Green Synthesis, Characterization, Antimicrobial Activity and Applications of Cu, and CuO, Nanoparticles

D. T. Sakhare

U.G., P.G. & Research Centre, Department of Chemistry, Shivaji, Art's, Comm. & Science College Kannad. Dist. Aurangabad.431103, Maharashtra, India.

E-mail- sakharedhondiram@yahoo.com

Abstract

Green method for the synthesis of metallic and metallic oxide nanoparticles has been known to play a significant role in the advancement of nanomaterial applications in various sectors since last few decades. Green synthesis of copper and copper oxide nanoparticles (Cu and CuO, NPs) was more economical and an alternative method to many existing physical and chemical methods. Green fabricated Cu and CuO NPs finds applications in catalysis, photocatalysis, electrocatalysis, organic dye degradation, biomedicine, pharmaceutics, cosmetics and energy. The morphology and topography of biogenic NPs widely depend on the bioactive components of the plant extracts and preparative conditions. The present review aims to bring awareness about various plants applied in the biogenic synthesis of Cu and its oxide NPs for multifunctional applications in antimicrobial activity evaluation and catalysis. The characterization of biogenic Cu NPs by number of analytical tools for their compositional, morphological and topographical features has also been discussed.

Keywords:

Green Synthesis, Copper Nanoparticles, Antimicrobial Activity, Morphology, Catalysis, Application.

1. Introduction

Copper (Cu) is one of the indispensable microelements obligatory for the growth and development of plant. It can be present as Cu^{2+} and Cu^{+} under natural conditions. Optimum concentration is regularly involved in the plants, ranging from 10^{-14} to 10^{-16} M. In addition to many of its important functions such as cell wall metabolism and protein regulation, it also acts as secondary signaling molecule in plant cells. It takes part in the mitochondrial respiration, photosynthetic electron transport, iron mobilization, hormone signaling, oxidative stress response, and also acts as cofactor for many enzymes [1, 2]. However, a higher dose of Cu leads to oxidative stress generation, growth inhibition, cellular malfunctioning, and photosynthesis retardation [2–4].

Though, nanotechnology is considered to be the next industrial revolution, the search is still ongoing for better nontoxic, hazard free, and eco-friendly approach for synthesis of nanomaterials [5]. In comparison to chemically synthesized nanoparticles, green synthesized nanoparticles are more effective and eco-friendly [6]. Until now various biological organisms are reported to have their potentiality for the production of metallic nanoparticles. However, the rate of metal nanoparticle synthesis with the help of plant extract is stable [7], much faster [8,9], and extremely mono-dispersive [10] in respect to other biological methods. Moreover, in the case of copper, di_erent organisms suchas microbes [11,12], algae [13], fungi [14,15], and angiosperm plant extracts [16,17], are utilized for the nanoparticles production.

A metallic nanoparticle are multifunctional in nature and hence finds huge number of applications in various sectors for environmental, biomedical and antimicrobial, solar power generation and catalytic causes.[18]. Application of plant extracts to synthesize copper and its oxide nanoparticles is a green chemistry methodology which establishes strong relationship between natural plant material and nanosynthesis. [19].

It has been reported in the past study that copper, gold and silver nanoparticles exhibited excellent antimicrobial activity against various disease causing pathogens. In recent years, copper nano particles (Cu NPs) have gained significance due to their multifunctional uses in industries and medicine. However, other nanoparticles, such as platinum, gold, iron oxide, silicon oxides and nickel have not shown bactericidal effects in studies with Escherichia coli.[20] The antibacterial study on E. coli and Bacillus subtilis using Cu and Ag NPs, revealed the fact that Cu exhibited superiority over Ag.[21] Cu NPs have wide applications as heat transfer systems[22] antimicrobial materials[23], sensors[24], and catalysts.[25]. In addition, copper and its compound have been applied as antifungal, antiviral, and molluscicidal agents. The synthesis of Cu NPs by using extracts of various plants found all over the globe have been reported by many researchers in the past.[26,27].

It is essential to develop clean, reliable, biocompatible, cheap, and nontoxic green method of nanoparticle's synthesis. Many plants parts or whole plants have been used for the green synthesis of Cu NPs [28] due to the presence of large number of bioactive compounds in plants. The extracts of plants Nerium oleander [29], Punica granatum[30], Aegle marmelos[31] & Ocimum sanctum,[32] Zingiber officinale[33] have been efficiently applied for this purpose.

The present work concentrates on biogenic synthetic processes for Cu NPs using extracts of diverse range of plant species including medicinal plants found across the globe and their applications in electronic, magnetic, optoelectronic, biomedical, pharmaceutical, cosmetic, energy and catalysis.

2. Nanoparticle Synthesis Methods

Bottom-up and top-down are the two approaches recommended for the biosynthesis of nanoparticles [34]. In case of a bottom-up approach, the most important reaction occurred is oxidation/reduction. .The synthesis of nanoparticles is currently an important area of research, which seeks an eco-friendly approach and green materials for current scenario [35]. .The major steps involved in the preparation of nanoparticles that have to be evaluated from the point of green chemistry are (i) the solvent medium used for the synthesis, (ii) environmentally benign reducing agent, and (iii) the nontoxic material for the stabilization of the nanoparticles. .The majority of the chemical and physical methods mentioned so far largely depend on organic solvents. .is is principally due to the hydrophobicity of the capping agents used [36]. Synthesis with bio-organisms is compatible with the principles of green chemistry: (i) ecofriendly approach, (ii) the reducing agent used, and (iii) the capping agent in the reaction. .The synthesis of inorganic metal oxide nanoparticles using biological elements has received immense attention due to their unusual properties (optical, electronic, chemical, etc.) [37].

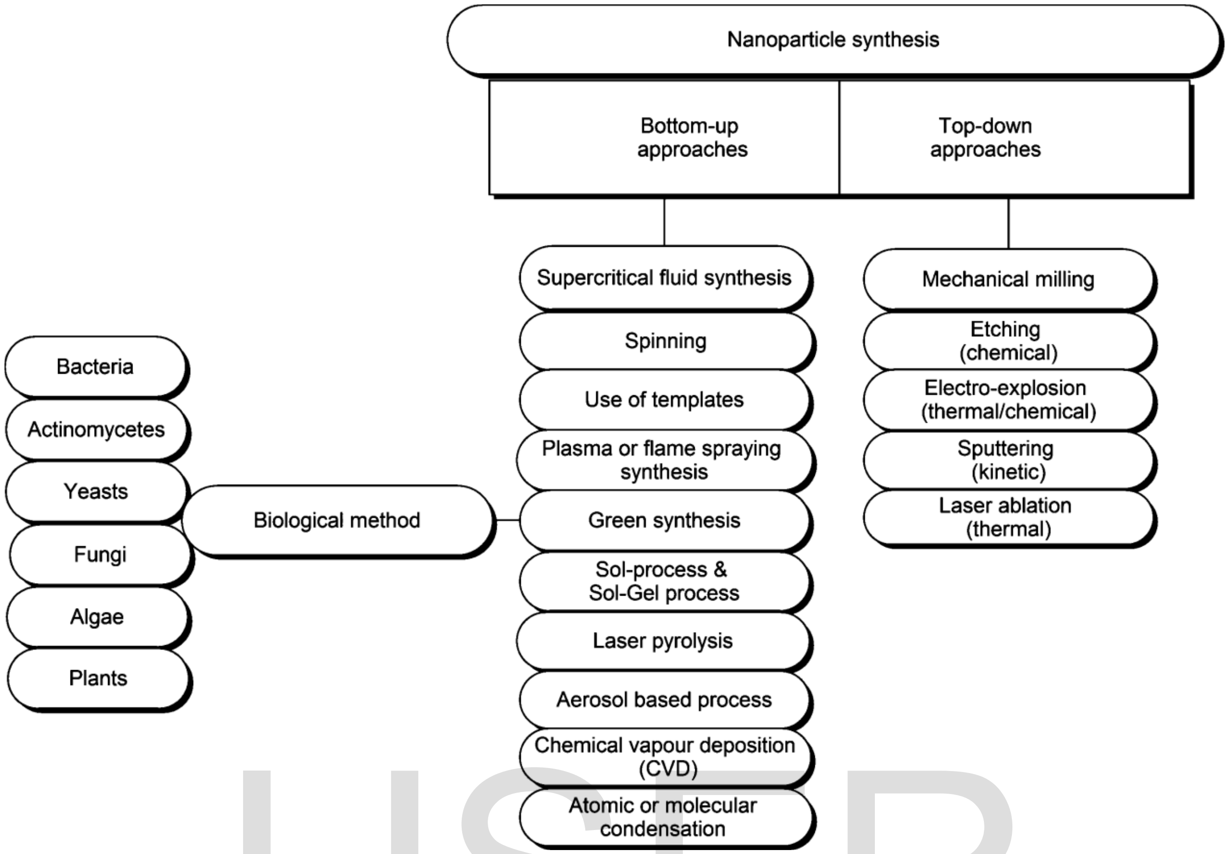

Fig. 1 Some important manufacturing methods used in nanoparticle synthesis.

3. Green Synthesis of Cu and CuO NPs

Plants consist of large number of biologically active compounds and hence, most of the plants have proven record for their anthelmintic, antitumor, antimutagenic, antibacterial and fungicidal properties. The synthesis of metallic NPs involves simple mixing of metal solution with extract of plant. Nanoparticles are produced in the medium due to reduction of metal ions. The scheme of synthesis of metallic NPs is as shown in Fig. 2.

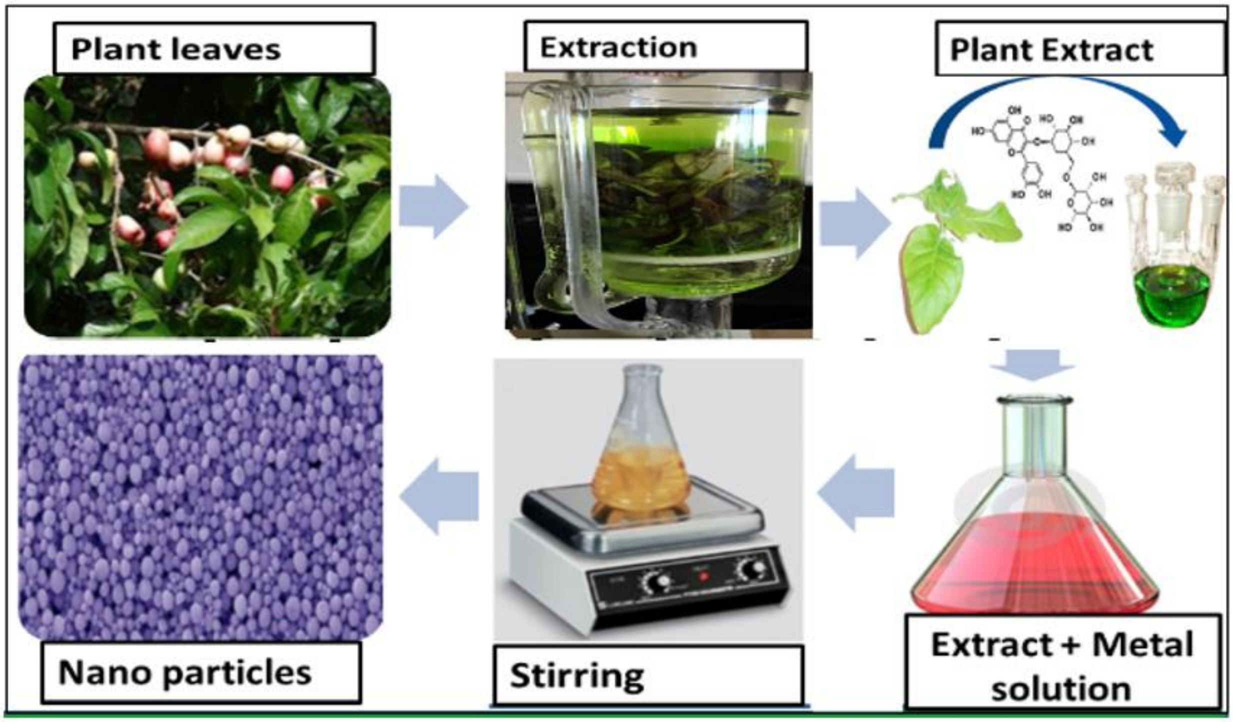

Fig. 2: A schematic diagram of green synthesis of metal nanoparticles from plant extracts

Many earlier investigations revealed that Cu NPs can be synthesised by the application of most common precursor copper salts namely, cupric acetate (monohydrate) ((CH3COO)2Cu·H2O)[38], Copper chloride di-hydrate (CuCl2. 2H2O)[39] and Copper sulfate pentahydrate (CuSO4.5H2O).[40] Various factors such as concentration, pH, temperature, influence the nature and properties of synthetic Cu NPs as well as CuO NPs.

The reduction of copper ions to get stable copper nanoparticles can be attributed to the presence of biologically active compounds present in the leaf broth of Azadirachta indica.[41]. It was found in this study that the rate of production varied linearly with percentage of leaf broth. The other optimum conditions for the synthesis are; [CuCl2] = 7.5 X 10-3 M, pH =6.6 and temperature = 85oC.

Formation of greenly synthesized copper nano particles capped with T. cordifolia (Cu NPs@Tc) was also reported.[42]. Synthesis of Cu nanoparticles has been successful with extracts of various parts of plant species that include, Citrus medica Linn. (Idilimbu) juice,[43] Ziziphus spina-christi (L.) Willd,[44] Asparagus adscendens Roxb. Root and Leaf,[45] Eclipta prostrata leaves,[46] Ginkgo biloba Linn,[47] Plantago asiatica leaf, [48] Thymus vulgaris L,[49] black tea leaves[50], Terminaliacatappa leaf[51] presented in Table 1.

Table 1: Various plants extracts used in the synthesis of Cu and CuO NPs and their applications

Sr, No.	Plant	Image	Precursor	Size, morphology, surface plasmon vibration (SPV)	Applications	Ref
1	Syzygium aromaticum bud		Cupriacetate (monohydrate) ($(CH_3COO)_2Cu·H_2O$)	-12 nm, spherical SPV@ <580 nm	Antimicrobial properties	38
2	Stachys lavandulifolia		Copper chloride di-hydrate ($CuCl_2 2H_2O$)	80 ± 8 nm, near spherical, SPV@ ~ 590 nm	antibacterial activity	39
3	black bean		Coppersulfate pentahydrate ($CuSO_4.5H_2O$)	~26.6nm, spherical, hexagonal and uneven shapes,	anticancer activity	40
4	Azadirachta indica leaves		Cupric chloride di-hydrate ($CuCl_2.\ 2H_2O$)	48nm, cubical,SPV@ ~ 506 nm	-	41
5	Tinospora cordifolia		Copper chloride ($CuCl_2$(II))	50–130nm, spherical, SPV@~250 nm	Catalytic Degradation	42
6	Citrus medica Linn. (Idilimbu) juice		Copper sulphate ($CuSO_4$)	33nm, SPV@ ~ 631 nm	antimicrobial activity	43
7	Ziziphus spina-christi (L.) Willd		Copper sulphate ($CuSO_4$)	8–15nm, spherical, SPV@ ~ 551 nm	triphenylmethanedye and antibacterial assay	44

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8	Asparagus adscendens Roxb. Root and Leaf		Copper sulphate ($CuSO_4$)	10–15 nm, Spherical, SPV@ ~ 500 to 700 nm	Antimicrobial Activities	45
9	Eclipta prostrata leaves		Copper acetate ($Cu(OAc)_2$)	31±1.2nm, spherical hexagonal and cubical SPV@ ~ 565 nm	antioxidant and cytotoxic activities	46
10	Ginkgo biloba Linn		Copper chloride ($CuCl_2$)	15-20nm, spherical, SPV@560 to 580 nm	catalytic activity	47
11	Plantago asiatica leaf		Cupric chloride di-hydrate, ($CuCl_2 \cdot 2H_2O$)	7–35nm, spherical, SP V@ 565 nm	catalytic activity	48
12	Thymus vulgaris L.		Copper sulphate ($CuSO_4$)	various sizes, sheeted,SPV @ ~ 520 nm	catalytic activity (MB)	49
13	Black tea leaves		Copper sulphate ($CuSO_4$)	26–40nm, Spherical,	antibacterial, antifungal aflatoxin B_1	50
14	Terminalia catappa leaf		Copper sulphate pentahydrate ($CuSO_4\ 5H_2O$)	21–30 nm, Spherical,	Antibacterial test	51
15	Rheum palmatum L.		Copper chloride ($CuCl_2$)	10–20 nm, Spherical, SPV@ ~ 250–300 nm	catalytic activity	52
15	Aloe vera extract		Copper sulphate $CuSO_4$	15 and 30 nm, dispersed, versatile and spherical, SPV@ ~ 265 and 285 nm	-	53

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16	Oak Fruit Hull (Jaft)		Copper acetate ($Cu(CH3COO)_2$)	34nm, quasi-spherical, SPV@ ~ 590 nm	Photocatalytic Degradation (Violet 3)	54
17	Ixoro coccinea leaf		Copper sulphate $CuSO_4$	80–110 nm, Spherical, SPV@ ~ 191 nm	-	55
18	Syzygium alternifolium (Wt.) Walp.		Copper sulphate pentahydrate ($CuSO_4$ $5H_2O$)	17.5 nm, spherical, SPV@ ~ 285 nm	Antiviral Activity	56
19	Ferulago angulata (schlecht) boiss		Copper acetate ($Cu(CH_3COO)_2$)	~44nmSPV @~ 554 nm	Photocatalyticdegradation of Rhodamine B	57
20	Rosa canina fruit		Cupric acetate, $Cu(OAc)_2$	Spherical15-25SPV@ ~ 262 nm	C-N Ullmann couplingreactions	58
21	Azadirachta indica		Copper nitrate Trihydrate ($Cu(NO_3)_2.3H_2O$)	28-35 nm, spherical SPV@~262nm	Antibacterial activity (E. coli)	59
22	Olea europaealeaf		Copper sulphate $CuSO_4$	20–50 nm, Spherical, SPV@ ~ 289 nm	toxicity activities	60
23	Malus Domestica leaf		Copper sulphate $CuSO_4$	18 - 20 nm, spherical and crystalline, SPV	antibacterial,antioxidant, DNA	61
24	Bauhinia tomentosa leaf		Copper sulphate $CuSO_4$	22-40nm, Clustered & spherical, SPV@ ~ 384 nm	antibacterial	62
25	Moringa oleifera Leaves		Copper sulphate pentahydrate ($CuSO_4$ $5H_2O$)	6 and 61 nm	Nitrates Removal	63

26	Abutilon indicum leaf		Copper(II) nitratetri hydrate $(Cu(NO_3)_2.\ 3H_2O)$	nm range agglomerated hexagonal wurtzite, SPV@ ~ 725nm	Antimicrobial, antioxidant and photocatalytic dye degradation activities	64
27	Eclipta prostrata leaves		Cupric acetate, $Cu(OAc)_2$	31±1.2nm, face-centered cubic structure, SPV@ ~565 nm	antioxidant and cytotoxic activities	65
28	Calotropis procera		Copper sulphate pentahydrate $(CuSO_4\ 5H_2O)$	15–20 nm, quasi-spherical, SPV@ ~ 565 nm	adsorptive of Cr(VI)	66
29	Euphorbia Chamaesyce leaf		Copper chloride $(CuCl_2)$	~ 36–40 face-centered cubic nm, Spherical (fcc), SPV@ ~ 325 nm	catalytic activity (4nitrophen ol)	67

The organic hydrocarbon part of citron24 facilitates the protection of copper. The antioxidant nature and acidic property of citron also prevents oxidation of copper as the protons present in the medium influence electro-deposition of copper at low pH range. Cu colloid formation of non-oxidized Cu NPs was observed with uv-absorption peak at 565 nm during the green synthesis of Cu NPs by Eclipta prostrata leaves extract.[46]

The reduction of Cu2+ ions to Cu NPs by the phenolics and other chemicals of Thymus vulgaris L. leaf extract was reported.[49] These biomolecules cogently reduce copper salts but also avoid agglomeration. The hydroxyl and ketonic groups of phenolic compounds bind to metals and show chelate effect. Flavonoids can directly scavenge molecular species of active oxygen. Antioxidant action of flavonoids resides mainly in their ability to donate electrons or hydrogen atoms.

The reduction of copper ions to give Cu NPs was attributed to the phenolic compounds present in the Rheum palmatum L. root extract.[52] The extract constituents believed to function both as reducing and capping agents in the stabilization of prepared Cu NPs.

The bioactive molecules present in the Carica papaya leaves extract61 also found to reduce precursor copper sulphate to form copper oxide nanoparticles.

In the similar way CuO NPs were also synthesised by using plant extracts of Aloe vera[53], Oak fruit hull (Jaft),[54] Ixoro coccinea leaf,[55] Syzygium alternifolium (Wt.) Walp,[56] Ferulago angulata (schlecht) boiss,[57] Rosa canina fruit,[58] Azadirachta indica,[59] Olea europaea leaf extract,[60] Malus Domestica leaf extract,[61] Bauhinia tomentosa leaves extract,[62] Moringa oleifera leaves Extract,[63] Abutilon indicum leaf extract,[64] Eclipta prostrata leaves extract,[65] Calotropis procera[66],Euphorbia Chamaesyce leaf extract[67] as above Table 1.

4. Characterization of Cu and CuO NPs

The Characterization of biogenically synthesized Cu and CuO nanoparticles has been carried out by using analytical tools namely, uv-visible spectroscopy (uv-vis), x-ray diffraction (XRD), energy dispersive x-ray spectroscopy (EDS), dynamic light scattering (DLS), scanning electron microscopy (SEM), tunneling electron microscopy (TEM), Fourier transform infra-red spectroscopy (FTIR), particle analyzer, Surface Plasmon resonance etc. The uv– vis absorption spectroscopy was applied to detect color change in Cu nanoparticle synthesised by using Ziziphus spina-christi leaves [44] which is possibly due to the surface plasmon vibrations. The surface plasmon vibration bands for Cu-NPs synthesised by many plant extracts was found to be between 191 nm and 721 nm as given in Table 1.

XRD patterns (Fig. 3) obtained for the Cu NPs synthesized using citron juice and Aloe vera extract showed intense peak confirming crystalline copper [43] and crystalline CuO NPs[33,50] (Fig.4) respectively.

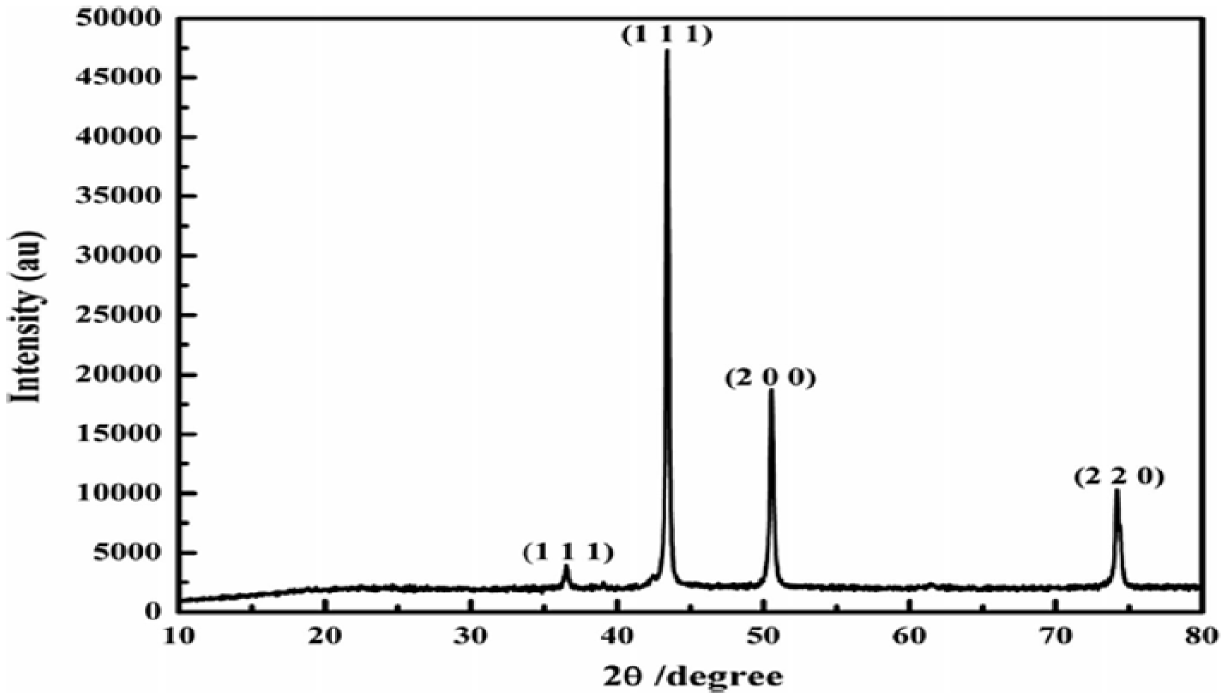

Fig. 3: XRD pattern of Cu NPs showing the FCC structure of crystallite

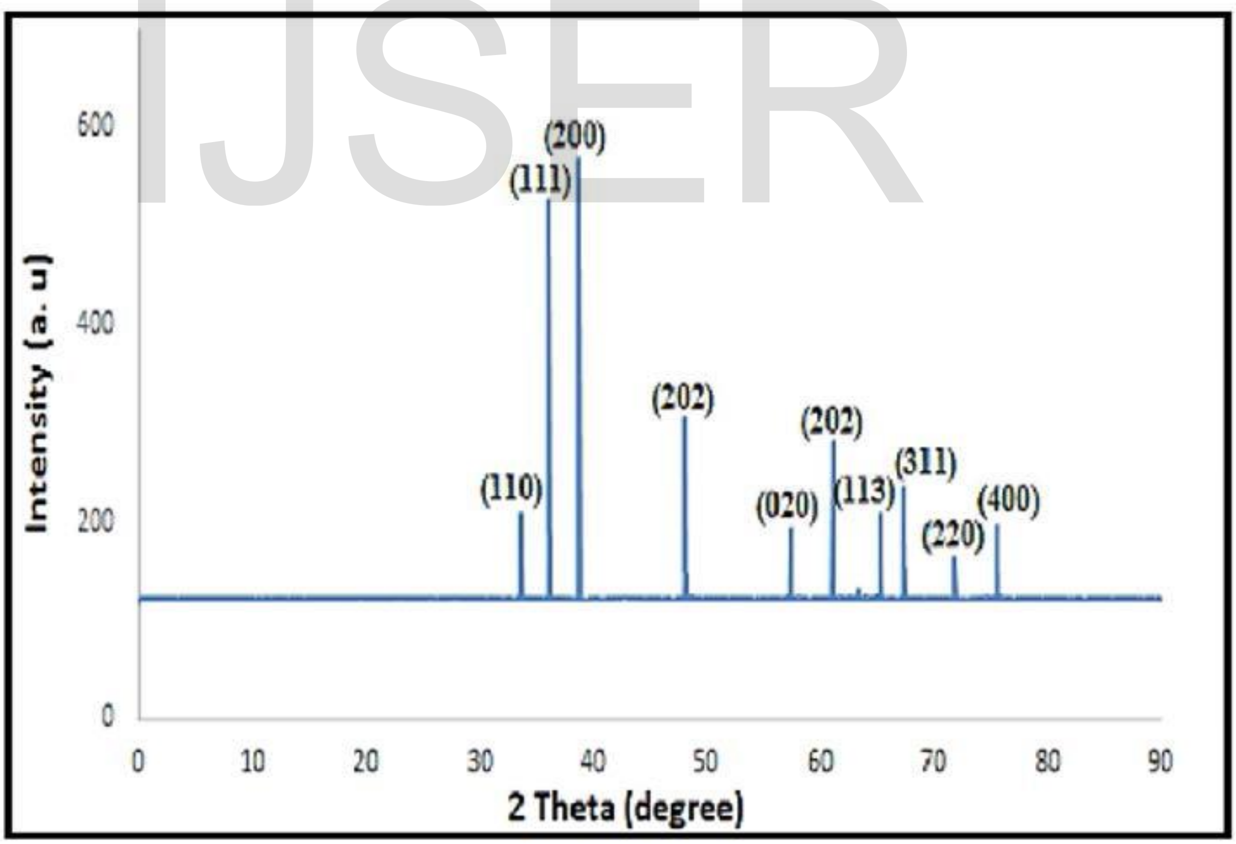

Fig. 4: XRD pattern of green synthesised CuO NPs

The analysis of FTIR spectra provides information about functional groups of biomolecules present in plant extracts. IR peaks were observed at 3,333 cm-1 for the hydroxyl group (H-bonded OH stretch); 2,917 cm-1 for methylene C-H asym. / sym. stretch; 1,615 cm-1 for aromatic ring stretch.[46] The peaks at about 3400, 1650, 1595, 1400 and 1100 cm-1 corresponds to -OH, C=O, C=C, C-OH and C-H vibrations.[47] The common IR bands[51] for cellulose were usually found at 3304 cm−1, 2891 cm−1, 1664 cm−1, 1011 cm−1 corresponds to vibrations of -OH, CH2, H2O, and C-OH groups. Peaks at 610, 499 and 415 cm-1 confirmed Cu–O bond vibrations that support the presence of monoclinic phases of CuO synthesised by Aloe barbadensis Miller extract.[53]. The IR band recorded at about 800 cm-1 corresponds to C–H out of plane bending vibrations due to adsorbed phenolic compound on to the CuO NPs.[54] Electron microscopy is used for morphological characterization and internal composition of biogenic copper and silver nanoparticles. Homogeneous and spherical morphology of biogenic Cu NPs were revealed by FESEM image [44] as shown in Fig.5.

The average particle size varied from 20 nm to 500 nm. TEM micrographs also revealed spherical nature for NPs with least tendency towards agglomeration. DLS studies reveal size distribution of Cu NPs. The average particle size of NPs synthesised by using Azadirachta indica leaves was found to be around 50 nm.[41]

The spherical morphology and narrow diameter distributions [44,47] of Cu NPs were also confirmed by TEM image (Fig. 6). Biomolecules present in Aloe vera extract [53] believed to act as stabilizing and capping agent for copper caused a raise in the size of NP up to 30 nm but without change in shape.

FESEM images of CuO NPs too confirmed their spherical nature (20 nm to 300 nm). CuO NPs synthesised by Oak fruit extract exhibited average diameter of 34 nm.[54]. CuO NPs were found to exhibit agglomeration tendency thus enhancing average particle size to as high as 300 nm.[55]. HRTEM studies involving in-depth analysis of CuO NPs synthesised by using fruit extract of Syzygium alternifolium[56] recorded particle size of 2 nm. HRTEM image of CuO NPs[65] is shown in Fig.7 given below,

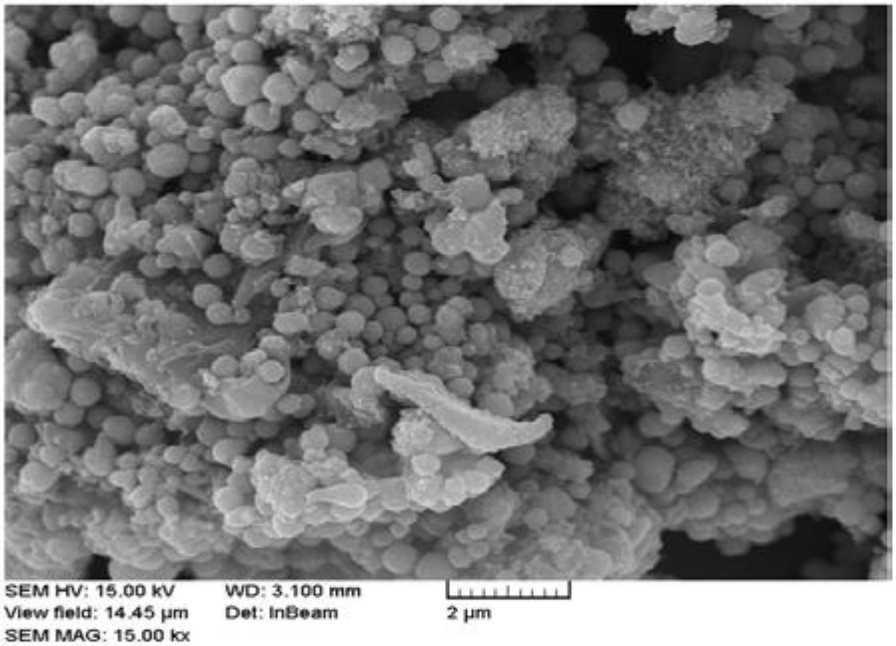

Fig. 5: FESEM image of biosynthesized Cu-NPs

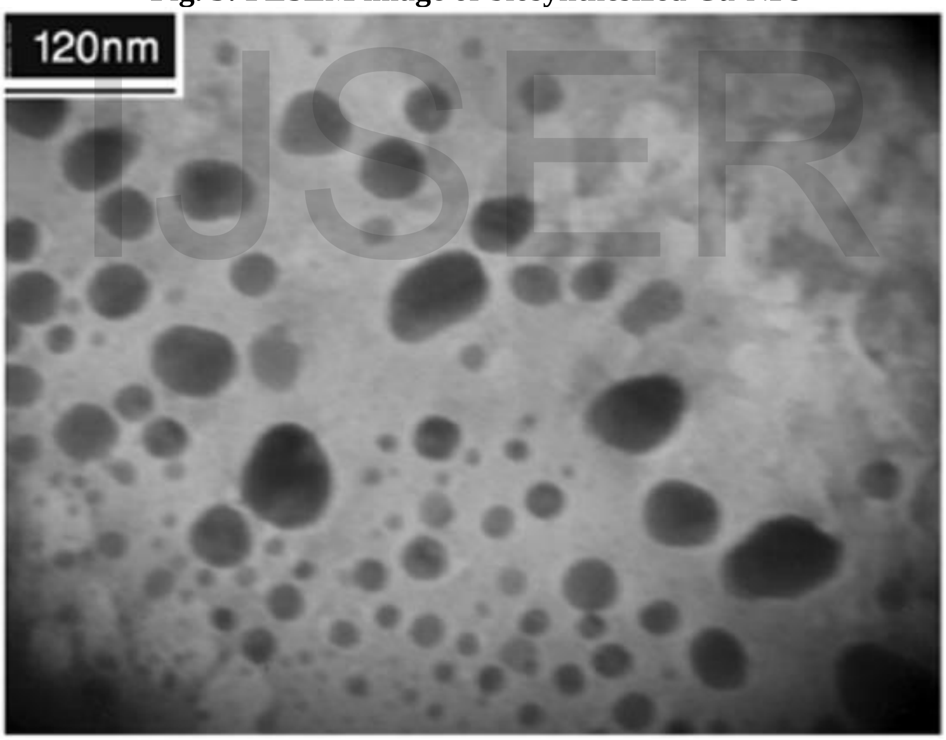

Fig. 6: TEM image of biosynthesized Cu-NPs

CuO NPs synthesised by ferulago angulata (schlecht) boiss extract[57] revealed shell like sheet structure. CuO NPs with relatively good monodispersed and virtually spherical structures were obtained with size range of 15 to 25 nm without agglomeration.[58] TEM analysis of CuO

NPs synthesized using B. tomentosa leaf extract[62] also showed spherical morphology (size of 22 to 40 nm). EDS will reveal the elemental composition of the particles. EDS spectrum of green synthesised CuO NPs is as shown in Fig. 8.

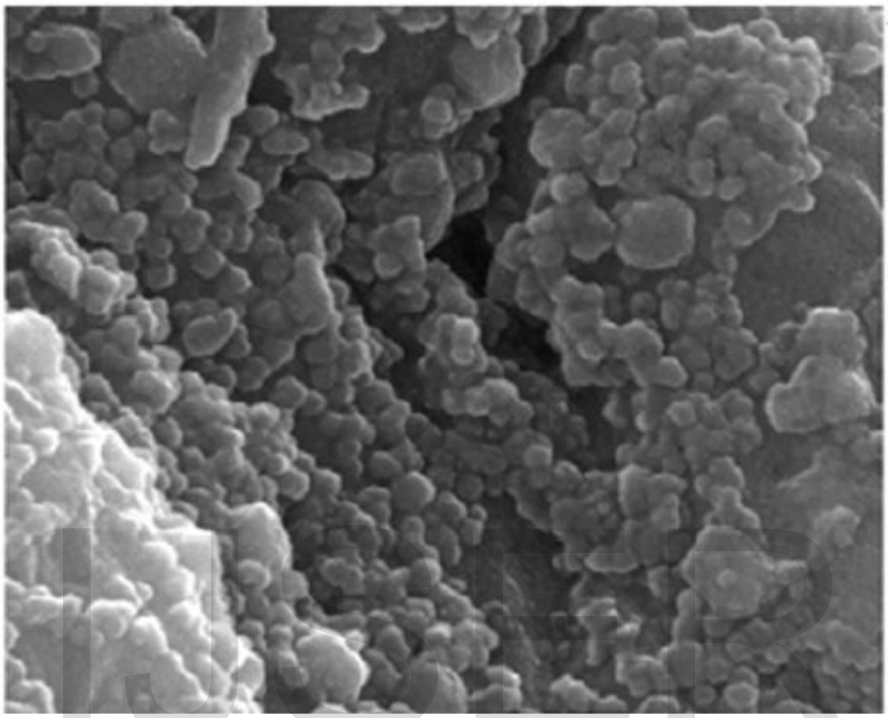

Fig. 7: HRTEM image of biosynthesized CuO-NPs

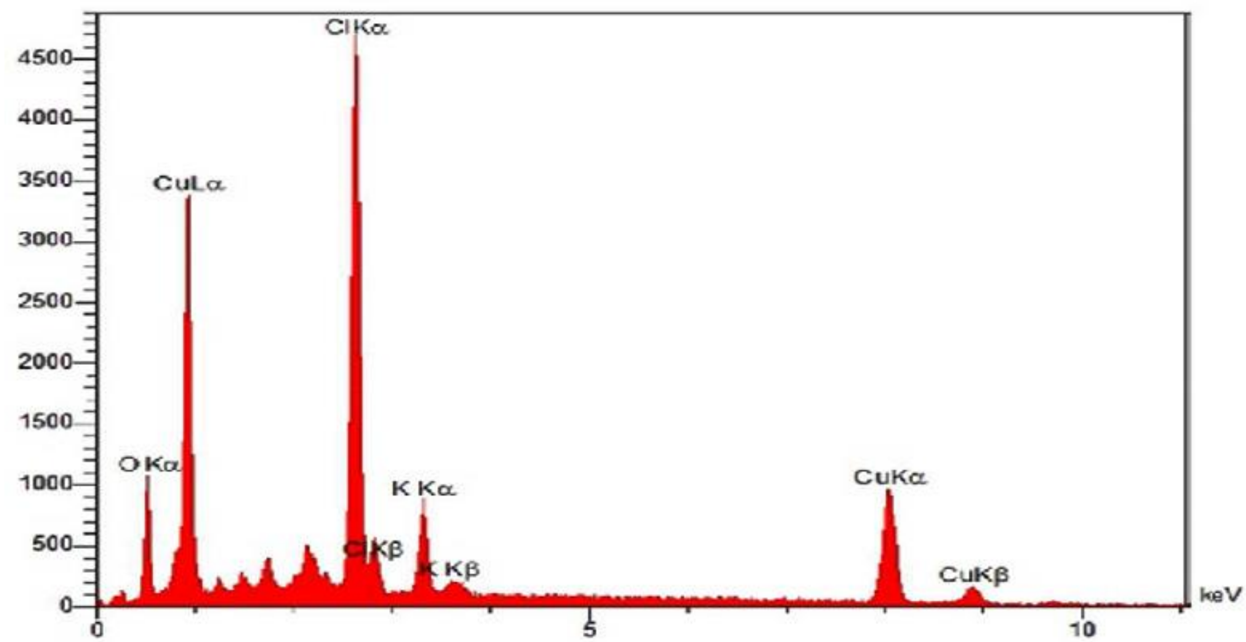

Fig. 8: XRD pattern of green synthesised CuO NPs

5. Biological Behavior: Antimicrobial Activity

Since a decade, the metal and metal oxide nanoparticles such as silver, zinc, gold, or titanium dioxide have been used as antimicrobial agents. Currently, the behavior of nanometals at nanometrics sizes against pathogenic organisms is still being studied [68].The high antimicrobial activity of the Cu NPs has been shown in multiple studies focusing on the optimal size range of about 1 to 10 nm [69, 70].

The Cu NPs have been promising for medicine and dentistry fields due to their properties, specially their interaction with pathogens, their large active surface area, and their high chemical and biological reactivity [71].

Copper is an essential element for some metabolic processes but at low concentrations because large doses could be serious consequences in themetabolic performance. It can act as electron donor or electron acceptor in some enzymes due to its redox properties increasing its toxicity for bacterium, which is induced by Cu^{+1} and Cu^{+2} ions [72–74]. Some bacteria such as *Clostridium difficile* developed important mechanisms to protect themselves from the toxic effects of copper ions while they are in contact with the surface of the Cu NPs. A possible mechanism of bacterial resistance to copper is the formation of endospores, which allows its rapid diffusion. However, the antibacterial response of the copper is being studied, mainly in human pathogens [75].

The most analyzed bacteria species in contact with Cu NPs are *C. difficile*, *E. coli*, and *P. aeruginosa*, which were significantly inhibited with a particle size between 22 and 90 nm, finding a decrease in the viability cells of these microorganisms [76-78]. Gram-positive bacteria (e.g., *S. aureus*) are more sensitive to Cu NPs and Gram-negative bacteria (e.g., *E. coli*) are associatedwithROS (ReactiveOxygen Species) expression by different sizes of Cu NPs. These features could change through free surface energy of the particles directly associated with size and morphology and the pH inner of cells too [79]. The antimicrobial effect is directly related to the nanoparticle size and minimum inhibitory concentration (MIC) (Table 2) and the oxidation degree of the surface [80].

The cell membranes of the microorganisms interact with the medium, so metal NPs especially Cu NPs will have some interactions to release metal ions that interfere with the processes of the DNA replication, cellmembranes formation, cell division, and so forth, of certain microorganisms such as bacteria, which results in an antimicrobial effect [81, 82]. The action mechanism of the copper NPs occurs through the interaction of enzymes and -SHgroups causing damage in the DNA and therefore oxidative stress generation [83–85].

Table 2: Minimum inhibitory concentrations (MIC) related to biological effect.

Sr.No.	Metal NPs	MIC	Size (nm)	Microorganism	Reference
1	Cu	140mg/mL 140–240mg/mL	6–16	*S. aureus* *E. coli*	[86]
2	Cu	3.2 ± 0.41mg/mL 1.6 ± 0.22mg/mL 3.6 ± 0.43	5–12	*S. aureus* *E. coli* *Salmonella typhi*	[87]
3	Cu	1.875–3.75mg/mL 3.75mg/mL	50	*S. aureus* *C. albicans*	[88]
4	Cu	140 μg/mL		*S. aureus*	[89,90]

5. Applications of Cu and CuO NPs

Cu and CuO nanoparticles are multifunctional in nature and hence finds significant role in applications that include antimicrobial activities, catalytic degradation, anticancer activity, photocatalytic degradation, antiviral activity, Biofilm formation, nitrates removal, upshot against human pathogens, photoluminescent activities, organic dye degradation catalysis, etc.

Cu NPs demonstrated good antimicrobial influence on Bacillus spp. and prominent fungicidal influence on Penicillium spp. microorganisms.[38] Cu NPs exhibited greater inhibition on Escherichia coli in comparison with Klebsiella pneumoniae, Pseudomonas aeruginosa, Propionibacterium acnes and Salmonella typhi. Fusarium culmorum was found to establish more sensitive plant pathogenic fungi, [45]. Cu NPs were also used for antioxidant and cytotoxic activities.[46]

Cu NPs were found to be excellent antibacterial agent against the wide range of bacterial species noparticles are multifunctional in nature and hence finds significant role in applications which could be attributed to interactions of NPs with -SH groups leading to protein denaturation.[91] Cu NPs were believed to exert effect on cell membrane due to their strong affinity towards amines and carboxyl groups present on the cell surface of organisms like B. subtilis.[92,93] Cu NPs bind with DNA molecules and disturb the helical structure by cross-linking within and between the nucleic acid strands.[94].

CuO NPs adsorbed on cell surface of E.coli interact with the cell wall and later cause damage to the cell membrane, increasing its permeability and leading to a decrease in the viability of bacteria in copper oxide solution. The exact mechanism concerning antimicrobial effect of copper nanoparticles is not understood fully and needs to be elucidated.

Cu NPs green engineered by Ginkgo biloba L. leaf extract [47] found catalytic application for Huisgen [3 + 2] reaction. Cu- NPs synthesized with Z. spina-christi fruits extract proved to be excellent nanoadsorbent for Crystal Violet removal from aqueous solution.[44]

Catalytic degradation of basic violet 3 dye in water was successful with CuO NPs obtained by using extract of Oak fruit hull.[54] The extract of Rheum palmatum L was also used to synthesize CuO nanoparticles which proved to be efficient catalyst for degradation of 4-nitrophenol, methylene blue rhodamine B and Congo red.[95] Effective catalytic application The role of CuO as catalyst can be attributed to high surface to volume ratio associate with large number of active sites. On the same line these particles were found to be photocatalyst,[96,97] for Congo red degradation and nanocatalyst for arylation recation.[98,99]

CuO NPs synthesised by aqueous extracts of Anthemis nobilis flowers[100], Thymus vulgaris L. leaves[101] and Euphorbia esula L[102] were reported to be catalytically active for the synthesis of propargylamines via aldehyde–amine–alkyne (A3) coupling reaction, and Ullmann-coupling reaction respectively. CuO particles synthesized by Saraca indica Leaves exhibited photoluminescence properties.[103]. Aloe vera leaf extract mediated biogenic CuO NPs exhibited the capability to serve as antimicrobial agents against fish bacterial pathogens.[104]

Cu nanoparticles and nanobiocomposites synthesised using plants animal sources found to have potential electronic device applications.[105] Cu NPs synthesized by using peel extract of Punica granatum[106] have demonstrated significant antibacterial inhibition against pathogens. In general, large number of plant extracts has been applied towards the green synthesis of Cu and CuO nanoparticles for applications [107-113] such as catalytic, antimicrobial activity (urinary tract), photocatalytic, antioxidant and organic dye degradation.

6. Conclusions

Green synthesis of copper and copper oxide nanoparticles has gained great significance in the recent past due to its simplicity, cost effectiveness and environment friendly nature. Large numbers of plant extracts have been successfully applied for the biogenic synthesis of Cu and CuO NPs. The bioactive compounds in the plant extracts were found to play dual role of reduction of the copper ions and also stabilization of copper NPs. UV-Visible spectroscopy, XRD, EDS, DLS, SEM, TEM, FTIR, HRTEM, Particle analyzer and Surface Plasmon Resonance are the most applied analytical tools for the characterization of copper and its oxide nanoparticles. Cu and CuO NPs were found to exhibit spherical morphology with size range of 2 - 500 nm depending on concentration of extracts as well as on preparative conditions. Cu and CuO nanoparticles proved to be multifunctional in nature with significant applications with great future implications in the fields of catalysis, photo catalysis, organic dye degradation, cosmetics, biomedicine and pharmaceutics.

7. Acknowledgements

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