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Calotropis gigantea assisted green synthesis of nanomaterials and their applications: a review

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Abstract

Background: Nanotechnology has been receiving wonderful impetus in the current emerging technological era by opening a pool of scientific ideas to compete with the daily challenges of developing technology. So far, numerous properties and countless applications of nanomaterials have been explored which have been even proved to be based on characteristic shape, size, surface area and surface chemistry.

Main content: By the time, several attempts have been made for green synthesis of nanomaterials, using plant extracts. *Calotropis gigantiea* (L.) R. Br is the plant belonging to Apocynaceae, have been screened and proved to possess various pharmacological activities, due to different polar phytochemicals like flavonoids, lignans and terpenoids. This review focus on phytochemicals so far reported from different parts of the plant; pharmacological activities exhibited; green synthesis of nanomaterials, particularly metallic nanoparticles green synthesised by facilitating reaction of metallic ion donor molecule/salt and aqueous extract of leaves or flowers of *C. gigantiea* and their biological or non-biological applications. The use of *C. gigantea* in the fabrication of nanomaterials is an eco-friendly and safe approach. Secondary metabolites present act as a stabilizing agent for nanomaterials. Cadmium sulphide, titanium dioxide, nickel and nickel oxide nanoparticles synthesised using *C. gigantea* exerted better anti-microbial action, compared to extracts. Nanoencapsulated magnesium oxide nanoparticles avoided biochemical degradation of MgO; increase its bioavailability and proved beneficial in type II diabetes mellitus. Cupric oxide nanoparticles got applied in dye-sensitised solar cell. Silver nanoparticles showed better cytotoxicity in HeLa cells. Biomaterial-supported zero-valent iron and stannic oxide nanoparticles proved to have utilities in water purification. Green synthesised Eu^{3+} doped Y_2SiO_5 nanophosphors had significant chromaticity coordinates and average correlated colour temperature, hence find application in displays.

Conclusion: Variety of nanomaterials including nanoparticles and nanophophors could successfully be biosynthesised using *Calotropis gigantean* extract or its latex. These green synthesised nanomaterials have several applications in the healthcare system and technology.

Keywords: Nanotechnology, *Calotropis gigantea*, Metal nanoparticles, Zero-valent iron nanoparticles, Eu^{3+} doped Y_2SiO_5 nanophosphors, Applications

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1 Background

Nanotechnology has gained marvellous impetus in today's rapidly emerging technological era by generating a wealth of scientific concepts to tackle with daily challenges of developing technology [1]. The nanomaterials have been proved to possess countless applications and physicochemical properties [2, 3] which are exerted due to their characteristic size, shape, area and surface chemistry [4]. These features of nanomaterials enable them to be highly reactive and thereby more attractive for researchers [5]. These nanomaterials may exist in the form of nanotubes, nanocrystals, nanoparticles, nanospheres, nanophosphors or even in their combination, i.e. nanohybrids. In the recent era, different metallic nanoparticles are gaining research interest in material chemistry due to their unique catalytic, electrical and optical characteristics. These nanomaterials could be conjugated with various functional biomolecules such as antibodies, ligands, and drugs of interest for biomedical applications.

1.1 Manufacturing of nanomaterials

Depending upon the particular type, nanomaterials can be manufactured by one of the two approaches: *bottom-up* and *top-down*. The bottom-up approach involves placing of atom by atom or molecule by molecule; which can be achieved by chemical synthesis, self-assembly and positional assembly. Top-down strategy implicates etching, milling or grinding of a larger piece of material to be converted to its nanoform. In this approach, complex devices are used, requiring high energies and producing more wastes. Hence, bottom-up strategies are preferred where atoms or molecules are get arrange themselves into ordered nano-structures by physical and/or chemical interactions.

2 Main text

As far as *Calotropis gigantea* is concerned, different research articles pertaining to a variety of aspects, right from primary microscopic features of different parts, their preliminary phytochemical evaluation, various pharmacological screening and application of its extracts in green synthesis of nanomaterials have been published. Most of these research articles are available on internationally reputed, well-recognised search engines like ScienceDirect (http://www.sciencedirect.com), Wiley Online Library (http://onlinelibrary.wiley.com), Springer (http://linnk.springer.com), Taylor and Francis (http://www.tandfonline.com), Nature (www.nature.com) and PubMed (http://www.ncbi.nlm.nih.gov>pubmed). This review highlighted the phytochemicals reported to be present in a given part of plant *Calotropis gigantea* which could be claimed to be present in extract using which several successful attempts of green synthesis of nanomaterials were made. This review throws the light on the method used for their green synthesis as well as the biological/pharmacological and non-biological applications of these nanomaterials.

2.1 Botanical description of *Calotropis gigantea*

The word *Calotropis* was derived from the Greek word "*Kalos*" meaning beautiful and "*tropis*" meaning keel, referring to the shape of the coronal scales. *Calotropis gigantea* (crown flower) (Fig. 1) is a large shrub or small tree, belonging to family Asclepiadeae, characterised by the presence of a smooth and soft tomentum on stems and lower leaf surfaces, calyx lobes with many glands at the base, broadly campanulate corollas, and coronal scales with a recurved spur at the base. Among various species, this one, *C. gigantea* is an Asiatic, occurring widely throughout the Indian subcontinent, southern China, South East Asia and has also been introduced into New Guinea and Hawaiian islands [6].

2.2 Phytochemical composition of *Calotropis gigantea*

Over time, variety of secondary metabolites have been reported to be isolated from different parts of *Calotropis gigantea* and structurally elucidated.

As per Lhinhatrakool T, Sutthivaiyakit S. [7], the leaves of *C. gigantea* contain pinoresinol, medioresinol, uzarigenin, calotropin, calactin, calacitnic acid, calacitnic acid methyl ester, 19-carboxyl-calacitnic methyl ester, drummondol, 15b-hydroxycalotrin, the C-11 bicylic lactone, norisopenoid, the rare diphenyl furfuran lignan and

Fig. 1 *Calotropis gigantea* (Crown flower), belonging to family Asclepiadeae

salicifoliol. Seeka and Sutthivaiyakit [8] isolated 15-β-Hydroxycardenolides and 16-α-hydroxycalactinic acid methyl ester while Nguyen et al. [9] isolated a lignan, 9′-methoxypinoresinol and two new glycosylated 5-hydroxymethylfurfurals, calofurfuralside A and calofurfuralside B from the leaves of *C. gigantea.* Di-(2-ethylhexyl) Phthalate and anhydrosophoradiol-3-acetate were isolated from flower [10]. Sen et al. [11] isolated flavonol glycosides, isorhamnetin-3–0-[2-O–β-D-galactopyranosyl–6–O–α–L-rhamnopyranosyl]–β-D-glucopyranoside, isorhamnetin-3-O-rutinoside, isorhamnetin–3–0-glucopyranoside and taraxasteryl acetate from aerial parts of *C. gigantea*. The fixed oil separated from seeds of *C. gigantea* was reported to contain lauric acid, myristic acid, palmitic acid, palmitoleic acid, stearic acid, oleic acid, linoleic acid, linolenic acid, arachidic acid and behenic acid (book chapter). These fatty acids are also present in the form of mono-, di-, and tri-acyl glycerols at the surface of and internal to leaves [12]. Terpenoids derivatives like pentacyclic Triterpenic Esters and lupeoul acetate were isolated from the roots of *C. gigantea* [13].

2.3 Pharmacological potential of *Calotropis gigantea*

Calotropis gigantea is a notorious weed, so far not cultivated commercially. Still, the plant has been screened for different pharmacological activities, in the form of extract of any part, isolated compound or latex, using different scientifically accepted in-vivo or in-vitro models [14]. Based on phytochemicals present, different parts of *Calotropis gigantea* were reported to possess different pharmacological activities (Table 1).

2.4 Green synthesis of nano-structures and their applications

Several researchers tested the hypothesis which was based on nanostructures if synthesised using *C. gigantea* or its latex, could have improvement in pharmacological potential exhibited by different extracts prepared using different parts of *C. gigantea* or latex collected; or else, these nanomaterials could be used in non-biological applications like those in the field of energy or television displays (LEDs and LCDs).

2.5 Cadmium sulphide nanoparticles

In 2017, Ayodhya and Veerabhadram [29] synthesised cadmium sulphide nanoparticles using aqueous extract of leaves of *C. gigantea*. The extract was further mixed with 40 mL of 1 mM of cadmium acetate and 40 mL of 1 mM of sodium sulphide to obtain spherical CdS NPs. CdS NPs were then characterised for their morphology, stability and particle size; photocatalytic activity was studied under sunlight irradiation using MB and EY dyes. The XRD pattern of CDs NPs exhibited three prominent peaks at 2θ values of 26.4°, 43.4° and 51.6°;

Table 1 Pharmacological activities of *C.gigantea*

Part of plant	Pharmacological Activity	Pharmacological model used	Reference
Flowers	Analgesic	Acetic acid induced writhing	[15]
Flowers	Anti-tumoric	Ehrlich's ascites carcinoma in mice	[16]
Latex	Antibacterial	Agar well diffusion method using cariogenic bacteria	[17]
Leaves	Antibacterial	Agar well diffusion method using Klebsiella spp	[18]
Flowers	Anti-fungal	Disc diffusion assay method using *Aspergillus flavus* and *Aspergillus fumigatus*	[10]
Flowers	Cytotoxicity	Brine shrimp lethality bioassay	
Aerial parts	Antipyretic	TAB (typhoid) vaccine-induced pyrexia in rabbits and Brewer's yeast-induced pyrexia in rats	[19]
Root bark	Antitumour	Ehrlich's ascites carcinoma in mice	[20]
Peeled roots	Anticonvulsant and skeletal muscle relaxant activity	Pentobarbitone-induced sleeping time model and rotating rod model	[21]
Leaves	Anticonvulsant and skeletal muscle relaxant activity	Maximal electroshock seizure (MES) and Strychnine-induced convulsions models and rotating rod model	[22]
Leaves	Cytostatic and cytotoxic activity	SRB assay using tumour cell lines: MDA-MB-231 (human breast cancer), PC-3 (human prostate cancer), MCF7 (human breast cancer), HT-29 (human colon cancer), 4 T1 (mouse mammary cancer), and RAW-267 (mouse leukemic monocyte macrophage)	[23]
Leaves	Antiplasmodial	Lactate dehydrogenase assay using human blood	[24]
Latex and fruits	HIF-1 inhibitory activities	T47D cell-based dual-luciferase reporter assay	[25]
Root bark	Wound healing	Excision, incision and dead space wound models	[26]
Roots	Pregnancy interception	Postcoital contraceptive efficacy evaluation	[27]
Latex	Procoagulant activity	Re-calcification time and fibrinogenolytic activity	[28]

corresponding to the (111), (220) and (311) diffraction planes of cubic crystals. The average particle size of CdS NPs was found to be 12 nm. The nanophase and quantum confinement nature of the synthesised CdS NPs was indicated by enhancement of the optical band gap of 2.42 eV. It was also observed that as in particle size decreases, the energy of separation between the ground and excited electronic states increases; resulting in a blue shift in absorption. The capping effects and functional groups of *C. gigantea* leaf extract phytochemicals on CdS NPs surfaces were investigated by ATR–FTIR. The longevity of CdS NPs was tested by recycling the photocatalyst used in the photocatalytic degradation of MB and EY dyes under 60 min of sunlight irradiation. The result indicated that the CdS catalysts are fairly photostable and practically applicable. It was claimed that electron-donating functional groups of phytochemical present in aqueous extract of *C. gigantea* leaves are responsible for the stability of CdS NPs and the reduction of both dyes. Further, CdS NPs were evaluated for antimicrobial activity and compared with that exerted by core *C. gigantea* leaves extract. In the culture of bacteria, *E. coli*, *P. aeruginosa*, *S. aureus* and *B. thuringiensis*; and fungi, *A. niger* and *C. albicans*; zone of inhibition obtained with CdS NPs were 4 to 6 times wider than those obtained with *C.gigantea* leaves extract. About antifungal activity, it was claimed that CDs NPs got saturated and adhered to fungal hypha and to disrupt them.

2.6 Magnesium oxide nanoparticles

As such oral magnesium supplements are consumed to increase insulin sensitivity and reducing the risk of the onset of type 2 diabetes. This is because magnesium is an important co-factor/prosthetic group for phosphorylation causing enzymes like tyrosine-kinase, playing a significant role in insulin signalling pathway. But commonly available supplement, magnesium oxide, MgO has poor oral bioavailability and thereby may get decomposed by gastric acid. Hence, with the hypothesis that nanoencapsulated magnesium oxide nanoparticles (MgO NPs) can avoid all these biochemical degradation of MgO and increase its bioavailability. Carried out the synthesis of MgO NPs using aqueous extract of *C. gigantea* and their nano-encapsulation into polymer polyvinylpyrrolidone (PVP) or Eudragit L [30]. Aqueous extract of *C. gigantea* leaves played a significant role in the formation and stabilization of MgO NPs. The MgO NPs so formed were then encapsulated by following conventional emulsion solvent evaporation method where 10 mg of MgO NPs and 20 mg of PVP or 20 mg of Eudragit L were dissolved in 10 mL of ethanol. Then, about 10 ml of distilled water containing Tween80 (2%, w/w) or 10 mL liquid paraffin containing sorbitan sesquioleate (2%, w/w) was added as the emulsifier. Then, these mixtures were heated to 80C and stirred at an agitation speed of 250 rpm on a magnetic stirrer until ethanol was fully disappeared and that nanosuspensions were centrifuged at 13200 rpm for 20 mins to get PVP-MgO NPs or Eudragit L-MgO NPs. The average size of MgO NPs obtained was 48.38 nm while their crystallite size was 8 nm. When encapsulated by emulsion solvent evaporation, PVP-MgO NPs and Eudragit L-MgO NPs, particle size increased to 96.65 and 53.37 nm, respectively. Eudragit L-MgO NPs had higher stability. Drug entrapment efficiency (%) and drug loading (%) for Eudragit L-MgO NPs were found higher than those for PVP-MgO NPs. It was also observed that drug release pattern of Eudragit L-MgO nanoparticles was as per Fickian diffusion mechanism and coincided well with the Weibull model.

2.7 Nickel and nickel oxide nanoparticles

Nickel (Ni) is the transition metal, exhibiting magnetism and catalytic properties. Nickel nanoparticles (NiNPs) have been proved to adsorb environmentally hazardous dyes and inorganic pollutants [31]. They also possess good antibacterial and anti-inflammatory activities [32]. On the other hand, its oxide form NiO has cubic crystal lattice structure with p-type semiconductor properties. Nanoparticles of NiO (NiO-NPs), due to their electron transfer capability with their own high chemical stability and super-capacitance properties [33]; they exhibit technical applications in battery cathodes, fuel cells, electrochromic films, magnetic materials, optical fibres and gas sensors [34]. Considering these potential applications, Din et al. [35] fabricated Ni-NPs and NiO-NPs using hydro-methanolic (40% methanol) extract of freshly collected leaves of *C. gigantea.* In UV/vis spectrum, sharp exciton absorption was positioned at 415 nm, suggested that *C. gigantea* extract assisted green synthesised NiO NPs were stable. The FT-IR spectra of both Ni and NiO NPs did not show a peak around 1000–1100 cm^{-1} while peak for O–H bond got reduced in Ni NPs FTIR spectrum and almost completely reduced in NiO NPs FTIR spectrum; suggesting the important role of alcohols and halogens in metal ion reduction. Amines also played role as a capping agent in the fabrication of Ni-NPs. As per the results of XRD-analysis the particle size of Ni-NPs was in the range of 20–40 nm while that may higher up to 60 nm for NiO NPs. Further, on antimicrobial screening of Ni and NiO-NPs against *Pseudomonas auruginosa*, these were found equally potent, compared to Chloramphenicol.

2.8 Titanium dioxide nanoparticles

Infection by tick parasites like *Rhipicephalus microplus* and *Haemaphysalis bispinosa* is major hindrance in having and sustaining new generations of cattle. To have a scientific check for hypothesis that titanium dioxide nanoparticles (TiO_2 NPs) could be exhibiting significant

acaricidal activity, Marimuthu et al. [36] attempted the green synthesis of TiO_2 NPs using aqueous extract *C. gigantea* flowers and morphologically characterised. XRD pattern of TiO_2 NPs showed diffraction peaks at 2θ values of 27.33°, 35.83°, 43.87°, 54.02°, 56.39°, 66.64° and 74.07° could be assigned to the (110), (101), (210), (211), (220), (301) and (320), respectively; indicating faced centre cubic lattice structure of TiO_2 NPs. SEM showed their spherical shape with particle size ranging between 160 and 220 nm [36]. also evaluated TiO_2 NPs against *R. microplus* and *H. bispinosa* by filter paper impregnated bioassay protocol. Researchers found that LC_{50} values shown by aqueous extract of flowers and TiO $(OH)_2$ solution are around four times higher than those shown by TiO_2 NPs, indicating TiO_2 NPs can be used to treat the tick parasitic infection in cattle.

2.9 Cupric oxide nanoparticles

To fulfil the increasing demands for energy, the development of photovoltaic technology especially, dye-sensitised solar cells (DSSCs) are getting importance and research interest. Cupric oxide (CuO) is a p-type semiconductor with narrow bandgap (Eg 1.2 eV) and material for the fabrication of various electronic and optoelectronic devices [37]. Therefore, in the fabrication of DSSCs, CuO NPs have been considered as an alternative counter electrode material. CuO NPs can also be used in making high-temperature superconductors [38] gas sensors [39] and giant magnetoresistance materials [40]. When incorporated into coatings, plastics and textiles, CuO NPs acts as anti-fouling and antimicrobial [41]. Considering these technical applications, Sharma et al. [42], synthesised CuO NPs from Cupric Nitrate added to aqueous extract of *C. gigantea* leaves and fabricated CuO nanoparticles based counter electrode that to be used in DSSC. Initially, the formation of nanostructures was confirmed by the increased bandgap of 1.86 eV. In XRD analysis, several intense peaks at 2θ values of 32.4, 35.5, 38.7, 48.7, 53.4, 58.3, 61.5, 66.2, 68.0, 72.4 and 75.2°, were obtained, which could be assigned to (110), (002), (111), (202), (020), (202), (113), (311), (113), (311) and (222), respectively; indexing as typical monoclinic structure of CuO NPs. TEM analysis revealed the spherical shape of CuO NPs with a particle size up to 20 nm. The cyclovoltametric measurement exposed that CuO NPs-based material showed to be a reasonably good platform for the reduction of triiodide ions in redox electrolyte, signifying its good electrocatalytic activity towards the iodide ions (Fig. 2). Kumari et al. [43] attempted synthesis of CuO NPs by the addition of floral extract of *C. gigantea* to1 mM $CuCl_2$ solution and characterised by advanced techniques. The hydrodynamic diameter of synthesised CuO NPs showed the diameter of 109 ± 11 nm. The zeta potential of CuO NPs was found to be − 34 ± 12 mV. The XRD peaks were observed at 2θ values of 32.5, 35.5, 38.7, 48.7, 53.0, 58.2, 63.4, 66.2 and 68.1 corresponding to (110), (002), (111), (202), (020), (202), (113), (311) and (113), respectively. The result indicated a typical monoclinic structure of CuO NPs [43]. also explained the mechanism of

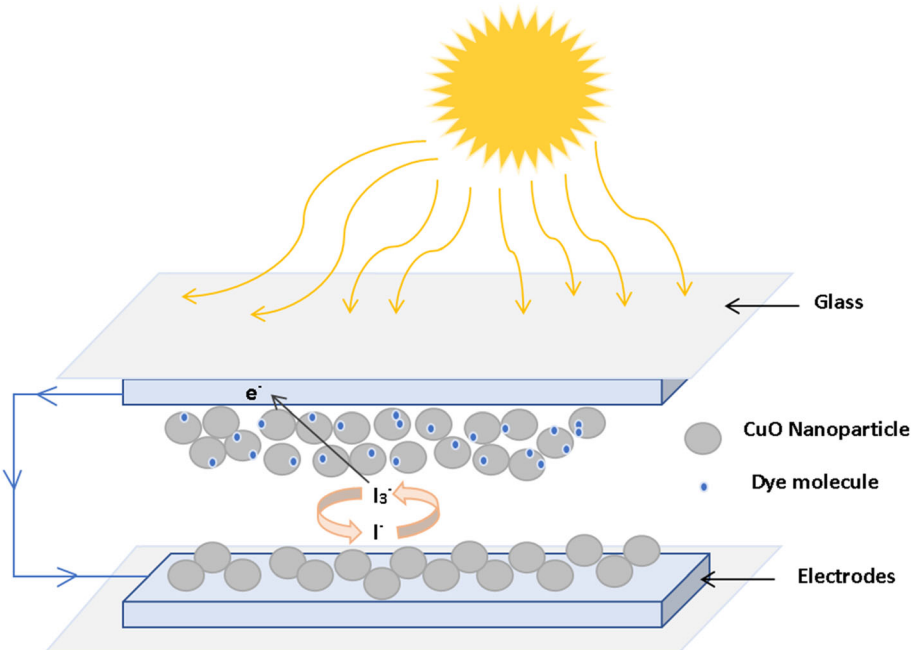

Fig. 2 Cupric oxide nanoparticles (CuO NPs) employed in dye-sensitized solar cells (DSSCs)

biosynthesis of CuO NPs, according to which phytochemicals having hydroxyl groups played a significant role in reducing copper (II) chloride to copper hydroxide (Cu $(OH)_2$). Further, Cu $(OH)_2$ got reduced to CuO NPs which were capped and stabilised by phytochemicals present in the floral extract of *C. gigantea* extracted in an aqueous medium.

$$CuCl_2.2H_2O + 2(\text{Phytochemical})OH \rightarrow Cu(OH)_2 + 2(\text{Phytochemical})Cl$$
$$+4H_2OCu(OH)_2 \rightarrow CuONPs(\text{Cappedandstabilised}) + H_2O$$

The toxicity of CuO NPs was evaluated by determining their effect on physiological and morphological changes in Zebrafish embryo. Surprisingly, the hatching rate was found higher in the case of embryos exposed to CuO NPs as compared to the commercial one. It was also observed that CuO NPs got accumulated at chorion, yolk sac and skin surface of 24, 48 and 72 h post-fertilization (hpf).

To determine the effect of synthesised CuO NPs in Zebrafish embryos at the cellular level, ROS induction and apoptosis were analysed in embryos after 72 hpf of treatment with the help of flow cytometry and Acridine orange staining-based fluorescent microscopy.

2.10 Zinc oxide nanoparticles

Two successful attempts were made for green synthesis of zinc oxide nanoparticles (ZnO NPs) using *C. gignatea*. Vidya et al. [44] used aqueous extract of *C. gignatea* leaves. They got hexagonal ZnO NPs ranging in size of 30–35 nm. Panda et al. [45] employed milky latex obtained by making an incision on the intact branches of *C. gignatea* and precursor zinc acetate; and carried out alkaline precipitation method. XRD pattern showed 13 characteristic diffraction peaks of (100), (002), (101), (102), (110), (103), (200), (112), (201), (004), (202, 104) and (203), observed at 2θ angles; 31.77°, 34.42°, 36.25°, 47.54°, 56.6°, 62.86°, 66.38°, 67.96°, 69.09°, 72.56°, 76.95°, 81.37° and 89.6°, respectively, reflecting wurtzite crystalline structure of ZnO NPs. *C. gigantea* milky latex-based ZnO NPs induced oxidative stress in DNA damage as determined by Comet assay in the root assay system of *L. sativus*, which was found comparable to that induced by the commercially available ZnO NPs-S (S for Sigma-Aldrich, St. Louis, MO, USA).

2.11 Silver nanoparticles

Rajkuberan et al. [46] synthesised silver nanoparticles (AgNPs) using freshly collected milky white latex of *C. gigantea*. Latex was first converted to 3% aqueous extract and then about 1 ml was added to 9 ml of 2 mM silver nitrate, $AgNO_3$. Then, AgNps were characterised by UV-Vis absorbance spectroscopy, FTIR analysis, X-ray diffraction, FeSEM and TEM techniques; and evaluated for their antibacterial activity against *Shigella* and *P. aeruginosa*; and cytotoxicity against HeLa cells. XRD pattern showed diffraction peaks at (111), (101), (103) and (105) corresponded to 2θ values of 38.12, 47.08, 57.93 and 76.71°, respectively depicted that AgNPs had mixed phase of cubic and hexagonal structures. As per Debye–Scherrrer's equation, the average particle size was calculated as 12 nm. About antimicrobial activity, it was observed that zone of inhibition created by lowest concentration 10 μl of AgNPs was 2 to 3 times higher in diameter than those created by 3% aqueous latex extract. Cytotoxicity exerted by these AgNPs against HeLa cells was also significant with LC_{50} of 91.3 μg; however, that with 3% aqueous latex extract was found to be 311 μg.

2.12 Iron oxide nanoparticles and biomaterial-supported zero-valent iron nanoparticles

Jain et al. [47] employed aqueous extract of *C. gigantea* for phytofacation of iron oxide nanoparticles. The XRD pattern of the product can be clearly pointed to the face-centered cubic spine structure of iron oxide nanoparticles with a lattice parameter of a = 8.393 Å and a size ranging between 3 and 6 nm; exposing that reduction of Fe^{3+} by *C. gigantea* aqueous extract leads to FeO NPs as the final product. Further, in 2018, zero-valent iron nanoparticles (ZVIN) were synthesised by green eco-friendly method using aqueous extract of *C. gigantea* flowers and characterised by UV-Vis, FT-IR, XRD, SEM, and EDX [48]. The ZVIN so synthesised were spherical in shape and 50–90 nm in size. From the FT-IR and UV-visible spectrum, Sravanthi et al. 2018 concluded that polyphenols present in the flower extract were responsible for the reduction and stabilization of ZVIN. Then, they proved the effectivity of ZVIN in controlling water pollution by adsorptive removal of organic waste such as methylene blue (synthetic dye) (Fig. 3) and aniline (aromatic primary amine) from contaminated water.

2.13 Tin oxide/stannic oxide nanoparticles

Tin oxide/stannic oxide (SnO_2) is one of the n-type semiconductor having a bandgap of 3.6 eV, thereby used in photoconductive and photochemical device in liquid crystal display and lithium-ion batteries; and transparent conductive electrode for solar cells, gas sensors [49]. Because of the high surface to volume ratio, SnO_2 NPs exhibit increased sensitivity and adsorption and can be used as photocatalyst [50]. Considering this significance, Bhosale et. al. [51] attempted the green synthesis of SnO_2 NPs by the addition of dilute aqueous extract of leaves to 0.05 M solution of tin chloride ($SnCl_4 \cdot 5H_2O$) with constant stirring. They claimed that tin chloride reacted with polyphenols present in the extract and

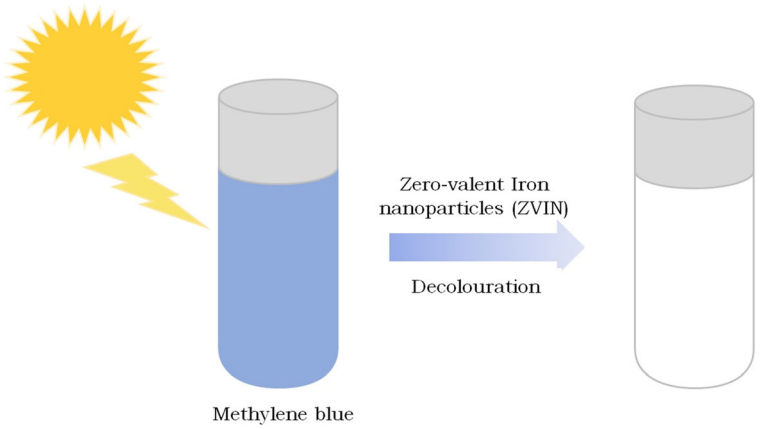

Fig. 3 Use of zero-valent iron nanoparticles (ZVIN) photocatalytic decolouration of dye methylene blue

following calcination, they got SnO_2 NPs with spherical morphology of an average size of 35 nm. In XRD pattern, the peaks at 2θ values of 26.5°, 34°, 37.9°, 51.7°, 54.4°, 57.7°, 61.7°, 64.8°, 71.3° and 78.5° were associated with (110), (101), (200), (211), (220), (002), (310), (301), (202) and (222) planes, respectively, proving the formation of SnO_2 NPs with tetragonal structure. Then, Bhosale et al. 2018 also explained the plausible mechanism for the formation of SnO_2 NPs, according to which $SnCl_4.5H_2O$ salt solution on mixing with *C. gigantea* leaf extract, Sn^{4+} ions form a complex with hydroxyl groups. The complex so formed got decomposed on calcination. Polyphenolic molecules then kept Sn^{4+} cations together forming SnO_2 NPs. Taking dye methyl orange as a model pollutant under UV-light, its degradation was further tested as a function of photocatalytic potential of the synthesised SnO_2 NPs (Fig. 4).

2.14 Eu_3^+ doped Y_2SiO_5 nanophosphors

During the last decade, white light-emitting diodes (WLEDs), due to high efficiency, energy-saving, long lifetime, safety and environmental protection have fascinated a lot of research interest in the solid-state lighting [52]. White light was obtained by the foremost technique involving the mixing ultraviolet (UV) LED chip with tricolour phosphors [53] but the lack of appropriate red phosphors decreased colour rending index (CRI). So far newly designed red phosphor, Y_2O_2S: $Eu3^+$ has shown low efficiency and poor chemical stability. Therefore, Ramakrishna et al. [54] accepted this challenge of developing a new red phosphor with sufficiently high luminous efficiency and fabricated red-emitting Eu3+ doped Y_2SiO_5 nanophosphors using *C. gigantea* latex, Yttrium nitrate (Y $(NO_3)_3$, Europium nitrate (Eu $(NO_3)_2$, H_2O and NaCl. The Eu3+ doped Y_2SiO_5 nanophosphors so obtained were irregular shape with an average size of 32 nm which was found decreasing on the increasing concentration of (Eu $(NO_3)_2$. Determination of optical properties of Eu3+ doped Y_2SiO_5 nanophosphors was based on emission spectra and Judd–Ofelt theory. It was observed that there is ionic bonding between Eu3+ ions and host; and assembled in symmetrical in coordination

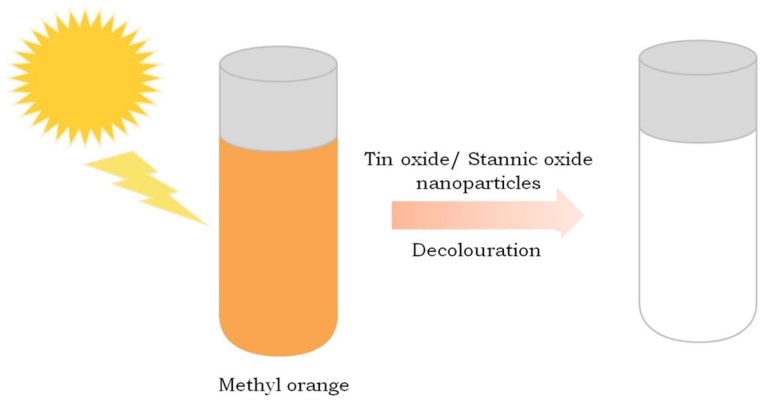

Fig. 4 Use of tin oxide/stannic oxide nanoparticles photocatalytic decolouration of dye methyl orange

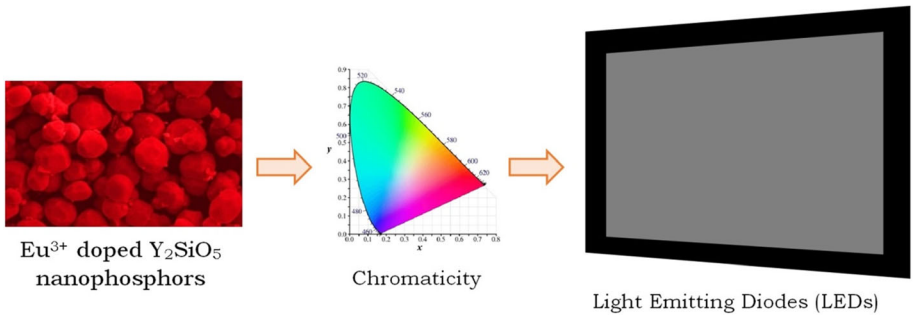

Fig. 5 Application of Eu3+ doped Y_2SiO_5 nanophosphors that can used in light-emitting diodes (LEDs)

structure surrounding the (rare earth) RE ion. This newly synthesised phosphor exhibited admirable International Commission on Illumination (CIE) chromaticity coordinates (0.5866, 4026) and average correlated colour temperature CCT value 2018.5 K. Hence, researchers claimed that these Eu3+ doped Y_2SiO_5 nanophosphors could have potential application in the fabrication of near-ultraviolet excited white light-emitting diodes (Fig. 5).

3 Conclusion

Calotropis gigantea (Asclepiadeae) is the plant having several well-proved pharmacological actions. Several types of nanomaterials have been synthesised following green approach using aqueous extract of different parts of *C. gigantea*; evaluated for different pharmacological activities and potential were compared that with extracts. Nanomaterials tried to get synthesised include nanoparticles and nanophophors. Importantly, green synthesis of nanoparticles has upsurge as new nanobiotechnology to produce eco-friendly and cost-effective synthetic processes for highly stable nanoparticles which emerges as a safer alternative to conventional methods. These nanoparticles were proved to have better antimicrobial action against both animal and plant infecting pathogens and utilities in controlling the water pollution by adsorbing or precipitating pollutants, demonstrated using dyes and other organic compounds. Nanophosphors have been extensively investigated during the last decade due to their application potential for various high-performance displays and devices.

Abbreviations

Ag NPs: Silver nanoparticles; CCT: Correlated colour temperature; CdS NPs: Cadmium sulphide nanoparticles; CRI: Colour rending index; CuO NPs: Cupric oxide nanoparticles; FT-IR: Fourier transform-infrared spectroscopy; Ni-NPs: Nickel nanoparticles; NiO-NPs: Nickel oxide nanoparticles; SEM: Scanning electron microscopy; SnO_2 NPs: Tin oxide/stannic oxide nanoparticles; TEM: Transmission electron microscopy; TiO_2 NPs: Titanium dioxide nanoparticles; XRD: X-ray diffraction; ZnO NPs: Zinc oxide nanoparticles; ZVIN: Zero-valent iron nanoparticles

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Author's contributions

SPP initiated the idea of designing this review, carried out the survey of the available literature and written the review manuscript. The author read and approved the final manuscript.

Authors' information

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