Green Synthesis of Copper Oxide Nanoparticles and its Applications - A Review

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Abstract— Engineered nanoparticles (ENPs) are particles with distinct properties that have been used for various applications, including biomedicine, agriculture, and industry. Copper oxide nanoparticles (CuO NPs) are ENPs widely used in multiple applications. Several potential applications of copper oxide nanoparticles (CuO NPs) have recently been identified, including gas sensors, waste treatment, food preservation, high-temperature superconductors, field emission emitters, and agriculture. CuO NPs have demonstrated distinct anticancer, antimicrobial, and antioxidant efficacy, making them a promising tool for biomedical applications. Copper oxide nanoparticles are more critical than other nanoparticles because of their exceptional catalytic, mechanical, magnetic, electric, and thermal properties. Copper oxide nanoparticles have applications in catalysis, sensors, dye degradation, fungicidal and nematicidal treatment, and agricultural, industrial, environmental, and medical fields. Furthermore, the synthesis technique is critical for the properties of the final nanosystem because it controls the size and morphology of the nanoparticles. As a result, the various synthesis methods of CuO Nps and their multiple applications in the respective field are briefly discussed in this review.

Keywords: Biomedical Applications, CuO Nanoparticles, Nanotechnology

I. INTRODUCTION

Engineered nanoparticles (ENPs) are nanoscale particles ranging from one to a hundred nanometers. They have been employed for various reasons, including medical, agriculture, and industrial, due to their unique features. However, widespread ENP use results in unavoidable and permanent ENP emission into the environment. Copper oxide nanoparticles (CuO NPs) are among many types of ENPs used in a wide range of applications. As a result, the world is expected to uptake at least 200,000-830,000 kilogram of copper oxide nanoparticles per year between 2020 and 2025.

For a few decades, nanotechnology innovations have pathed a vital role in the medicinal, pharmaceutical, and textile industries. Ag, Zn, Cu, and Au nanoparticles have long been utilized as therapeutic agents in medical facilities. Several researchers have recently looked at the biological effects of MO NPs such as CuO. These nanoparticles outperform metal nanoparticles in terms of biological and photocatalytic activities. Copper oxide nanoparticles (CuO NPs) have recently been a potential application for gas sensors, waste treatment, food preservation, high-temperature superconductors, field emission emitters, and agriculture. CuO NPs have demonstrated distinct anticancer, antibacterial, and antioxidant effectiveness, making them an intriguing biological tool. Because of their remarkable catalytic, mechanical, magnetic, electric, and thermal capabilities, CuO NPs are more important than other forms of NPs. Copper oxide nanoparticles can be employed in agricultural, industrial, environmental, and medical applications and catalysis, sensors, dye degradation, fungicidal, and nematicidal applications.

Due to their wide variety of uses, metal oxide nanoparticles have recently enticed researchers to examine their properties, particularly their capacity to affect compounds' physical, optical, and electrical properties. Copper oxide nanoparticles are absorbing among transition metal oxides because of their utility as nanofluids, antibacterial agents, and cancer inhibitors. As a result, the numerous techniques for producing copper oxide nanoparticles and their biological applications have been briefly discussed in this study. (1)

II. SYNTHESIS METHODS FOR BIOMEDICAL CUO NANOPARTICLES

Because of its crucial biological and industrial applications, CuO NPs production technologies have evolved dramatically in the recent decade. Because it determines the dimension and morphology of the nanoparticles, the synthesis technique is tough for the attributes of the completed nanosystem. Furthermore, these nanoparticles differ from bulk solid materials in terms of optical and magnetic characteristics, mechanical strength, and electrical resistivity. CuO NPs come in various sizes, depending on the process used to make them. Table 5 shows the essential techniques and the typical particle sizes that occur. (2)

A. Electrochemical

Switzer is the inventor of the electrochemical process for making ceramic films. This approach has been utilized to manufacture nano-MOs such as Zinc Oxide, CuO, and other MOs. Cu was utilized as a sacrificial anode in the first CuO nanocrystals discovered. Chemical reactions between the electrode and the electrolyte are the basis of the electrochemical methods. Electrodeposition happens on a few electrode sections due to chemical potentials built on the electrode's surface. Copper oxide nanoparticles are made via various soft chemical processes, including the electrochemical approach (3-5).

One of the most prominent benefits of this process is the capacity to alter the morphology and dimension of the concluding copper oxide nanoparticles by changing the temperature, time, current density, composition, or voltage. By raising the thickness from 5 mA•cm^2 to 10 mA•cm^2 and finally to 20 mA•cm^2, Zhang et al., 2013 generated CuO nano spindles and nanorods. By altering the electrolytic solvent, these researchers made CuO nanorods with diameters varying

from 20nm to 50nm and lengths ranging from 200nm to 300nm. Via a Cu sheet as an anode and a Pt sheet as a cathode, Jadhav et al., 2011 created copper oxide nanoparticles utilizing an electrochemical technique (6).

Katwal et al., 2015 described an electrochemical approach for making CuO NPs in various reaction conditions. The electrodes, the Cu plate, and inert Pt were all positioned at 1 centimeter as per protocol. A supporting electrolyte was added to CH3CN and a H2O to CH3OH solution in a 12:1 molar ratio at room temperature. Before being calcined and described, the dark brown deposits are centrifuged, rinsed, and drained. This approach also indicated that changing the reaction parameters and molar ratios of the chemicals employed could change the physical and chemical properties of the nanostructures (including their size) (5).

B. Glycol Polyethylene (PEG)

PEG (polyethylene glycol) is a nonionic surfactant used to make metal oxides at a low cost. Because it is biocompatible with the complete structure, it is also employed in numerous medical approaches, particularly in drug distribution. PEG 400 has been the most often used version due to its lower toxicity. This surfactant was employed by Ranjbar-Karimi et al., 2010 to study the impact of its existence on the dimension and shape of copper oxide nanoparticles. Copper oxide nanoparticles were made by mixing different amounts of sodium hydroxide and copper acetate solutions in ethanol/water. The sample carried 50 ml of copper acetate (0.05 M) and 100 ml of sodium hydroxide, sonicated for 1 hour with 30 Watts ultrasound strength (0.1 M). Nanoparticles with relatively uniform size (average diameter of 70 nm) were produced using this technology (6-9).

PEG has also been demonstrated to substantially impact the size of copper oxide nanoparticles in various investigations. $CuCl_2$, NaOH, and Glycol Polyethylene 400 made CuO NPs. The resultant was rinsed with C_2H_5OH and dried to detach the polyethylene glycol 400. The solid that resulted was calcined at 400, 600, and 800 degrees Celsius. Samples calcined at 800 degrees celsius produced homogeneous molecules ranging in size from 400 to 454nm, whereas samples calcined at 400 °C formed NPs with dimensions of about 65nm. The increase in temperature was related to the amount of particle agglomeration. Copper oxide nanoparticles and Copper oxide nanorods generated with Glycol Polyethylene 400 and Glycol Polyethylene 6000 exhibited the same uniform shape as copper oxide NPs correlated with 10ml or 20ml of Glycol Polyethylene 400. On the other hand, CuO NPs made with PEG 6000 have the best shape and distribution of all the PEGs studied. (9, 10).

C. Sonochemical:

The sonochemical approach is an easy three-step method that includes (i) production, (ii) development, and (iii) implosive collapse of the microcavities. This procedure necessitates ultrasound throughout the product's production (11-13).

Suleiman et al., 2011 used a sonochemical approach to build copper oxide nanoparticles with enormous structure employing Cu $(CH_3COO)_2$ as a precursor and polyvinylpyrrolidone (PVP) as a reductant. Using the sonochemical approach, Karunakaran et al., 2014 synthesized four samples. Following sonication and calcination, the first two samples were made up of copper oxide nanoparticles and Cetyltrimethylammonium bromide (CTAB), while the next two samples were made up of CuO NPs without CTAB. According to the absence of Cetyltrimethylammonium bromide (CTAB), NPs have an uneven form and molecular aggregation in the findings. The presence of CTAB, stimulates the production of CuO crystals. Wongpisutpaisan et al., 2011 employed the same sonochemical process to make CuO NPs, which were subsequently calcined for 2 hours at temperatures ranging from 200 to 700 degrees Celsius. CuO NP formation was incomplete at 400 and 500 degrees Celsius. (14)

At 600 and 700 degrees Celsius, however, the authors noticed the formation of crystals and the creation of homogenous nanoparticles. CuO nanoparticles for medical purposes were made using this method. Copper oxide nanoparticles were created via a sonochemical process by Abramov et al., 2009 and then utilized to cover medical injury dressings with cotton and bandages. This combination was shown to prevent microbial colonization and even kill a variety of therapeutically relevant bacteria, including *Escherichia coli*, which has been known to form colonies the injuries of patients with skin damage, necessitating the use of dressed in cotton. Perelshtein et al.,2009 also created coated textiles from CuO NPs using the sonochemical approach. Because these nano-coatings have shown to have effective antibacterial action, they are being explored for other biomedical applications, such as the construction of anti-infectious surfaces, diagnostic equipment, and anti-biofilm techniques (6,15,16).

D. Sol-gel

The sol-gel process is commonly used to design nanoparticles since it is easy and rapid. This approach is popular because it ensures precise nanoparticle size control. The process was tweaked to manufacture nanoparticles varying from 10 to 40 nanometers. CuO NPs with diameters of 25nm were created by Karthik et al. using a sol-gel technique. The calcination period and the sol-gel process are used to affect the physical properties of CuO NPs (6, 17).

In addition, due to the size of nanoparticles in the sol-gel process is corresponding to temperature, physical boundaries are crucial when designing functional nanoparticles with this method. For example, Jayaprakash et al. used ethylene diamine tetraacetic acid to make uncapped and capped CuO NPs in a sol-gel technique (EDTA) (18).

A blocking agent was used to check the size of CuO NPs. Copper oxide nanoparticles were produced using copper acetate and CH_4N_2O. The morphology and shape of nanoparticles may be finely controlled using this technology, according to the researchers (17).

III. Applications of Copper Oxide Nanoparticles

A. Antibacterial Implementation

Biosynthesized CuO NPs were tested for their antibacterial inhibitory activity against gram-positive and gram-negative bacterial strains. The microbial approach of photosynthesized Copper oxide nanoparticles generated from *Tecoma castanifolia* leaf extract has been consistently demonstrated,

suggesting that they could be valuable in medical applications. Earlier studies have shown that the biomolecules in green extracts employed in the production of CuO NPs have higher antibacterial activity. The antimicrobial activity of Copper oxide nanoparticles has been connected to terpenoids discovered in the extract during the capping process. The antimicrobial study of CuO NPs attained via the agar well diffusion method against gram positive bacteria (*Streptococcus mutans and Staphylococcus aureus*) and gram negative bacteria (*Pseudomonas aeroginos, Klebsiella pneumoniae,* and *Escherichia coli*) revealed CuO NPs harmful in demolishing the growth of tested infectious agents. The presence of highly reactive oxygen species on the surface of copper oxide nanoparticles, such as (OH, H_2O_2, and O_2), has a bactericidal effect. The uses and activity of copper oxide nanoparticles produced from plant extracts are summarized in Table 1 (19-22).

CuO NPs were investigated for antimicrobial approach against *Escherichia coli, Pseudomonas aeruginosa, Klebsiella pneumoniae, Enterococcusfaecalis, Shigellaflexneri, Salmonella typhimurium, Proteus vulgaris,* and *Staphylococcus aureus,* among other microorganisms. The microorganisms and their Minimum Incubatory Concentration in g/mL are listed in Table 2.

S/N	Plant name	Plant part	Precursor used	Application	Activities	Ref
1	Eupatorium odaratum	Leaf	Copper sulfate	Antibacterial	12-30 mm	52
2	Tea	Leaf	Copper nitrate	Antibacterial activities	Showed remarkable antibacterial activity against *K. pneumoniae and V. cholerae* with inhibition zones of 10.5 at 200Ng/disc	53
3	Eucalyptus globulus	Leaf	Copper sulphate	Antibacterial	Potential ROS generation for interruption of bacterial cells	28
4	Sida acuta	Leaf	Copper sulfate	Antibacterial	Higher antimicrobial activity against the growth of studied infectious pathogens	57
5	Bauhinia tomentosa	Leaf	Copper sulfate	Antibacterial	CuO NPs offered antibacterial efficacy qualify for utilization in biomedical applications	20
6	Zea mays	Husk	Copper acetate	Antibacterial	It showed effective inhibition against the growth of *Pseudomonas aeruginosa* and *Bacillus licheniformis* than *Escherichia coli* and *Staphylococcus aureus*	58

Table 1: CuO nanoparticle applications and antimicrobial activities synthesized from plant extracts.

Organisms	MIC(μg/mL)
Escherichia coli	31.25
Pseudomonas aeruginosa	125
Proteus vulgaris	125
Klebsiella pneumonia	250
Enterococcus faecalis	31.25
Shigella flexneri	125
Salmonella typhimurium	62.5
Staphylococcus aureus	62.5

Table 2: Microorganisms and their MIC in μg/mL.

CuO NPs were tested for antibacterial activity against pathogens such as *E. coli, Enterococcus sp., Proteus sp., and Klebsiella sp.,* which can cause urinary tract infection, using the agar disc diffusion method (UTI). Lasting one night, cultures of each strain were swabbed evenly onto separate petri dishes of disinfected and cooled LB Agar. After that, varying quantities of copper nanoparticles were impregnated with 6mm diameter sterile discs (25, 50, and 75 L, corresponding). The impregnated discs were placed on the petri dishes and left to incubate for one day at 37°C. Commercial antibiotic discs (ampicillin) was used to act as a check. After incubation, non-identical amounts of the area generated around the discs were calculated. (23).

CuO nanoparticles were investigated for antibacterial activity against *Escherichia coli, Shigella dysenteriae 1, Streptococcus pneumoniae, Staphylococcus aureus Vibrio cholerae non.0139 (L4), and Vibrio cholerae non.0139 (CSK6669)*. The antibacterial experiment were performed by the disc diffusion method. CuO nanoparticle mixtures were made with distilled water at concentrations of 200, 100, 50, and 1 g/disc. By distributing 40 L of each strain on a spread plate, the test microbes (freshly cultivated in LB broth) were put into the appropriate agar–agar medium. The sterilized paper discs (5mm in width and 0.4mm in depth) were then placed in petri dishes with a 100mm width and varying concentrations of liquids applied to each disc. Distilled water was utilized as a check for each mixture. The petri dishes were then incubated at 37°C lasting one night. To assess the zone of inhibition, antibacterial activity was measured in millimetres (mm). The value of the results was calculated succeeding three repetitions of every experiment.

B. Anticancer Application

CuO NPs produced from black bean extract using the sulforhadamine-B assay show anticancer properties, revealing some changes in mitochondrial structure and a significant reduction in cervical carcinoma cell proliferation. In addition, CuO NPs mediated by *Ficus religiosa* were discovered to have anticancer effects in human alveolar basal epithelial cells from A549 adenocarcinoma (24-25).

Due to their proven toxicity, which manifested as oxidative stress damage and DNA damage in tumor A549 alveolar cells, CuO NPs have been advocated for creating and designing cancer cell-targeting delivery vehicles. CuO NPs induced by Pterolobium hexapetalum leaf extract significantly increased the cytotoxicity of MDA-MB-231 human breast cancer cells. Compared to chemically synthesized nanoparticles, the in-vitro toxicity investigation of phytosynthesized copper oxide nanoparticles demonstrates that they have greater toxicity efficacy, which is advantageous in biomedical applications. To choose nontoxic nanoparticles with different biological activities, toxicity testing is critical. CuO NPs mediated by *Olea europaea* were tested for toxicity using a 25 healthy male albino mouse model, revealing that the CuO NPs cause reduced weight and had concentration-dependent harmfulness. In several investigations, CuO NPs have been shown to exhibit cell toxicity towards cancer cell proliferation. CuO NPs anticancer activities and applications are summarized in Table 3, and the mechanism of CuO NPs-induced cell toxicity in tumor cell lines is depicted in Figure 1 (26-32).

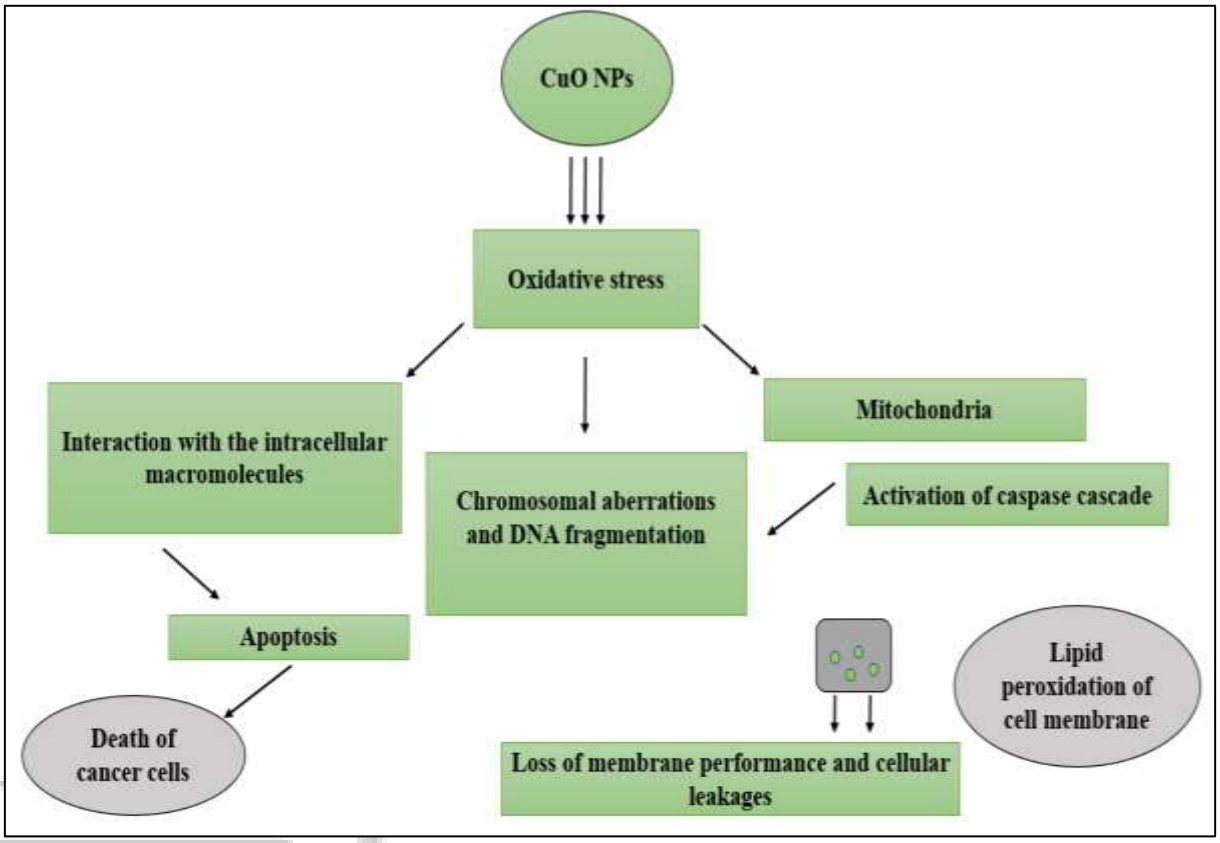

Fig. 1: The probable mechanism of copper oxide nanoparticles induced cell toxicity in tumor cell lines.

S/N	Plant name	Plant part	Precursor used	Application	Activities	Ref
1	Eucalyptus globulus	Leaf	Copper sulfate	Anticancer	Cell cycle distribution and upregulation of pro apoptotic genes in MCF-7 cells	63
2	Camellia sinensis	Leaf	Cupric acetate	Anticancer	Remarkable cytotoxic effect of 50% mortslity at 50 yg/ml against breast cancer cell lines (MCF-7)	56
3	Coleus aromaticus	Leaf	Copper sulfate	Anticancer	It offered an efficient platform for intracellular miRNA delivery and improving therapeutic outcomes for lung cancer	54
4	Azadirachta indica	Leaf	Copper acetate	Anticancer	Cytotoxicity against the tested cancer cell lines without affect the human cell	55
5	Hibiscus rasa-sinensis	Leaf	Copper acetate	Anticancer	Great cytotoxicity against the tested cancer cell lines	55
6	Murraya koenigii	Leaf	Copper acetate	Anticancer	High cytotoxicity against the tested cancer cell lines without affect the human cell	55

Table 3: CuO NPs anticancer activities and their application.

CuO NPs have therapeutic uses in cancer study, meaning they are utilized for monitoring or therapy. In addition, CuO NPs might be employed in medicinal techniques to induce systemic immune responses against malignancies, including photothermal therapy combined with immunotherapies. Cu NPs photothermal activity was thriving utilized to cause the killing of remaining tumor cells and prevent local tumor relapse in vivo following a single enhancement session in the in vivo tests. In vivo, doxorubicin-loaded transferrin-based CuO NPs successfully suppressed tumor development (33-36).

According to a long-term active research effort, copper-based radioisotopes, notably the 64Cu isotope, have a potential future in cancer diagnostics and therapies. ^{64} Cu had antitumor activity and significantly increased survival in a hamster model of human colorectal cancer. Surprisingly, the anti-L1-cell adhesion molecule suppressed the proliferation of human metastatic ovarian carcinoma cells when combined with the ^{67}Cu radioisotope and a monoclonal antibody. In oncology, metal-based treatments are crucial. Copper-based compounds, as previously said, have a bright future in the sector. As a result, the development of copper complexes with anticancer characteristics is based on the modification of Cu metabolism in cancer (37-42).

C. Antifungal activity:

Copper oxide NPs have antifungal action and are generally robust against many infections. The disc diffusion method and fungus stains such as *Candida albicans* and *Aspergillus niger* test antifungal activity. Fluconazole was used as the standard to determine the zone of inhibition. The lowest inhibitory concentration of CuO NPs was determined to be 100 g/ml^{-1} after serial dilutions for the produced CuO NPs were done according to the technique (European Committee for Antimicrobial Susceptibility Testing (EUCAST)) (43).

1) Antifungal disc diffusion method

The antifungal properties of produced CuO nanoparticles were evaluated by applying the conventional disc diffusion method. *Candida albicans* and *Aspergillus niger* fungal stains were employed in this investigation. The disc diffusion method required inoculums to be produced with the appropriate broth, and the medium was dried at 30–35 ℃ before use. In a previously sanitized petri plate, the standardized inoculums were put. Surplus inoculums were removed from the culture tube by firmly pressing and spinning the swab on the side of the tube above the liquid level. The petri dish was dried at 37°C for 24 hours with the stopper (44).

The materials were placed on the petri dish using sterile forceps separated into pieces. The Dimethylsulfoxide (DMSO) solvent is employed to act as a check. It took more or less 10g/ml-1 of regular Fluconazole to get consistent grass. Next, dilutions were utilized to make various amounts of CuO NPs, and around 100g/ml^{-1} was employed to test its antifungal activity. To allow for diffusion, petri dishes were kept in the refrigerator at 4°C or at 37°C for one hour before being incubated at room temperature for 24 hours. Finally, the zone of inhibition caused by various materials were assessed by a standard ratio.

Table 4 shows that the produced CuO NPs had greater antifungal activity. Their size and concentration influence cuO NPs antibacterial activity. The antifungal activity of the CuO NPs generated by the green synthesis is outstanding (43).

Organisms	Fluconazole(10 μg/Ml^{-1})	CuO NPS(100 μg/Ml^{-1})
Aspergillus niger	10	9
Candida albicans	9	9

Table 4: Antifungal activities of CuO NPs.

D. Antioxidant activity

The capacity of CuO nanoparticles produced using *Galeopsis herba* extract to neutralize the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical was tested in this work to identify their antioxidant potential. During the reaction with the tested CuO nanoparticles solution, the absorbance of the DPPH methanol solution decreased, indicating neutralization. Several dilutions were created from 0.01 to 5 g/ml. A spectrophotometer, the Carry E 500, was used to measure changes in absorbance intensity. Next, 0.1 ml of the test solution and 0.7 ml of the 2,2-diphenyl-1-picrylhydrazyl (DPPH) reagent at a concentration of 0.1 mM were added to the light-protected test tubes. The DDPH reagent had been prepared and kept away from light for 24 hours. In test tubes, the solutions were shaken for 30 minutes.

Then, the absorbance was analyzed at a wavelength of 515nm. 0.1 ml of water and 0.7 ml of methanol were utilized as a control. The absorbance of the samples was measured first, then the absorbance of the DPPH solution, which was determined by measuring the absorbance of a solution comprising 0.1 ml distilled water and 0.7 ml 2,2-diphenyl-1-picrylhydrazyl (DPPH). The ability to reduce free DPPH radicals was calculated using the following formula:

$$Aa=(AoAi/Ao)\ 100\%$$

Aa stands for action of antioxidants [percent], Ai for average absorbance of the fluid under test, and Ao for the DPPH solution's average absorbance. The difference in absorbance between the control and test samples was used to calculate the total absorbance, and the IC50 value was calculated. The difference in absorbance between the control and the experimental groups was used to calculate the real absorbance, and the IC50 value was calculated.

Cu NPs were discovered to have significant antioxidant activity in scavenging free radicals. There was a concentration-dependent inhibition in general, with 400 g ml-1 functioning much compared to the other concentration; this one is superior and has the antioxidant activity (44.3%) at its

maximum. The active ingredient in the plant extract was 20%, while the active ingredient in the positive control was 92 percent. Cu NPs made from *O. europaea* leaf extract have antioxidant characteristics that can be linked to the functional groups connected to them. The ability of selenium, platinum, silver, and copper nanoparticles to scavenge DPPH was improved. Antioxidants are useful in the treatment of many severe diseases because of their capacity to scavenge free radicals (45, 46).

Antioxidants can also create peroxynitrite from nitric oxide, producing damaging radicals like the hydroxyl radical. Still, to fully comprehend the mechanism of Cu NPs antioxidant effect, additional refined experimental proofs are required (47).

Preparation method	Size (nm)
Electrochemical	4 nm
Sonochemical synthesis	20-30 nm
Sol-gel	7-9 nm
Micro emulsion system	5-25 nm
Precipitation synthesis	4 nm
Microwave irradiation	3-5 nm

Table 5: Methods for preparing CuO NPs.

IV. Additional Synthetic Methods

Other methods for making Copper oxide Nanoparticles have been discovered, including hydrothermal synthesis, thermal oxidation, alcohol-thermal synthesis, liquid ammonia, and microwave-assisted synthesis (16, 48-50).

The direct thermal decomposition approach is commonly used to make CuO NPs. For example, the addition of Na_2CO_3 to $CuSO_4$, followed by the calcination process, produces spherical-shaped CuO NPs in this approach (29).

Thermal plasma-produced CuO NPs have better physical and chemical characteristics that could be advantageous in biomedical applications. For example, these nanostructures have improved antibacterial efficacy against drug-tolerant microbes while retaining acceptable biocompatibility and modest dimensions (51).

In recent years, green synthesis has been the favored way of producing CuO NPs. Nanoparticles are suitable for biomedical applications because they are timid for living systems, more ecofriendly, and have physical and chemical properties acceptable for biomedical applications (24).

V. Conclusion

The importance of recent characterization techniques for determining the identities of CuO NPs is effectively addressed. The anticancer, antioxidant, and antibacterial properties of biosynthesized Copper oxide NPs have been comprehensively investigated. The mechanisms of synthesis and toxicity are fully explained. To increase the biological applications of CuO NPs, further research should be focused on possible approaches for decreasing CuO NPs. CuO NPs produced using the green technique had remarkable antifungal efficacy. CuO NPs could thus be employed as antibacterial agents in surface coatings on substrates to inhibit microbes from adhering, colonizing, spreading, and creating biofilms in indwelling medical devices. According to this study, the mechanisms of the antimicrobial response of CuO NPs in several bacterial species. The synthetic approach is easy to use, affordable, and safe for the environment.

CuO NPs synthesized via a green technique may have biological applications. As a result, biological uses for green-produced CuO NPs are possible. CuO NPs were revealed to have a spherical form with a 50–100nm size range. The antimicrobial properties of such nano formulations enable the development of a wide range of products, ranging from antibacterial solutions used to disinfect surfaces and medical devices to antimicrobial wound dressings, textiles, and coatings.

The current review highlights the importance of green-produced CuO nanoparticles in medical science, particularly tumor therapy because they have shown great activity in vitro and in vivo against various malignancies. According to these findings, CuO NPs may have antibacterial and cytotoxic effects on cancer cells, inhibiting proliferation, raising oxidative stress, and causing apoptosis. In addition, CuO nanoparticles have an exceptionally high antioxidant activity.

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