REVIEW ARTICLE

Harnessing Nature's Potential: A Review of Copper Nanoparticle Biosynthesis and Its Applications

Manisha Singhal and Deepak S. Rajawat*

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Abstract

Nanomaterials are being used in an increasing number of engineering and technological domains. One of their main advantages is that nanomaterial's properties differ from those of bulk materials with the same composition. One can readily change their properties by changing the size, shape, and chemical environment of nanoparticles. Due to its biological applications, copper nanoparticles have become a particular emphasis among other nanomaterials. Conventional methods of synthesizing copper NPs are harmful and toxic to human health and the environment because of the involvement of chemicals associated with environmental toxicity. Therefore, biological methods are emerging to fill the gap and tackle the problem. Green synthesis outperforms chemical and/or biological techniques by employing biological molecules generated from plant sources in the form of extracts. Through to the use of plants, plant extracts, fungi, algae, bacteria, biomolecules, and other microorganisms, the green synthesis method creates nanomaterial in a clean, safe, economical, and ecologically friendly manner. To make these biological techniques acceptable for the synthesis of metal nanoparticles, they go through a carefully monitored assembly process. There were reduced risks of failure, lower costs, and easier characterization with green approaches, making them more successful for generating NPs. The present review provides an overview of the various sources that can be used to make copper nanoparticles (Cu-NPs) using eco-friendly techniques. Employing naturally available substances and low-energy processes offers a sustainable method for generating nanomaterials.

Keywords: Nanomaterial, Biomolecules, Microbes, Green synthesis, Coating material

Highlights

- The article emphasizes the synthesis and applications of copper nanoparticles.
- Conventional methods of synthesizing Copper nanoparticles are harmful and toxic to human health and the environment.
- The transition from the conventional methods to green synthesis methods for creating copper nanoparticles is highlighted, emphasizing their environmental, economic, and practical advantages.
- Green synthesis techniques by employing biological molecules are used.
- Various plants, plant extracts, fungi, algae, bacteria, biomolecules, and other microorganisms are successfully utilized for nanoparticle synthesis are detailed.
- There are reduced risks of failure, lower costs, and easier characterization and eco-friendly production made them more successful.

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Introduction

Traditionally, civilizations were named after the metals used, such as the Stone Age, Bronze Age, Iron Age, etc. The Nano Age herds the current age. Richard P Feynman stated in 2000 that it was not until the year 1960. Its flexible use and quickly expanding demand have opened the door for creative approaches to the production of higher-quality nanomaterial. Traditional synthesis techniques were used in the early stages, and both toxic chemicals and high-energy input were relied on to produce nanosized material. Additionally, pollution as a result of traditional synthesis techniques creates a need for environmentally safer synthesis techniques (Murty *et al.*, 2013., Kenneth *et al.*, 2009).

Employing biological systems, green nanomaterial synthesis produces nanomaterials. Green synthesis from plants, plant extracts, fungi, algae, bacteria, biomolecules, etc has proved with the advantages of lower failure rates, lower costs, and simpler characterization, it is more efficient for the creation of NPs. (Fig. 1). The creation of nanomaterials using the green synthesis technique is a clean, safe, economical, and eco-friendly procedure. Metal nanoparticles (NPs) can be made in a variety of sizes and morphologies. Quantum size effects, electrical structure size dependence, special properties of surface atoms, and high surface/volume ratio are a few factors that make NPs unique. The size and form of metal NPs affect their characteristics (Fig. 2). In the production of chemical and biosensors, as well as the synthesis of catalysts, electronic devices, imaging systems, medical and environmental applications, several metal NPs of various sizes, shapes, and morphologies are used (Li *et al.*, 2010., Kobayashi *et al.*, 2009., Wang *et al.*, 2013).

Due to their affinity for -SH groups and biocompatibility, gold nanoparticles are frequently used in medical practice. As a cancer-targeted medication delivery system, colloidal

Department of Chemistry, IIS (Deemed to be University), Jaipur, Rajasthan, India

***Corresponding author:** Deepak S. Rajawat, Department of Chemistry, IIS (Deemed to be University), Jaipur, Rajasthan, India, Email: drdeepaksr@gmail.com

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gold nanoparticles are employed. Because of its antibacterial properties, silver nanoparticles have been used in the healthcare sector, food preservation applications, and textile industries. Silver nanoparticles are additionally commonly employed in electronics. Similar to silver, copper has long been known to have antibacterial, antifungal, and antiviral properties. Due to their low cost, copper NPs are commonly employed as an alternative to silver and gold NPs in current investigations (Ersoz *et al.*, 2018). By changing a nanoparticle's size, shape, and chemical environment, one can readily change its properties. In part of their widespread use in electronics, optics, sensors, catalysts, and medical applications, metallic copper (Cu), cupric oxide (CuO), and cuprous oxide (Cu_2O) NPs as well as composites of Cu/Cu_2O and Cu_2O/CuO are attracting interest from a variety of scientific fields (Poole and owens, 2003).

Fig. 1: Materials used for green synthesis of metallic nanoparticles

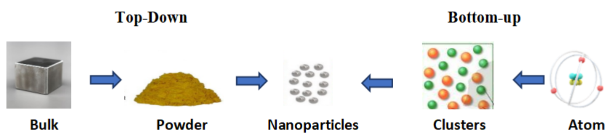

Fig. 2: Top-down and Bottom-up approaches for the synthesis of nanomaterials

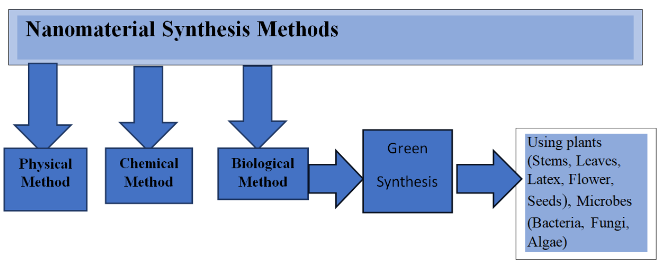

Fig. 3: Synthesis Methods for preparation of nanomaterial

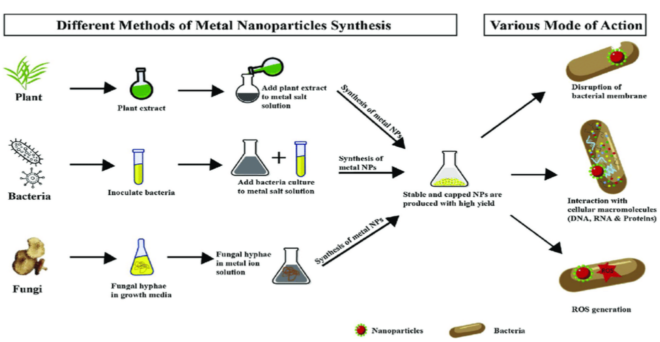

Fig. 4: Pictorial representation for green synthesis of metallic nanoparticles from plant, bacteria and fungi (Singh *et al.,* 2020)

Physical and chemical methods of synthesizing Copper NPs (Fig. 3), are poisonous and hazardous to both human health and the environment, could enhance particle reactivity and toxicity, and could have unintended negative impacts on health due to the absence of composition assurance. The creation of nanomaterials using the green synthesis technique is clean, safe, economical, and ecologically beneficial. Natural biological systems are used in green approaches to produce copper nanomaterials. The current review highlights environmentally friendly approaches for creating copper nanoparticles, which are just as effective—if not more so—as conventional synthesis. By utilizing naturally sourced raw materials and low-energy techniques, it offers a sustainable method for producing nanomaterials (Gawande *et al.*, 2016., Hongda *et al.*, 2020., Goutam *et al.*, 2019).

Here we discuss the biological method in which green synthesis occurs by using plant extract like stems, leaves, flowers, seeds and by using microbes like bacteria, fungi, and algae. Fig. 4 shows different method of synthesis of copper nanoparticles.

Green synthesis of the copper nanoparticle

Plant extract

The creation of nanomaterials using plant or food waste is the most intriguing and environmentally benign method of green synthesis. The procedure usually involves extracting certain chemical compounds from plant or food waste. The plant or food scrap is often dried, powdered, or broken up, immersed in hot water for a while, then filtered and stored at 4°C (Waris *et al.*, 2021). The metal salt (copper sulfate, copper nitrate, copper chloride) is mixed with the plant extracts, and the reaction takes 1-3 hrs at room temperature to complete (Fig. 5). The plant extracts contain different bioactive metabolites such as s flavonoids, phenols, proteins, terpenoids, and tannins that act as reducing agents and reduce the metallic salts into respective nanoparticles (Shobha *et al.*, 2014).

Sankar *et al.,* 2014 reported the preparation copper oxide

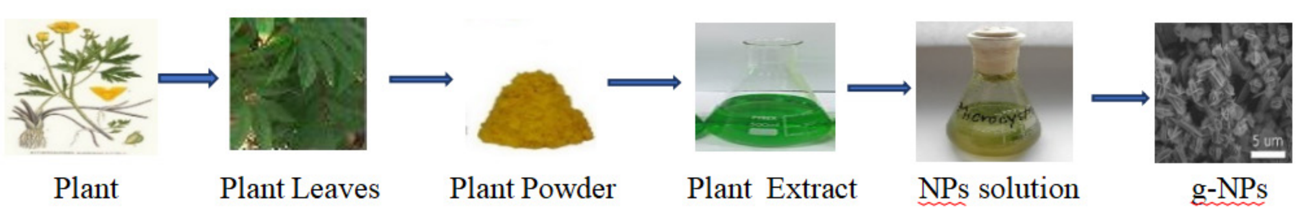

Fig. 5: Scheme for the synthesis of g-Cu NPs

nanoparticles (Cu NPs) by *Carica papaya* leaves extract. Surface plasmon resonance (SPR) peak features at 250-300 nm in UV-visible spectra provided evidence that CuONOs had formed. SEM and DLS reveal rod-shaped copper oxide nanoparticles have a mean particle size of 140 nm, respectively. Similarly, Naika *et al.,* 2015. reported Gloriosa superba extract that is used as fuel in a green synthesis method to produce CuONPs. SEM and TEM images confirm the spherical shape and the size was found to be in the range of 5–10 nm. Leaf extract of *Ixoro coccinea* was used for the synthesis of copper oxide nanoparticles by Vishveshvar *et al.,* (2018). Characterization of nanoparticles was done by using various techniques such as FTIR, SEM, TEM, and UV-visible spectrophotometer. The SEM and TEM results reveal the aggregation ability of the CuONPs and the average size, respectively. It was concluded that it is an eco-friendly and low-cost synthesis method and does not require any toxic chemicals for the synthesis. A noble biological synthesis of copper nanoparticles was carried out by Nagar *et al.* (2017). through a unique biological synthesis, A. indica leaf broth was created. In addition to lowering the metal ions and stabilizing the metal NPs, the biomolecules in the leaf broth also contribute to these effects. CuNPs that have been synthesized have a size of 48 nm on average, are cubical in shape, and are crystallized.

Kulkarni *et al.,* 2013. reported the use of leaf broth extract of *Ocimum sanctum* (local name Tulasi) as medicine. Several additional medicinal plants have been reported for the production of CuNP, including *Hagenia abyssinica* (Brace), *Krameria sps* (Rhatany), *Punica granatum*, juice of *Citrus medica* (Idilimbu) etc, are a traditional medicinal plant of India.

Some reagents have the capacity to serve as capping and reducing agents. Plant extracts contain phenolic chemicals that are water soluble, non-toxic, and biodegradable, facilitating a green method of production. Mohindru *et al.,* 2017. Developed green synthesis method using tea leaf extract that are reduced to a nanoparticle size of 50 to 100 nm. Optical spectrum Gap, as determined by UV analysis, grows with respect to the magnitude of the copper nanoparticles, which in turn depends on the amount of copper ions present in the solution. Paramagnetic behavior was evident in the magnetic characteristics of the synthesized nanoparticles.

According to Ashtaputrey *et al.* (2017). *Murraya koenigii (*Curry leaves) leaf extracts are used in the environmentally reliable and sustainable synthesis of CuNPs. The characteristic SPR peaks detected at 340 nm in UV-vis spectra indicated the formation of CuNPs. The morphological analysis of the SEM images reveals that the copper extract residue on the leaves contained asymmetrical, spherical-sized copper nanoparticles.

Amjad *et al.,* 2021, reported extracellular biogenic production of CuNPs from the leaves of *Fortunella margarita.* The method employed for the synthesis was safe for the environment, non-toxic, quick, and inexpensive. CuNPs are used in biological applications, drug delivery systems, and drug development, among others. When the phytochemicals from *F. margarita* come into contact with Cu^{+2} ions, a sudden and spontaneous synthesis of CuNPs is plainly visible as a color change from dark green to bluish-green. SEM demonstrates the spherical yet agglomerated shape of CuNPs with sizes in the range of 51.26 to 56.66 nm, while UV-vis analysis reveals the SPR of CuNPs with a distinctive absorption peak at 679 nm.

Kausar, *et al.* in 2022. used the aqueous extract of mint (*Mentha longifolia L.*) as a suitable and eco-friendly technique for the synthesis of CuNPs. There was no need for surfactant templates or chemical reagents. CuNPs were applied to wheat, and it was discovered that as CuNP concentration increased, wheat plant growth and germination also increased. However, it has been demonstrated that seed germination and seedling growth decreased after a specific dosage (50 mg CuNPs/L). The overall results indicated that the use of CuNPs affects germination and seedling growth at various concentrations. They also demonstrated that green synthesis is highly effective for recycling and eliminating heavy metals. The UV-vis absorption peak confirmed the synthesis of CuNPs at 558 nm.

Fernando, *et al.* in 2016. using *Syzygium cumini* leaves extract as a reducing agent, CuNPs were effectively synthesized. FTIR analysis demonstrated the functional groups in the leaf extract which are in charge of reducing the copper ions in the extract into metallic CuNPs. TEM and CV characterise spherical shape and the redox property of prepared CuNPs, respectively. Shuang Wu *et al.* in 2020 concluded that *Cissus vitiginea* based on green synthesis, copper nanoparticles are highly protective against DPPH (diphenylpicrylhydrazyl) free radicals and microorganisms that cause urinary tract infections Fig. 6. Similarly (Baranwa, *et al.*, 2016., Buazar *et al.*, 2019) show XRD spectrum and AFM shows crystalline nanostructured copper particles and the spherical shape of nanoparticles with aggregation, respectively while the TEM confirms that the size of CuNPs is between 10 and 20 nm, the UV-Vis examination exposes the SPR of CuNPs, revealing a distinctive absorption peak at 340 nm. Green synthesis highly proficient for recycling and for removing heavy metal and improve water quality from waste water. Table 1 show different plant and their part that is used for the synthesis of copper nanoparticles.

The development of instrumentation have allowed scientist to observe material and phenomena leading to understanding much deeper structure of nanostructured materials like, as shown in Table 2. Scanning electron microscopy (SEM), transmission electron microscopy (TEM), X-ray diffraction (XRD), fourier transform infrared spectroscopy (FTIR), cyclic voltammetry (CV), X-ray photoelectron spectroscopy (XPS),

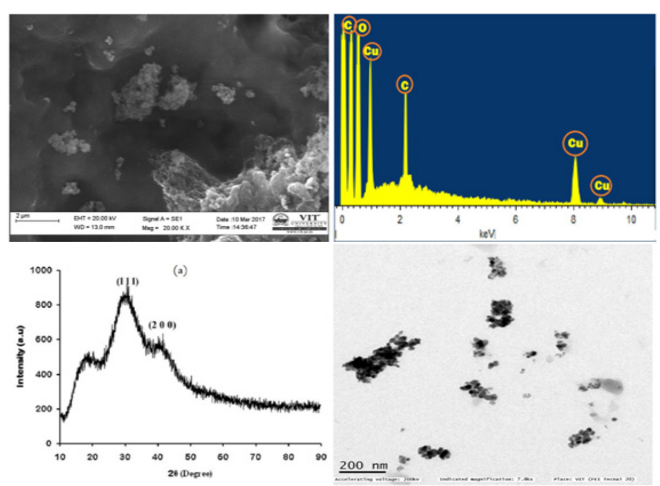

Fig. 6: EDX, SEM, XRD, TEM of copper nanoparticles synthesized using *C. vitiginea* leaf extract (Shuang *et al.*, in 2020)

Table 1: Plants parts used for the preparation of copper nanoparticles

Plant name	*Part used*	*Size (nm)*	*Characterization*	*References*
Tabernaemontana divaricate	Leaf	48	EDX, XRD, FTIR, SEM, TEM	Sivaraj *et al.*, 2014.
Rosa Sahandina	Fruit	<50	FESEM, EDX, XRD, FTIR, SEM, TEM	Saeed *et al.*, 2014.
Malva sylvestris	Leaf	5–30	XRD, FT-IR, TEM, SEM, UV-vis	Awwad *et al.*, 2015.
Calotropis gigantean	Leaf	20	EDX, XRD, FTIR, SEM, TEM	Sharma *et al.*, 2015.
Aloe vera	Leaf	20–30	EDX, XRD, FTIR, SEM, TEM	Vijay Kumar *et al.*, 2015.
Albizia lebbeck	Leaf	<100	UV-vis, XRD, FTIR, SEM	Gokulpriya, *et al.*, 2015.
Rubus glaucus	leaf and fruit	43.3	EDX, XRD, FTIR, SEM, TEM	Kumar *et al.*, 2015.
Punica granatum	Peel extract	40	UV–vis, TGA, SEM, XRD, FTIR, TEM	Ghidan *et al.*, 2016.
Coffea	Whole plant extract	262	XRD, UV-Vis, SEM, FT-IR	Taghavi *et al.*, 2016.
Phaseolus Vulgaris	Whole plant extract	26.6	XPS, DLS, SEM, SAED, TEM, XRD, Raman spectroscopy, FT-IR, and EDX	Bhuvaneshwari *et al.*, 2018.
Ziziphus mauritiana L	Whole plant extract	20–45	XRD, TEM, EDX, SEM	Pansamba *et al.*, 2017.
Syzygium Aromaticum	Bud extract	12	XRD, TEM, FESEM, EDS, and FTIR	Rajesh *et al.*, 2018.
Hibiscus rosasinensis	Flower extract	26.54	UV-vis, XRD, FTIR, SEM	Rajendran *et al.*, 2018.
Ferulago Angulate	Whole plant extract	44	FT-IR, TEM, XRD, SEM	Shayegan *et al.*, 2018.
Zea mays L.	Dry husk extract	36–73	XRD, FTIR, EDX	Chinwe *et al.*, 2019.
Avicennia marona	Leaf		XRD, TEM, EDX, SEM	Essa *et al.*, 2021.

Table 2: Characterization

Method	*Function*
XRD	To assess the size and shape of a unit cell and to determine the crystal structure of an unidentified substance.
SEM	To provide details on the morphology, structure, and properties of the nanomaterial.
TEM	To provide information about 3D orientation of the nanomaterial.
FTIR	To impart information on functional groups.
UV-Vis (λ)	To Identify absorption spectra
Raman spectroscopy	To determine chemical species and molecular structure.
TGA	To assess how physical and chemical qualities alter with passing time or rising temperature
EDX	To identify the elemental composition of materials.
XPS	To determine the energy of electrons released in relation to X-rays of various frequencies, one may establish the elemental composition at a solid surface.

thermogravimetric analyzer (TGA), energy dispersive X-ray analysis (EDX), surface plasmon resonance (SPR), selected area electron diffraction (SAED) and dynamic light scattering (DLS) (Napagoda *et al.*, 2023).

Fungi

Yeast is technically a kind of fungus, which is an umbrella term for all eukaryotic organisms. Additionally, the chitin-containing cell walls of fungi can promote the creation of nanoparticles with a variety of sizes, shapes, and compositions. In order to create nanomaterials from fungi, enzymes and protein residues can produce nanoparticles both intracellularly and extracellularly. Fungi extract without cells act as reducing, catalysing, or capping agents in the biogenic synthesis of nanoparticles. The green chemistry method used by fungi to synthesise nanoparticles has numerous benefits, including the process's simplicity of scaling up, feasibility from an economic standpoint, and the capacity to cover a wide surface area with mycelia grown under the right conditions, among others.

To make copper nanoparticles, mycelial-free water extract was combined with Cu $(NO_3)_2.3H_2O$ salt or copper salt and stirred at 40°C overnight in the dark. This process was then followed by heating the mixture for three hours at a temperature of 75 to 80°C. Change in color of solution indicate the synthesis of copper oxide nanoparticles. Produced nanoparticles were cleaned and investigated for size, shape, texture, crystallinity, purity, functional groups, and using UV-Vis, XRD, XPS, TEM, EXD, and FT-IR (Waris *et al.*, 2021).

Pavani *et al.*, 2013. examine the biogenesis of copper nanoparticles using *Aspergillus species*. The copper nanoparticles were verified to be stable because there was no variation at the highest absorbance. Spectroscopic investigation revealed a maximum peak at 300 nm showing the presence of nanoparticles in broth. Spherical, polydispersed nanoparticles

Table 3: Some other fungal species used for the preparation of copper nanoparticles

Fungal species	*Characterization*	*Size(nm)*	*References*
Rhodotorula Mucilaginosa	SEM, TEM, XPS, EDS	10.5	Salvadori *et al.*, 2014.
B. cinerea	EDX, XRF, SDD, TEM	60-80	Kovačec *et al.*, 2017.
Pleurotus ostreatus	UV-Vis, XRD, TEM, FTIR, DLS	25-36	Ibrahim *et al.*, 2018.

Table 4: Bacteria species used for the preparation of copper nanoparticles

Bacterial Strain	*Gram+/Gram-*	*Characterization*	*Size (nm)*	*Reference*
Serratia	Gram-	UV-vis, XPS, FTIR, TEM, XRD	10–30	Hasan *et al.*, 2008.
Escherichia coli	Gram-	SEM, XRD, FTIR,		Singh *et al.*, 2010.
Morganella Psychrotolerans and *M. morganii RP42*	Gram-	UV-Vis, TEM, XPS, FTIR, XRD	15–20	Ramanathan *et al.*, 2011.
Salmonella typhimurium	Gram-	UV-vis, DLS, SEM	49	Ghorbani *et al.*, 2015.
(Migula)Castellani	Gram-	EM, SEM, XRD, FTIR	100–150	El-Batal *et al.*, 2017.
Shewanella loihica PV-4	Gram-	TEM, EDX, XRD, XPS	6–20	Lv *et al.*, 2018.
Proteus mirabilis	Gram-	UV-vis, XRD, EDX, DLS, TEM	-	Eltarahony *et al.*, 2018.
Chalmer	Gram-	EM, SEM, XRD, FTIR	100–150	Andra *et al.*, 2019.

formed with diameters ranging from 600 to 684 nm was visible on an SEM image.

Consolo *et al.*, 2020. reported CuO nanoparticles from *Trichoderm harzianum*. Thermogravimetric analysis, wide angle X-ray scattering, DLS, and the TEM were used to characterise the NPs' structure, shape, and physicochemical characteristics. This is the first time that this fungus has produced numerous extracellular NPs. NPs may also find significant use in the food, apparel, cosmetics, and pharmaceutical industries. Noor *et al.*, 2020. studied a simple fungus-based synthesis method for the preparation of copper nanoparticles. *Aspergillus niger* strain STA9 was used for CuNPs synthesis. The CuNPs were produced at optimized conditions with a size of 500 nm. Viet *et al.*, 2016, reported procedure for generating copper nanoparticles (Cu Nps) through chemical reduction with the use of the reductive agent CTAB (cetyltrimethylammonium bromide). XRD, FT-IR, TEM, and UV-vis absorption spectra were used to analyze their characteristics. Studies on *Fusarium* sp. allowed researchers to assess the antifungal activity of CuNPs. CuNPs with an average size of 20–50 nm and a spherical form were produced. The studies state that 93.98% of fungal growth was reduced when CuNPs were applied at a concentration of 450 ppm for a 9-day incubation. The more the CuNPs concentration more the inhibition efficiency increases. Cuevas *et al.*, 2015, reported the use of the mycelium-free extract of white-rot fungus *Stereum hirsutum* is an efficient tool for the biosynthesis of copper nanoparticles in the presence of $CuCl_2$ and under neutral or basic conditions. The majority of the nanoparticles (5–20 nm) were spherical and monodispersed, according to TEM examination. The UV-vis spectra demonstrated that the biosynthesized nanoparticles exhibited different oxidation states; therefore, a mixture of zero-valent copper (CuO), cupric oxide (CuO), and cuprous oxide nanoparticles was synthesized by the mycelium-free extract of *S. hirsutum*. Table 3 show different fungi and their species that is used for the synthesis of copper nanoparticles.

Bacteria

Nanoparticle synthesis by bacteria has a very high potential. Bacteria have been used to create amazing nanoscale morphologies via extracellular or intracellular pathways. Various bacteria species used for the preparation of copper nanoparticles are summarised in Table 4. They have benefits including a quick generation time, ease of culture, benign experimental conditions, high stability, extracellular synthesis of nanoparticles, and ease of genetic modification (Murthy *et al.*, 2020). At 28 °C and 150 rpm for 42 hours, the bacterial biomass was exposed to the copper sulphate salt. The created nanoparticles were further cleaned and examined using TEM, SEM, XRD, FTIR, and SAED.

Hassan *et al.*, 2008. gram-negative bacteria used in a reported method of creating copper oxide nanoparticles. The nanoparticles produced by Bacterium serratia sp. are 10–30 nm in size. Varshney *et al.*, in 2010. prepared spherical Cu nanoparticles in nano regime by a novel biological synthesis technique. It is an easy, fast, and cost-effective technique, simple and environmentally benign. *Pseudomonas stutzeri,* a non-pathogenic bacterial strain obtained from soil, is used in production of copper nanoparticles. The size and shape of such copper nanoparticles are determined by UV-vis spectroscopy, XRD, and high-resolution TEM methods According to the research, the particles are spherical and naturally quite stable. Alasvand *et al*. (2016) stated that the *S. indica* strain's extracellular production of polydispersed CuONP was examined. *D. marinisedimins*, the bacteria that cause metal corrosion, can't thrive when these NP are present. UV-vis, XRD, TEM, DLS, and FTIR particle characterization revealed that the particle is polydisperse, with an average size of 400 nm. Parinaz *et al.*, 2020, reported CuONPs by probiotic bacteria (*Lactobacillus casei subsp. casei*) in eco-friendly and cost-effective process. John *et al.*, 2021. reported the use of five Antarctic bacterial strains to produce monodisperse, tiny, and extremely pure bio-CuONPs by reducing $CuSO_4$ in a green manner at low temperatures, such 22°C. These

Table 5: Algae species used for the preparation of copper nanoparticles

Algae	*Size(nm)*	*Characterization*	*References*
Sargassum polycystum	-	TEM, SEM, XRD, FTIR, EDX, UV-Vis	Ramaswamy *et al.*, 2016.
Cystoseira trinodis (Forsskål)C. Agardh	6-7	SEM, XRD, FT- IR, Raman, UV-Vis, EDX, TEM	Gu *et al.*., 2018.
Anabaena cylindrica Lemmermann	3.6	XRD, XPS, EDX	Bhattacharya *et al.*, 2019.

results demonstrated how these CuONPs are especially appealing in a variety of applications, including biomedical science, due to their economical and environmentally favorable biosynthesis. This study demonstrates that the tested Antarctic bacterial strains can be used to produce antibiotics that are effective against a variety of pathogenic Gram-positive and Gram-negative bacteria, as well as fungi like *Candida albicans*, *Staphylococcus aureus*, and *Escherichia coli*, as well as bioremediation to remove copper contamination from the environment.

Algae

Algae are a class of eukaryotic, photosynthetic creatures that are not commonly regarded as plants. The single or multicellular chlorophyll-containing organisms (depending on the species) are able to grow in water, but they lack the real stems, leaves, and vascular structures that distinguish plants from other living things. Various type algae are used for the synthesis of copper oxide nanoparticles such as *Bifurcaria bifurcate, Macrocystis pyrifera, Anabaena cylindrica*, etc. Table 5 shows the characteristics of the synthesised nanoparticles as determined by UV-vis, XRD, SEM, and FTIR.

Abboud *et al.*, 2013. reported brown algae *Bifurcaria bifurcate* in the biogenesis of copper oxide nanoparticles with dimensions 5-45 nm. Castro *et al.*, 2021. demonstrated a method for the environmentally friendly manufacture of copper nanoparticles by employing proteins precipitated from an aqueous extract of the brown alga *Macrocystis pyrifera* as both a capping agent and a reductant. Protein fractions with HMW (high molecular weight) and LMW (low molecular weight) were able to create spherical CuONPs and large proteins. DLS, Z-potential, FTIR, TEM, and EDS detectors were used to assess the characterisation of CuONPs. TEM scans revealed that the observed samples had diameters ranging from 2 to 50 nm. The manufacture of copper and silver nanoparticles using the extract of the green alga *Botryococcus braunii* was reported by Arya *et al.* (2018). According to the XRD pattern the particles were found to be crystalline in nature with a face-centered cubic (FCC) geometry and SEM images of synthetic metal nanoparticles showed their shape. Furthermore, it was found that these biosynthesized nanoparticles posed a serious risk to two strains of gram-negative bacteria, *Pseudomonas aeruginosa* (MTCC 441) and Escherichia coli (MTCC 442), two strains of gram-positive bacteria, *Klebsiella pneumoniae* (MTCC 109) and *Staphylococcus aureus* (MTCC 96), and one strain of fungal, *Fusarium oxysporum* (MTCC 2087).

Rehab *et al.*, 2021, produced copper oxide nanoparticles from the brown alga *Cystoseira myrica*. Human hepatocellular carcinoma (HepG2) and human breast cancer cell line (MCF-7) are two cancer lines in the efficacious doses of copper oxide nanoparticles (25, 50, 75, and 100) g/mL, which were synthesized from the aqueous extract of *C. myrica*, display strong anticancer activity against.

Applications

Due to their use in sensors, solar cells, data storage, heat transfer systems, textiles, water treatment, and surgical tool antimicrobial coating, copper nanoparticles (CuNPs) have attracted interest. This is because they have high electrical conductivity, low electrochemical migration, magnificent solderability, a high melting point, and optical, and catalytic properties. These include fundamental bacterial cell components like DNA, lysosomes, ribosomes, and enzymes, and they cause oxidative stress, heterogeneous alterations, variations in the cell membrane's permeability, problems with the electrolyte balance, an inhibition of enzymes, and changes in gene expression (Kumar *et al.*, 2020; Chandraker *et al.*, 2020). Copper nanoparticles are employed in many different industries because they can be produced more affordably than other noble metal NPs like Pt, Ag and Au. So that it can be used as an efficient antibacterial additive in textile coatings, disinfectants, and in antiseptic creams in areas such as food, medical and cosmetics applications. Biomedical uses for copper oxide nanoparticles include antimicrobial, anti-fouling, antifungal, antibiotics, antioxidants, drug delivery, and anticancer. Other uses for copper oxide nanoparticles are in the textile industry, thermo sensing and conducting materials, gas sensors, catalysis, synthesis of inorganic-organic nano size composites, magneto-resistant materials, and high-temperature (Mathur *et al.*, 2017). Generally, nanoparticles are incorporated in the food packaging system to improve physical and functional properties, transferring the packaging system into improved, active, or intelligent packaging. Different metal and nonmetal nanoparticles have been exploited in the food packaging system; for example, copper, copper oxide, gold, iron, iron oxide, silicon dioxide, silver, titanium dioxide, titanium nitride, zinc oxide, and so on. Many different organic reactions have been catalysed by copper-based nanoparticles. Borylation, oxidative coupling, tandem and multicomponent reactions, reduction and oxidation processes, A3 coupling, cross-coupling, tandem and multicomponent

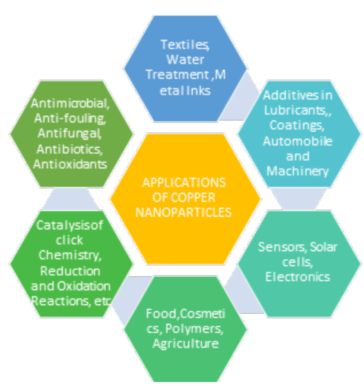

Fig. 7: Applications of copper nanoparticles

reactions, C-H functionalization, clock reactions and other unrelated reactions are all catalyzed by Cu-NP. The applications of nanoparticles are expanding day-by-day, and it is necessary to understand their biocompatibility, biodegradability, and safety. Copper nanoparticles (Cu-NPs) have demonstrated strong antifungal action against phytopathogenic fungi, making them a prospective and cost-effective substitute for traditional fungicides (Guozhong *et al.*, 2004; (Madkou *et al.*, 2022).

In addition to their wide range of uses, copper nanoparticles have demonstrated specialized drug transport properties and very effective photoluminescence properties, make that crucial material for the targeted administration of imaging agents and anti-cancer medications. Nanomaterials can be used as new strategies for cancer therapy (Alizadeh *et al.*, 2021; Fujimori *et al.*, 2012). Copper nanoparticles show antiviral activity, indicating that metal nanoparticles also have potential antiviral properties (Fujimori *et al.*, 2012). reported the Using a plaque titration assay, researchers were able to determine the antiviral capacity of copper iodide particles against the 2009 H1N1 pandemic influenza virus. They observed that the 50% effective concentration was roughly 17 g/mL within a 60-min exposure duration and revealed a dose-dependent activity of viral titer. A further examination revealed that the virus was inactive as a result of copper iodide particles degrading the virus's proteins, hemagglutinin and neuraminidase. This leads to the conclusion that these nanoparticles could be utilised to create filters, face masks, kitchen towels, or other products that guard against viruses.

Copper nanoparticles have also been employed to improve the performance of biodiesel and lower nitrogen oxide emissions in car engines. When using soybean biodiesel (B10) in a diesel engine, copper nanoparticles are used as a fuel additive. Copper nanoparticles reduced the nitrogen oxide emission compared to other formulations particles and exhibits better engine performance. Lubricants, polymers, coatings, metal inks, and other products have begun to incorporate copper nanoparticles as additives, as shown in Fig. 7. We must have an in-depth understanding of how CuNPs have unfavorable effects to accurately assess the risks and then increase their use securely. More work needs to be done into creating methodologies to further comprehend the toxicity brought on by dissolved Cu2+ or CuO nanoparticles (Tamilvanan *et al.*, 2014). It is crucial to alter parameters including size, surface properties, and the discharge of copper ions to lessen toxicity. Other biogenic NPs such as copper oxide NPs zinc oxde NPs, selenium NPs acted as potent anticancer agents (Madkou *et al.*,2022; Murthy *et al.*, 2018). Copper oxide nanoparticles' cytotoxicity was assessed against four cancer cell lines, including the human breast (MCF-7), cervical (HeLa), epithelioma (Hep-2) and lung (A549), as well as one cell line from the normal human dermal fibroblast (NHDF) tissue. Using the Hoechst 33258 staining technique, the morphological changes were assessed. According to Rehana *et al.*, 2017. green method-produced copper oxide nanoparticles were cytotoxic and high in antioxidants.

Conclusion

Over the past decade, a great deal of research has been done on the fast-evolving, emerging, and application potential of nanotechnology. In the quickly developing field of nanotechnology, nanoparticles are at the fore. Due to its numerous uses in antibacterial, antifungal, antiviral, anticancer, antioxidant, drug delivery, and many other fields, copper nanoparticles are receiving a lot of interest. Numerous industries, including catalysis, medicine, water treatment, dye degradation, textile engineering, bioengineering sciences, sensors, imaging, biotechnology, electronics, optics, and other biological sectors, use copper nanoparticles.

- Due to their lower toxicity, biologically produced nanoparticles have been an important advancement over those made chemically. Plants and microbes serve a major role in biological nanotechnology.
- This review highlights the new method or approach for the biological production of copper NPs. We have outlined how copper nanoparticles were created using several biological resources, including plant extract, fungi, algae, and bacteria.
- On a large scale, biological molecules may function as reducing agents, converting copper NPs from copper salt solution.
- Additionally, plants have several special molecules that aid in synthesizing NPs and increase the synthesis rate.

The use of plants, algae, fungi, bacteria, and microorganisms for the green synthesis of nanoparticles is an exciting and developing area of nanotechnology, but there is cause for concern regarding the long-term effects of these on humans and other animals, as well as the accumulation of these in the environment, which must be addressed in the future.

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Author Contribution

Deepak Singh Rajawat and Manisha Singhal are involved in the complete writing of the article. Deepak Singh Rajawat also involved in the overall formatting and editing, critical revision of tables and graphs, and improvement of the article.

Conflict of interest

None

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