extract had the highest inhibition percentage in the DPPH radical scavenging assay, while ethyl acetate extract had the highest IC50 value. The methanol and petroleum ether extracts exhibited potent scavenging abilities. Sharmila, N et al.[15] assessed the scavenging activity using the DPPH radical test and found the ethanol extract had strong potential. Vishva, P.H. et al.[10] explored the phenolic content and antioxidant properties of the leaves, revealing high levels of phenolic and flavanol content with significant antioxidant activity in multiple assays. Rao, S et al.[20] highlighted the antioxidant activity of flower extracts through the DPPH assay, showing potential for water purification due to their effects on aquatic bacteria and fungi.. Ch, S., et al.[6] found methanol and chloroform extracts exhibited significant antioxidant activity, correlating well with phenol and flavanol levels. Collectively, these studies underscore the robust antioxidant properties of *Crossandra Infundibuliformis* across various extracts, emphasizing its therapeutic potential. Additionally, the medicinal properties of these flower extracts were highlighted for their ecological benefits during the Dusshera festival. The studies consistently show strong antioxidant activities in methanol, ethyl acetate, and chloroform extracts, reinforcing the plant's potential as a source of natural antioxidants.

GREEN SYNTHESIS OF NANOPARTICLES

1. Copper oxide nanoparticles

Naika, H. R et al.[21] described the solution combustion method where 1 mL of plant extract and 2.32 g of cupric nitrate were combined with double distilled water, stirred for 10 minutes, and heated in a muffle furnace at 400 ± 10 °C to form CuO nanoparticles within 3-4 minutes. These nanoparticles were stored for further analysis. Different concentrations of plant extract were tested while maintaining a constant amount of cupric nitrate. Kaviya, S et al.[22] prepared a 1 nM aqueous solution of silver nitrate for synthesizing silver nanoparticles by adding 3 ml of plant extract to 40 ml of the solution, conducting the reaction at room temperature. Ananda Murthy, H. C et al.[23] noted that plants contain biologically active compounds effective in various applications and that metallic nanoparticle synthesis involves mixing metal solutions with plant extracts. Copper nanoparticles can be synthesized using precursors like cupric acetate monohydrate, copper chloride dihydrate, and copper sulfate pentahydrate, with factors such as concentration, pH, and temperature influencing their properties. Velsankar, K et al.[24] synthesized CuO nanoparticles by preparing a 0.1 M cupric nitrate solution with 20 mL of plant extract, boiling the mixture at 70 °C for 2-3 hours, centrifuging and washing it, drying it at 80 °C, and finally calcining it at 400 °C for 3-4 hours before characterization. Together, these studies highlight the potential for synthesizing metallic nanoparticles using plant extracts and various methods to influence their characteristics and properties.

2. Silver Nanoparticles

Arunavarsini K et al.[25] synthesized silver nanoparticles by preparing a 100 ml aqueous solution of silver nitrate ($AgNO_3$) and mixing it with *Crossandra infundibuliformis* flower extract in ratios of 9:1, 5:5, and 7:3. The 7:3 ratio (35 ml $AgNO_3$ to 15 ml extract) resulted in the highest nanoparticle yield. The mixture was centrifuged at 3500 rpm for 10 minutes, and the supernatant was discarded. The pellet was collected, air-dried for one day, and weighed at 0.06 µg. The dried pellet was dissolved in 983.4 µl DMSO and 16.6 µl of stock solution and stored in an Eppendorf tube for future use. This method demonstrated an efficient and eco-friendly approach to nanoparticle biosynthesis.

3. Polymeric nanoparticles

Jyothi et al.[17] synthesized three PLGA (50:50) nanoparticle formulations (N1, N2, N3) with varying extract/polymer ratios using the emulsion-solvent evaporation method. PLGA and plant extract were dissolved in DMSO and added dropwise into an aqueous PVA surfactant solution under continuous stirring. After 3 hours at 30°C, DMSO evaporated, leaving a colloidal suspension, which was centrifuged at 12,000 rpm to obtain encapsulated plant extract nanoparticles. The pellet was washed to remove unentrapped drug, demonstrating a method for incorporating plant extracts into nanoparticles for antimicrobial applications.

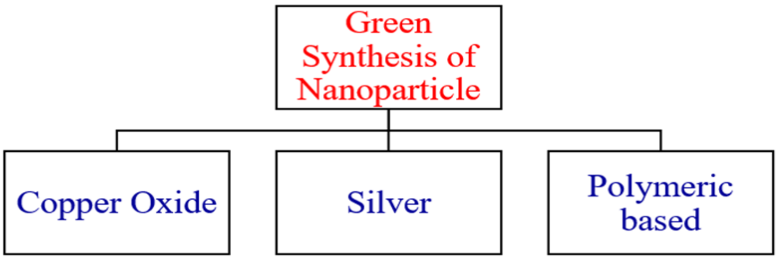

Figure 2: Green synthesis of nanoparticle.

CONCLUSION

To conclude, the green synthesis of nanoparticles using *Crossandra Infundibuliformis* provides a sustainable and environmentally friendly approach to producing metallic nanoparticles. The plant extracts effectively reduce metal ions, creating nanoparticles with significant antioxidant, antimicrobial, and anticancer properties. This method leverages natural resources and minimizes the environmental impact compared to conventional chemical synthesis methods. The nanoparticles produced have shown promising applications in medicine, catalysis, and other fields, underscoring the potential of *Crossandra Infundibuliformis* as a valuable resource for green nanoparticle synthesis.

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