Chapter 8
Plant-Mediated Synthesis of Copper Oxide Nanoparticles and Their Biological Applications

Archana Joshi, Ashutosh Sharma, Rakesh Kumar Bachheti, Azamal Husen, and Vinod Kumar Mishra

8.1 Introduction

As per the estimations of National Science Foundation (NSF), Alexandria, USA, the global market for the nanotechnology-based products would be reaching three trillion USD by the year 2020 (Roco 2011). More than a thousand commercial products containing nanoparticles (NPs), which range from 1 to 100 nm, are currently available in the market (Vance et al. 2015) with wide-ranging applications in the fields of biomedicine, wastewater treatment, environmental remediation, food processing and packaging, agriculture, horticulture, and crop protection (Husen 2017; Siddiqi and Husen 2016, 2017a, b; Siddiqi et al. 2018a, b, c).

In comparison to their bulk counterparts, NPs have a greater chemical reactivity, strength, and some novel properties due to their increased surface-to-volume ratio and quantum size effect. The surface plasmon resonance (SPR) exhibited by metal NPs is one of their most important characteristics. NPs can be produced by the breakdown (top-down) or the buildup (bottom-up) methods (Husen and Siddiqi 2014), involving various physicochemical techniques. However, these production

A. Joshi
Department of Environmental Science, Graphic Era University, Dehradun, India

A. Sharma
Department of Chemistry, Graphic Era University, Dehradun, India

R. K. Bachheti
Department of Industrial Chemistry, College of Applied Science, Addis Ababa Science and Technology University, Addis Ababa, Ethiopia

A. Husen
Department of Biology, College of Natural and Computational Sciences, University of Gondar, Gondar, Ethiopia

V. K. Mishra (✉)
Department of Biotechnology, Baba Farid Institute of Technology, Dehra Dun, Uttarakhand, India

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methods are usually expensive, labor-intensive, and potentially hazardous to the environment and living organisms. The most acceptable and effective approach for NP preparation is the bottom-up approach. Biological methods for NP synthesis utilize a bottom-up approach with the help of reducing and stabilizing agents.

Copper oxide nanoparticles (CuO NPs) are especially known for their catalytic, electric, optical, photonic, superconducting, and biological properties (Padil and Cernik 2013). However, their large-scale production has introduced risk to the environment and human health. Considering the wide-ranging applications and increasing demand of metal NPs, an alternative, cost-effective, safe, and green technology for large-scale production of CuO NPs is required. This chapter discusses the pros and cons of plant-mediated synthesis of CuO NPs, with the main focus on reduction, capping, and stabilization of NPs, and casts a cursory glance on their prospective applications.

8.2 Plant-Mediated Synthesis of Copper Oxide NPs

Extracts of various parts of different plant species have been used for synthesis of CuO NPs, as shown in Table 8.1, proving the ability of plant extracts to reduce copper ions to copper metals, yielding Cu NPs. Plant-mediated synthesis of MNPs is energetically efficient and can even be carried out at room temperature and is generally completed within few minutes.

Plant parts (leaf, root, bark, etc.) are thoroughly washed with tap water in order to remove dust particles, sun-dried for 1–2 h to remove the residual moisture, cut into small pieces, and extracted. The extract is purified by filtration and centrifugation. Different concentrations of plant extract and metal salts (e.g., cupric sulfate, cupric chloride, copper nitrate, cupric acetate) are incubated in a shaker for different time intervals, at different pH and temperature, for NP synthesis. Formation of NPs is monitored by change in color of the reaction mixture. At the end, the reaction mixture is centrifuged at low speed to remove any medium components or large particles. Finally, the NPs can be centrifuged at a high speed or with a density gradient, washed thoroughly in water/solvent (ethanol/methanol) and collected in the form of a bottom pellet.

In an experiment, CuO NPs were synthesized from black bean extract and characterized by XRD, FTIR, XPS, Raman spectroscopy, DLS, TEM, SAED, SEM, and EDX (Nagajyothi et al. 2017). XRD studies have shown that the particles were ~26.6 nm in size and spherical in shape. Rehana et al. (2017) used leaf extract of various plants (*Azadirachta indica*, *Hibiscus rosa-sinensis*, *Murraya koenigii*, *Moringa oleifera*, and *Tamarindus indica*) for synthesizing CuO NPs. UV-vis spectroscopy revealed the band centered between 220 and 235 nm, typical for CuO NPs. The SEM and TEM studies confirmed the spherical shape, with an average size of 12 nm, while SAED revealed the crystalline nature of the NPs. FTIR spectroscopy displayed bands at ~490 and ~530 cm^{-1} corresponding to metal–oxygen (Cu–O) vibration that supports the availability of monoclinic phase of CuO NPs. These NPs

Table 8.1 Plants and their parts used for biosynthesis of CuO NPs, together with their size, shape, and significance

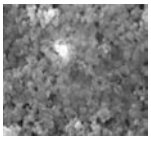
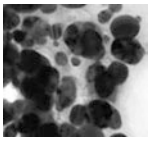
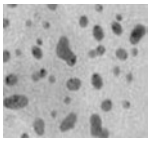
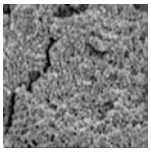
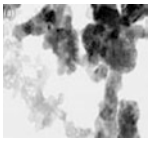
Plant (part used)	Size (nm)	Shape	Significance	References
Acalypha indica (leaf)	29	 Spherical	Antibacterial and antifungal effect against *Escherichia coli*, *Pseudomonas fluorescens*, and *Candida albicans*. Anticancer activity against MCF-7 human breast cancer cell line	Sivaraj et al. (2014b)
Albizia lebbeck (leaf)	<100	 Spherical	Cheap and effective reducing agent for CuO NP production in large scale	Jayakumarai et al. (2015)
Aloe vera (leaf)	24–61	 Octahedral	Photocatalytic activities	Kerour et al. (2018)
Aloe barbadensis (leaf)	15–30	 Versatile and spherical	Large-scale commercial production and health-related applications of CuO NPs	Gunalan et al. (2012)
Aloe vera (leaf)	20	 Spherical	Antibacterial activity against fish bacterial pathogens	Kumar et al. (2015)
Alternanthera sessilis (leaf)	22.6–25.2	 Spherical	Antimicrobial activity	Niraimathi et al. (2016)
Calotropis gigantea (leaf)	20–30	 Spherical	Solar cell applications	Sharma et al. (2015)

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Table 8.1 (continued)

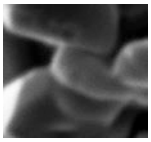
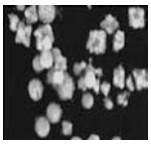
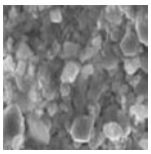
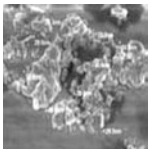
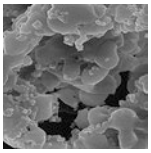
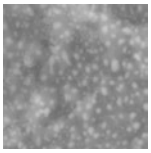
Plant (part used)	Size (nm)	Shape	Significance	References
Calotropis procera (leaf)	40	 Cylindrical	Optical studies	Reddy (2017)
Camellia sinensis (leaf)	34.36	 Cubes and spheres	Antibacterial activity	Riya and George (2015)
Cassia alata (flower)	110–280	 Spherical	Wide application in medicine	Jayalakshmi and Yogamoorthi (2014)
Curcuma aeruginosa (rhizome)	40	–	Antibacterial, antifungal, and antioxidant activity	George and Britto (2014)
Desmodium gangeticum (root)	28	 Spherical	Antioxidant activity against DPPH	Guin et al. (2015)
Ferulago angulate (aerial part)	44	 Shell-like sheet structure	Photocatalytic activity	Mehr et al. (2018)
Galeopsidis herba (Plant extract)	10	 Spherical	Antioxidant and catalytic activity	Dobrucka (2018)

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Table 8.1 (continued)

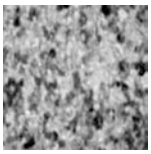
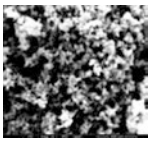
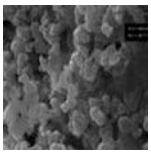
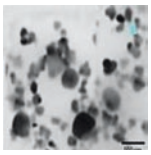
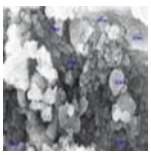
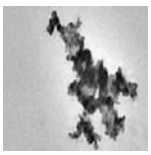
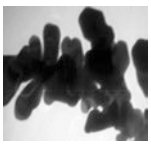
Plant (part used)	Size (nm)	Shape	Significance	References
Gloriosa superba (leaves)	5–10	 Spherical	Effective against *S. aureus* and *Klebsiella aerogenes*	Naikaa et al. (2015)
Malva sylvestris (leaf)	5–30	 Spherical	Antibacterial activity against *Shigella* and *Listeria* strains	Awwad et al. (2015)
Matricaria chamomilla (flower)	140	 Spherical	Antioxidant activity and interaction with plasmid DNA (pBR322)	Duman et al. (2016)
Pterocarpus marsupium (wood)	20–25	 Spherical	Antibacterial activity against *E. coli*, *P. vulgaris*, *K. pneumonia*, *S. aureus*, *S. epidermidis*, and *B. cereus*	Rajgovind et al. (2015)
Pyrus pyrifolia (leaf)	24	 Spherical	Photocatalytic study	Sundaramurthy and Parthiban (2015)
Rubus glaucus (leaf and fruit)	43.3	 Spherical	Antioxidant activity against DPPH	Kumar et al. (2017)
Stachys lavandulifolia (flowers)	80	 Near-spherical	Antibacterial activity	Khatami et al. (2017)

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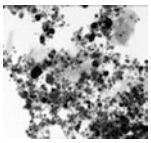
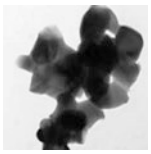
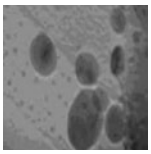
Table 8.1 (continued)

Plant (part used)	Size (nm)	Shape	Significance	References
Tabernaemontana divaricata (leaf)	48	 Spherical	Antibacterial activity against urinary tract pathogen	Sivaraj et al. (2014a)
Tinospora cordifolia (leaf)	6–8	 Spherical	Antioxidant, antimicrobial activity	Udayabhanu et al. (2015)
Thymus vulgaris (leaf)	30	 Face-centered cubic (fcc)	Catalytic activity	Nasrollahzadeh et al. (2016)

also displayed band in the region of 3442–3474 cm^{-1} due to O–H stretching vibration, whereas the band at 2370 and 2385 cm^{-1} was ascribed to the primary amines. The band at 1663 and 1674 cm^{-1} was reported due to amide I; however the band at 1530 and 1535 cm^{-1} was ascribed to the amide II region, which was characteristic of proteins and/or enzymes. Further, bands at 1030–1110 cm^{-1} corresponded to C–O stretching vibrations. Rehana et al. (2017) have suggested that the phenolic compounds and flavonoids acted as capping agents, thus preventing agglomeration, and stabilized the NP formation. Vishveshvar et al. (2018) synthesized CuO NPs using an aqueous solution of copper (II) sulfate and *Ixora coccinea* leaf extract. These particles were characterized using UV-vis spectroscopy, SEM, TEM, and FTIR spectroscopy. UV-vis spectroscopy showed a wavelength region from 200 to 300 nm. SEM images exhibited the formation of NP clusters of an average size of 300 nm. Further, TEM images of NPs, separated after ultrasonication of the dispersion, showed an average particle size of 80–110 nm. The FTIR spectroscopy peaks revealed the bonding vibrations such as Cu–O and O–H. In another recent study, Mehr et al. (2018) fabricated CuO and ZnO NPs by using the *Ferulago angulata* extract as a mild and nontoxic reducing agent and an efficient stabilizer without adding any surfactants and characterized them with the help of XRD, FTIR, and FESEM. The NPs produced were crystalline in nature, with high purity and an average size of ~ 44 nm. The FTIR spectrum of NPs showed two peaks at 912 and 620 cm^{-1}. Dobrucka (2018) synthesized CuO NPs (10 ± 5 nm in size) using the extract of *Galeopsidis herba* and characterized them by UV-vis, SEM, TEM, and

FTIR spectroscopy and EDS profile. SEM images confirmed the spherical shape of the NPs. FTIR spectrum showed bands at 417, 408, and 398 cm^{-1} indicating the formation of metal–oxygen stretching of CuO nanostructure. These NPs showed antioxidant as well as the catalytic activity in the reduction of malachite green. Octahedral and spherical CuO NPs were prepared using copper sulfate and *Aloe vera* aqueous extract (Kerour et al. 2018). The SEM images revealed octahedral and spherical agglomeration of NPs. XRD confirmed the cubic structure of NPs, which depends upon the crystallite size concentration of *Aloe vera* aqueous extract. The FTIR vibration measurements validated the presence of pure Cu_2O in the samples. The UV-vis spectra indicated that the prepared Cu_2O had a gap energy estimated from 2.5 to 2.62 eV. The photocatalytic activities enabled an improved and fast degradation of methylene blue in aqueous solution at room temperature under solar simulator irradiation (Kerour et al. 2018). Further details are given in Table 8.1.

8.2.1 Mechanism of CuO NP Synthesis

Plant extracts contain a wide range of metabolites that can act both as reducing and stabilizing agents in the metal NP synthesis. Bioreduction is a relatively complex process. As a reducing agent, biomolecules in the extract provide electrons to metal ions, thus reducing it into the elemental metal. After reduction, the atom so formed acts as the nucleation center, which is immediately followed by a period of growth when the smaller neighboring particles amalgamate to form a larger NP. In the final stage of synthesis, the plant extracts' ability to stabilize the NP ultimately determines its energetically favorable and stable morphology. In order to avoid further growth and maintain the particle in the nano-range, a substance called capping agent is added. Biomolecules present in the plant extract may act as the reducing agent, or the same molecules may function as both the reducing agent and the capping agent. Since different plant extracts contain different phytoconstituents, the NP formation mechanisms vary among different plant species, and their details are yet to be fully elucidated.

Secondary metabolites, such as terpenoids, polyphenols, flavonoids, alkaloids, phenolic acids, etc., are responsible for the reduction of metal ions to zerovalent metals or the stabilization of MNPs. Flavonoids constitute a large group of polyphenolic compounds that comprise of several classes, viz., anthocyanins, isoflavonoids, flavonols, chalcones, flavones, and flavanones. The transition of flavonoids from the enol to the keto may lead to reduction of the metal. The ability of flavonoids to chelate metal ions is well documented. Some flavonoids, such as quercetin and santin, are known to possess strong chelating activity due to the presence of hydroxyls and carbonyl functional groups (Anjum et al. 2015). Apart from the crude extract, individual pure secondary metabolites have the ability to synthesize metal NPs (Sahu et al. 2016; Kasthuri et al. 2009). It has been reported that amino acids, sugars, and fatty acids available in gum karaya could act as a reducing and capping agent for the formation of metal oxide NPs (Silva et al. 2003).

8.3 Controlling the Shape and Size of CuO NPs

Despite a significant progress in the biosynthesis of NPs, little could be achieved in controlling the shape of the metal NPs by biological routes. Polydispersity of nanoparticles still remains a challenge. During the course of biological synthesis of metal NPs, a number of physical and biological parameters, including pH, reactants' concentration, reaction time, and temperature, govern nucleation and the subsequent formation of the stabilized NP. The oxidation/reduction state of proteins and enzymes present in the cell-free extract is highly dependent upon the pH, making it a substantial factor to determine the shape and size of NPs. Further, metal ion concentration and pH, reaction time, and temperature can also affect the rate of nucleation and growth of NPs. As the reaction temperature increases, the reaction rate increases consuming metal ions to form the nuclei, thereby enhancing the biosynthesis process. Alteration of the reaction time can lead to variation in growth rate of seed particle, generating multi-shaped NPs. It is very clear that a single parameter cannot decide the fate of nuclei; rather it is the balance between all the parameters that can generate different shapes and sizes of NPs produced.

8.4 Characterization of CuO NPs

For characterization of synthesized NPs, several techniques, including ultraviolet-visible (UV-vis) spectroscopy, transmission electron microscopy (TEM), small-angle X-ray scattering (SAXS), Fourier transform infrared (FTIR) spectroscopy, X-ray fluorescence (XRF) spectroscopy, X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS), scanning electron microscopy (SEM), field emission scanning electron microscopy (FESEM), particle size analysis (PSA), Malvern Zetasizer (MZS), energy-dispersive X-ray spectroscopy (EDX/EDS), nanoparticle tracking analysis (NTA), X-ray reflectometry (XRR), Brunauer–Emmett–Teller (BET) analysis, selected area electron diffraction (SAED), and atomic force microscopy (AFM), are used (Table 8.2).

8.5 Applications of Copper Oxide NPs

8.5.1 Biological Application

Various studies have established that CuO NPs possess potent antimicrobial, antioxidant, and anticancer activities (Table 8.3).

Table 8.2 Characterization techniques, their use, and limitations

Technique	Main role	Limitation	References
High-resonance transmission electron microscopy (HRTEM)	Used for the determination of shape and size of nanostructures	Particle size larger than 1.5 nm cannot be determined	Thakur et al. (2014)
X-ray diffraction (XRD)	Size and crystallinity of NPs can be determined by this technique	Composition of plasmon and NPs cannot be analyzed	Din et al. (2017)
Scanning electron microscopy (SEM)	Used for the determination of shape and size of nanostructures	Samples must be solid and elements with atomic number <11 cannot be determined	Kalpana et al. (2016)
Atomic force microscopy (AFM)	Particle size and characterization	Can be used for gas and liquid samples only	Daniel et al. (2013)
Brunauer–Emmett–Teller analysis (BET)	Specific surface area is measured	–	Karimi and Mohsenzadeh (2015)
X-ray fluorescence spectroscopy (XRF)	Used for the measurement of chemical composition and concentration	Limited ability to measure precisely and accurately	Karimi and Mohsenzadeh (2015)
Nanoparticle tracking analysis (NTA)	To visualize and measure particle size, concentration, and fluorescent properties of NPs	–	Cheirmadurai et al. (2014)
Particle size analysis (PSA)	To measure the distribution of size in the sample of solid or liquid particulate materials	–	Parihar and Balekar (2016); Shende et al. (2016)
Selected area electron diffraction (SAED)	Technique that can be performed inside a TEM	Cannot be recommended for quantitative identification	Karimi and Mohsenzadeh (2015)
Energy-dispersive X-ray spectroscopy (EDX/EDS)	Composition of NPs can be analyzed	Particles with size <2 nm cannot be analyzed	Nasrollahzadeh et al. (2015a); Harne et al. (2012)
X-ray photoelectron spectroscopy (XPS)	Elemental composition of NPs can be analyzed	Samples are decomposed	Lee et al. (2011)
Zeta size analyzer	Measures the size of NPs, zeta, potential, and protein mobility	In nano-range	Shende et al. (2016)

8.5.1.1 Antimicrobial Activity

The last decade introduced opportunities to investigate the bactericidal effect of metal NPs. Their small size and high surface-to-volume ratio allow them to interrelate strongly with microbial membranes which are not merely due to the release of metal ions in solution (Subhankari and Nayak 2013). Niraimathi et al. (2016) and

Table 8.3 Antimicrobial, antioxidant, anticancer, and catalytic activities of CuO NPs

Biological entity	Activity	Response	References
Aloe vera	Photocatalytic activities	Degradation of methylene blue	Kerour et al. (2018)
Alternanthera sessilis	Antimicrobial activity	Water treatment, synthetic textiles, biomedical and surgical devices, food processing and packaging	Niraimathi et al. (2016)
Andrographis paniculata	Antimicrobial activity	*Escherichia coli*, *Staphylococcus aureus*, and *Pseudomonas aeruginosa*	Devasenan et al. (2016)
Anthemis nobilis	Catalytic activity	A^3 coupling reaction	Nasrollahzadeh et al. (2015a)
Aerva lanata	Antibacterial activity	*E. coli*, *S. aureus*, *Bacillus cereus*, and *P. aeruginosa*	Hariprasad et al. (2016)
Artemisia haussknechtii	Antibacterial, antioxidant, and ion-chelating activities	*E. coil*, *S. aureus*, *S. epidermidis*, *S. marcescens*	Alavi and Karimi (2017)
Azadirachta indica	Anticancer activity	Cytotoxic against four cancer cell lines, human breast (MCF-7), cervical (HeLa), epithelioma (Hep-2), lung (A549) and one normal human dermal fibroblast (NHDF) cell line	Rehana et al. (2017)
Bifurcaria bifurcata	Antibacterial activity	*Enterobacter aerogenes* (Gram-negative) and *S. aureus* (Gram-positive)	Abboud et al. (2013)
Phaseolus vulgaris	Anticancer activity	Suppress the proliferation of HeLa cells	Nagajyothi et al. (2017)
Calotropis procera	Optical studies	Indirect optical transitions	Reddy (2017)
Centella asiatica	Catalytic activity	Photo catalytic degradation of methyl orange	Devi and Singh (2014)
Cassia auriculata	Antirheumatic activity	Arthritis	Shi et al. (2017)
Matricaria chamomilla	Antioxidant activity	Photooxidation of polymer	Duman et al. (2016)
Datura innoxia	Antimicrobial activity	Leaf blight disease of rice	Kala et al. (2016)
Desmodium gangeticum	Antioxidant activity	Inhibiting the free radical production	Guin et al. (2015)
Euphorbia nivulia	Anticancer activity	Human adenocarcinomic alveolar basal epithelial cells (A549 cells)	Valodkar et al. (2011a)
Ferulago angulata	Photocatalytic activity	Rhodamine B as organic contaminant	Mehr et al. (2018)
Galeopsidis herba	Antioxidant and catalytic activity	By DPHH method and degradation of malachite green	Dobrucka (2018)
Gloriosa superba	Antibacterial activity	*Klebsiella aerogenes*, *P. desmolyticum*, *E. coli*, and *S. aureus*	Naikaa et al. (2015)

(continued)

Table 8.3 (continued)

Biological entity	Activity	Response	References
Gundelia tournefortii	Catalytic activity	Excellent catalytic activity for reduction of 4-nitrophenol and synthesis of N-monosubstituted ureas	Nasrollahzadeh et al. (2015b)
Malus domestica	DNA-cleavage activity	pBR322 plasmid of *E. coli*	Jadhav et al. (2018)
Malus domestica	Antibacterial activity	Gram-positive and Gram-negative bacteria	Jadhav et al. (2018)
Malus domestica	Antioxidant activity	Free radical scavenging activity by the DPPH (1,1-diphenyl 2-picrylhydrazyl) method	Jadhav et al. (2018)
Magnolia	Antibacterial activity	*E. coli*	Lee et al. (2011)
Stachys lavandulifolia	Antibacterial activity	*P. aeruginosa*	Khatami et al. (2017)
Sterculia urens	Antibacterial activity	*E. coli* and *S. aureus*	Padil and Cernik (2013)
Tamarix gallica	Catalytic activity	*N*-arylation of nitrogen-containing heterocycles with aryl halides under ligand-free conditions	Nasrollahzadeh et al. (2015c)
Thymus vulgaris	Catalytic activity	*N*-arylation of indoles and amines	Nasrollahzadeh et al. (2016)

Kala et al. (2016) have reported the antimicrobial activity of copper bionanoparticles in the recent past. Acharyulu et al. (2014) studied the antimicrobial activity of biosynthesized CuO NPs from *Phyllanthus amarus* leaf extract against multidrug-resistant Gram-positive (*Bacillus subtilis* and *Staphylococcus aureus*) and Gram-negative (*Escherichia coli* and *Pseudomonas aeruginosa*) bacteria. Abboud et al. (2013) investigated that CuO NPs produced by using brown algae extract (*Bifurcaria bifurcata*) show high antibacterial activity against two different strains of *Enterobacter aerogenes* (Gram-negative) and *Staphylococcus aureus* (Gram-positive). Suleiman et al. (2013) claimed that biologically synthesized copper NPs can be used for treating several diseases; however, it requires clinical studies to ascertain their antimicrobial potential and efficacy. Padil and Cernik (2013) suggested the antimicrobial activity of CuO NPs against common pathogens *E. coli* and *S. aureus.* Das et al. (2013) and Heinlaan et al. (2008) demonstrated the antioxidant and antibacterial behavior of these NPs, whereas Hariprasad et al. (2016) observed their good antibacterial activity against *E. coli*, *S. aureus*, *Bacillus cereus*, and *Pseudomonas aeruginosa*. According to Naikaa et al. (2015), the synthesized CuO NPs were effective against the pathogenic bacteria *S. aureus* and *Klebsiella aerogenes.* Devasenan et al. (2016) also confirmed the ability of CuO NPs to inhibit the growth of various pathogens.

8.5.1.2 Antioxidant Activity

Antioxidant activity of nanomaterials is well established. Photooxidation of polymer creates aldehydes, ketones, and carboxylic acids at the end of the polymer chain. Antioxidants terminate these chain reactions by removing free radical intermediates and inhibit other oxidation reactions. The antioxidant and DNA-cleavage properties of CuO NPs biosynthesized with the help of *Chammomile* flower extract were reported by Duman et al. (2016). They suggested that CuO NPs can act as a chemical nuclease, can generate DNA cleavage, and may be useful for preventing cell proliferation. The improved antioxidant efficacy in Andean blackberry fruit than Andean blackberry leaf extract may be due to the presence of more bioactive molecules in the former than in the latter, which have a role as an encapsulating agent in CuO NPs. The highest antioxidant efficacy of CuO NPs against DPPH is probably derived through the electrostatic attraction between negatively charged bioactive compounds (COO^-, O^-) and neutral or positively charged NPs. CuO NPs bind to phytochemicals, and their bioactivity increases synergistically. Antioxidant activity of CuO NPs was measured by Das et al. (2013) using (2,2 diphenyl**-**1**-**picrylhydrazyl) DPPH method where DPPH was used as a radial source. Guin et al. (2015) found the biologically synthesized CuO NPs to be significantly effective against oxidative stress and less toxic than the precursor material.

8.5.1.3 Anticancer Activity

Copper oxide NPs also exhibit anticancer activity, as reported recently by Nagajyothi et al. (2017). Clonogenic assays have confirmed that the NPs-incubated cancer cells are not able to proliferate well. The CuO NPs can induce apoptosis (cell death) and suppress the proliferation of HeLa cells. These NPs have a high anticancer cytotoxicity on human colon cancer lines (HCT-116) with IC_{50} value of 40 μg mL^{-1}. According to Rehana et al. (2017), CuO NPs are cytotoxic against four cancer cell lines, viz., human breast (MCF-7), cervical (HeLa), epithelioma (Hep-2), and lung (A549), and one normal human dermal fibroblast (NHDF) cell line. The anticancer activity of brown algae**-**mediated CuO NPs was determined by MTT assay against the cell line (MCF**-**7) (Suleiman et al**.** 2013). CuO NPs synthesized by using stem latex of *Euphorbia nivulia* (common milk hedge) could be encrusted and stabilized by peptides and terpenoids present in the latex. These NPs have shown toxic effect against human adenocarcinomic alveolar basal epithelial cells (A549 cells) (Valodkar et al. 2011a, b).

8.5.1.4 Antirheumatic Activity

In a recent investigation, it was found that CuO NPs prepared using *Cassia auriculata* extract can be used as a vehicle in drug delivery as antirheumatic agent for rheumatoid arthritis treatment (Shi et al. 2017).

8.5.1.5 Catalytic Effect

According to Devi and Singh (2014), CuO NPs prepared from the leaf extract of *Centella asiatica* at room temperature show a catalytic effect. NPs have many active sites as compared to the bulk material because of their small size and large surface-to-volume ratio. These NPs could be used for the photocatalytic degradation of methyl orange. In the absence of reducing agents in aqueous medium, these NPs reduce methyl orange to its leuco form.

Nasrollahzadeh et al. (2015a) investigated the effectiveness of CuO NPs for the synthesis of propargylamines by elaborating the reaction conditions in A^3 coupling reaction between piperidine (1.2 mmol) and phenylacetylene (1.5 mmol) with benzaldehyde (1.0 mmol) as a model reaction. An assorted range of propargylamines was obtained in a superior yield. In addition, the reclaim and separation of CuO NPs were very easy, effectual, and economically viable. In another study, CuO NPs were found to be exceptionally heterogeneous catalyst for ligand-free N-arylation of indoles and amines. An excellent yield of N-arylated products was obtained, and the catalyst could be recovered and recycled for auxiliary catalytic reactions with approximately no loss in activity (Nasrollahzadeh et al. 2016).

8.6 Conclusion

Due to rich plant diversity, phytosynthesis of CuO NPs is proficient in producing superficial, ecologically safe, and economically viable NPs, in comparison to physical and chemical methods. During the bioreduction process, the biomolecules present in plant systems play a significant role. Different techniques used for the characterization of biosynthesized NPs include UV-vis spectroscopy, FTIR spectroscopy, XRD, SEM, EDX, Raman spectroscopy, DLS, TEM, SAED, etc. Applications of CuO NPs are significant especially in biomedicine and catalysis. The recent use of engineered CuO NPs in drug and gene delivery, in addition to their well-known catalytic effect and the antimicrobial, antioxidant, and anticancer activities, has attached a special prestige to them.

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