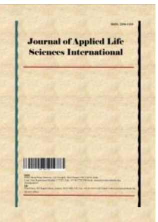

Journal of Applied Life Sciences International

23(7): 10-24, 2020; Article no.JALSI.59435
ISSN: 2394-1103

Green Synthesis of Copper Nanoparticles, Characterization and Their Applications

Swathi Pavithran[1], Manikantan Pappuswamy[1*], Yamuna Annadurai[2], Vijaya Anand Armugam[3] and Thirunavukkarasu Periyaswamy[4]

[1]Department of Life Sciences, CHRIST (Deemed to be) University, Bangalore-560029, Karnataka, India.
[2]Department of Biotechnology, Bharathidasan University, Tiruchirapalli, Tamilnadu, India.
[3]Medical Genetics and Epigenetics Lab, Department of Human Molecular Genetics, Bharathiar University, Coimbatore-641046, Tamilnadu, India.
[4]Department of Microbiology, Karpagam University, Coimbatore-641021, Tamilnadu, India.

Authors' contributions

This work was carried out in collaboration among all authors. Authors SP designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MP and YA managed the analyses of the study. Author VAA managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JALSI/2020/v23i730172
Editor(s):
(1) Dr. Palanisamy Arulselvan, Universiti Putra Malaysia, Malaysia.
Reviewers:
(1) Nabeel A. BaKR, University of Diyala, Iraq.
(2) Jaiber Humberto Rodriguez Llanos, São Paulo University, Brazil.
(3) Mohamed Bechir Ben Hamida, University of Hail, Saudi Arabia.
Complete Peer review History: http://www.sdiarticle4.com/review-history/59435

Received 20 May 2020
Accepted 25 July 2020
Published 05 August 2020

Review Article

ABSTRACT

Nanotechnology is one of the upcoming topics in the present era. Nanoparticles are synthesized by physical and chemical methods but limitations are due to their toxicity. Hence, green synthesis is more on demand which involves the use of plants, bacteria and fungi. In this review, copper nanoparticle synthesis is focused which is economically beneficial and eco-friendly when compared to other metal nanoparticles. Copper nanoparticles are used in diverse fields such as biomedicine, pharmaceuticals, bioremediation, molecular biology, bioengineering, genetic engineering, dye degradation, catalysis, cosmetics and textiles. Structural properties and biological effects of copper nanoparticles have promising affectivity in the field of life sciences. The characterization of biogenic copper nanoparticles by number of analytical tools for their compositional, morphological and topographical features has also been discussed.

**Corresponding author: E-mail: manikantan.p@christuniversity.in, humangentistmani@gmail.com;*

Keywords: Nanoparticle synthesis; copper nanoparticles; green synthesis; antimicrobial activity; anti-cancerous activity; characterization.

ABBREVIATIONS

NP	*: Nanoparticles*
VS	*: Visible spectrophotometry,*
FTIR	*: Fourier transform infrared spectroscopy*
XRD	*: X ray diffraction*
SEM	*: Scanning electron microscope*
TEM	*: Transmission electron microscope*
EDX	*: Energy Dispersive X ray spectroscopy*
AFM	*: Atomic force microscopy*
SPR	*: Surface plasmon resonance*
LSPR	*: Localized surface plasmon resonance*
SEM	*: Scanning electron microscope*

1. BACKGROUND

Nanotechnology is the upcoming and attractive area of research in the field of life science, chemical science, medical science and many more. It deals with the preparation of nanoparticles (NPs) in the range of 10^9 m and having dimensions of 1–100nm [1]. These molecules exhibit unique properties in contrast to particles of bulk materials; such as large surface to volume ratio, shape, small size etc. which eventually provide the NPs with strong surface activity, better catalytic function and easy interaction with other particles. All these are accountable for the multifunctional properties of NPs and their wide scale applications in various fields like drug delivery, dye degradation, wastewater management, molecular diagnosis, treating cancer cells and in therapeutic applications [2-5].

There are two different types of nanoparticles: organic NPs and inorganic NPs. Organic NPs include Poly-L-lysine, quaternary ammonium compounds, cationic quaternary polyelectrolytes, N-halamine compounds, and chitosan. But these are heat labile compounds. This led to the upcoming of inorganic NPs. It includes metal and metal oxides such as gold (Au), silver (Ag), iron oxide (Fe_3O_4), titanium oxide (TiO_2), copper oxide (CuO), and zinc oxide (ZnO) are a few among them [1]. They are more stable than the organic NPs.

NPs are synthesised by physical, chemical and biological methods that are classified into bottom up and top down approaches. To an extent, the synthesis method influences the characteristics of the NPs [6,7]. In top-down approach, the bulk materials are broken down into smaller components by means of external force including mechanical, chemical or other energy source. Ball milling, electrical wire explosion, laser ablation, ion sputtering is few physical methods [8-10]. All these are simple methods but requires expensive equipment, excessive energy consumption and results in imperfection of surface structure. Bottom-up approach has the reverse method where using either chemical or biological synthesis methods, the nanostructures are formed; by stacking atoms, molecule or cluster onto each other. It includes microemulsions, sol gel fabrication, microwave assisted synthesis, biological methods (green synthesis), co-precipitation etc. [11-15]. They have advantages in terms of cost, stability and uniformity. Merits and demerits of top-down and bottom-up methods are well explained in a review on this topic [16].

The bottom-up approach is classified as traditional and green chemical methods [17]. In traditional method synthesis of NPs is carried out by using toxic chemicals as the reducing agent [18,19] and green method by using natural compounds as reducing agents [20,21]. Since green synthesis is eco-friendly, non-toxic and cost effective it's the most widely appreciated and in demand approach. Here, the reducing agents are fungi, bacteria, algae, plants etc [22]. Along with this the up coming's in the field of electron microscopic techniques and other analytical tools enhanced the synthesis and characterisation of NPs.

2. GREEN METHODS OF SYNTHESIS

There are different ways of green synthesis methods to produce NPs exploiting plants, microbes etc. All these methods are considered to be safe and cost effective. The NPs are synthesised by using bacteria, algae, fungi or plant extracts and synthesis via plant extract is most widely studied.

3. PLANT EXTRACT MEDIATED SYNTHESIS

As mentioned above plant extract mediated is widely preferred among all the green synthesis methods. This is because in case of microbe mediated synthesis, initially the microbes have to be isolated, followed by providing them with the appropriate nutrients in culture, sub culturing etc. All these are time consuming. Plant mediated synthesis in contrast can be carried out by either living or dead extracts. Different parts of the plants like stem, leaves, roots, flower etc. can be used [23].

The biomolecules present in the plants such as terpenoids, flavones, ketones, aldehydes, proteins, amino acids, vitamins, alkaloids, tannins, phenolics, saponins, and polysaccharides play a vital role in reduction of metals [24]. Plant biomass are used either in powder form or as extract. They are mixed with desired metal solution. For synthesis of Cu NPs usually copper (II) sulphate pentahydrate ($CuSO_4.5H_20$), cupric acetate (monohydrate) ($CH_3COO)(2Cu{\cdot}H2O$), Copper (II) nitrate (Cu $(NO_3)^2$) etc. are used as common precursor copper salts. In general, the extract is mixed with a solution of metal salt at room temperature and desired pH with or without agitation. In a limited time, the synthesis of NPs will be completed (Fig. 1).

Rajeshkumar et al. synthesised copper NPs using leaf extract of *Cissus arnotiana* and they observed that the synthesised Cu NPs was irregular and spherical in shape with an average size in range of 60-90 nm [25]. Vidovix et al. synthesised Cu nanoparticles using *Punica granatum* leaf extract and resulted in spherical shaped NPs with average diameter 20.33nm [26]. On the other hand, Pawan Kaur et al. synthesised Cu nanoparticles using the peel extract of *Punica granatum* with the particles having size in the range 15-20 nm. The biologically synthesized CuNPs demonstrated high antibacterial activity against opportunistic pathogens, like, *Micrococcus luteus* MTCC 1809, *Pseudomonas aeruginosa* MTCC 424, *Salmonella enterica* MTCC 1253 and *Enterobactor aerogenes* MTCC 2823 *in vitro* [27]. Zangeneh et al. investigated Cu nanoparticles using *Falcaria vulgaris* leaf extract which showed to have potent cytotoxicity, antioxidant, antifungal, antibacterial, and cutaneous wound healing activities under in vitro and *in vivo* condition so, can be used for therapeutic and industrial applications [28]. Some other important results were obtained in biosynthesis of nanoparticles by different plant parts include, *Enicostemma axillare* leaf extract for CuO NPs [29], seedless date extract for Cu/Cu_2O nanoparticle [17] and fruit extract of *Myristica fragrans* for CuO NPS [30].

4. MICROBIAL SYNTHESIS OF NPs

Microbes are used in NPs synthesis due to their ease of handling, simple, cost-effective and no release of harmful compounds to the environment. Also, the biomolecules present not only reduce the metal ions but also stabilize the metal NPs hence preventing them from further oxidation.

The microbial mediated synthesis is classified as intracellular and extracellular synthesis as per the location of the NPs synthesised. In intracellular method, NPs are formed based on the presence of enzymes where ions are transported inside the microbial cell for the formation of nanoparticles. While in extracellular method, metal ions are trapped on the surface of the cells and are reduced to form nanoparticles with the help of enzymes [73]. Under metal stress conditions, microbes follow several mechanisms to eliminate the heavy toxic metals and survive such as an active efflux of metallic ions through the cell membranes, reduction of toxic metals ions to non- toxic ions, and also accumulating the metal ions within the cells. In most of the heavy metals this influx is carried out by ion pumps, carrier mediated transport ion channels or lipid permeation [74].

5. SYNTHESIS BY BACTERIAL STRAINS

The first report of Cu nanoparticles synthesis using thecbacterial strain was from *Pseudomonas stutzeri* isolated from soil. Here the biomolecules present in biomass helped in reduction of the metal ions as well as stabilization preventing the further oxidation [75]. Similarly, another biological method has been reported for the synthesis of copper nanoparticles (Table 1) using *Morganella* bacteria under aqueous physical environment to obtain polydispersed nanoparticles [76]. Cu NPs synthesis was also carried out using bacterial strain *Escherichia* sp. SINT7 which proved to be useful for treatment of textile effluents [77].

6. SYNTHESIS BY FUNGAL STRAINS

Different fungi have been exploited for copper NPs biogenic synthesis as they provide high metal resistance and are easy to handle. They produce variety of extracellular enzymes that plays an important role in biosynthesis of metallic nanoparticles. *Aspergillus niger* was used to synthesise Cu NPs due to its ability to bioaccumulate metals. *A. niger* is a common filamentous fungus with variety of enzymes like oxidative and hydrolytic enzymes, enabling metal ion absorption from aqueous solution [78].

Honary et al. synthesised copper nanoparticles from Penicillium vaksmanii, Penicillium aurantiogriseum, and Penicillium citrinum, segregated from soil, where the monodispersity, pH, and concentration affected their morphology [79]. Filamentous fungi have unique advantage over other microorganisms like bacteria and algae, like high metal tolerance, ability of bioaccumulation, intracellular metal uptake, ability to withstand flow pressure and agitation, ease of downstream processing and so on [80]

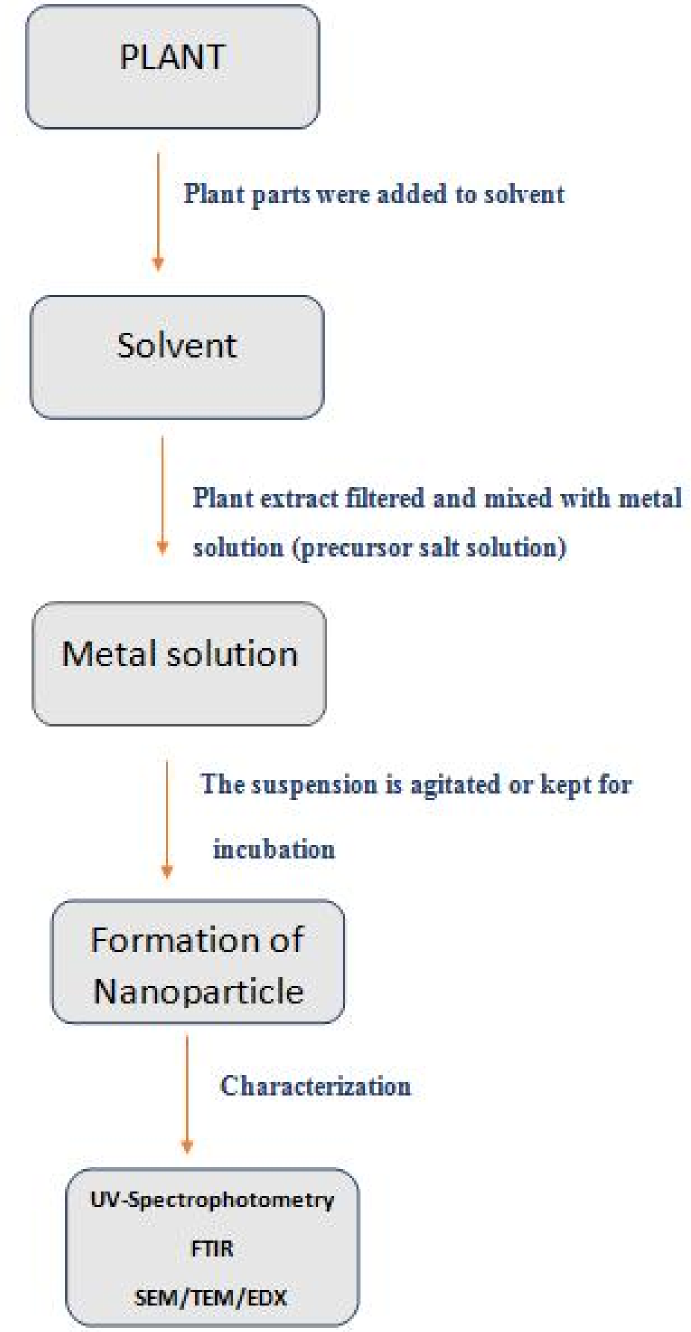

Fig. 1. Experimental protocol for plant-mediated biosynthesis of nanoparticles

Table 1. Green synthesis of copper nanoparticles by different plant species

Plant	Precursor	Size of the nanoparticles	Applications	Reference
Falcaria vulgaris	Copper (II) sulfate ($CuSO_4$)	20-25 nm	Antioxidant, antifungal, antibacterial, and cutaneous wound healing	[28]
Cissus quadrangularis	Copper acetate (Cu ($CH_3COO)_2$)	30-33 nm	Antifungal	[31]
Myristica fragrans	Copper acetate (Cu ($CH_3COO)_2$)	~4 nm	Antimicrobial and catalytic activity	[30]
Ocimum sanctum	Copper (II) sulfate ($CuSO_4$)	55-350 nm	Antibacterial	[32]
Persea americana seeds	Copper (II) sulfate ($CuSO_4$)	40-90 nm	Antimicrobial and antioxidant activities	[33]
Cissus arnotiana	Copper (II) sulfate ($CuSO_4$)	60-90 nm	Antibacterial and antioxidant activities	[25]
Punica granatum	Copper sulfate pentahydrate ($CuSO_4.5H_2O$)	20.33 nm	Contaminated water treatment	[26]
Agaricus bisporus	Copper nitrate ($Cu(NO_3)_2$)	2-10 nm	Antibacterial	[34]
Enicostemma axillare	Copper (II) sulfate ($CuSO_4$)	~6.4 nm		[29]
Impatiens balsamina	Copper (II) sulfate ($CuSO_4$)	5-10 nm	Degradation of toxic textile dyes	[35]
Carica papaya	Copper nitrate ($Cu(NO_3)_2$)	~150 nm	Degradation of chlorpyrifos in water	[36]
Calotropis procera	Cupric acetate ($Cu(CH_3COO)_2$)	~46 nm		[37]
Tamarindus indica	Copper acetate tetrahydrate ($C_4H_{16}CuO_8$)	~12 nm	Antioxidant and anticancer activity	[38]
Morus alba	Copper acetate monohydrate ($Cu(CH_3COO)_2{\cdot}H_2O$)	21–100 nm	Antioxidant	[39]
Capparis spinosa	Copper (II) sulfate ($CuSO_4$)	17-41 nm	Antibacterial activity	[40]
Citrus medica	Copper sulfate ($CuSO_4.5H_2O$)	10-60 nm	Antimicrobial activity	[41]
Murraya koenigii	Copper acetate tetrahydrate ($C_4H_{16}CuO_8$)	~12 nm	Antioxidant and anticancer activity	[38]
Punica granatum peel	Copper (II) sulfate ($CuSO_4$)	15-20 nm	Antimicrobial activity	[27]
Syzygium aromaticum bud	Copper acetate ($Cu(CH_3COO)_2$)	~15 nm	Antimicrobial activity	[42]
Tinospora cordifolia	Copper chloride ($CuCl_2$(II))	50 nm	Catalytic degradation of hazardous dyes	[43]
Aloe vera	Copper nitrate ($Cu(NO_3)_2$)	20-30 nm	Antibacterial activity	[44]
Magnolia kobus	Copper sulfate ($CuSO_4.5H_2O$)	50-250 nm	Antibacterial activity	[45]
Syzygium Cumin	Copper sulfate ($CuSO_4.5H_2O$)		Antimicrobial activity	[46]
Ziziphus spina christi	Copper (II) sulfate ($CuSO_4$)	~9 nm	Antibacterial activity	[47]
Cordia sebestena	Copper (I I) nitrate trihydrate $Cu(NO_3)_2.3H_2O$	25-30 nm	Photodegradation and antibacterial activity	[48]
Prunus domestica	Copper (I I) chloride ($CuCl_2$)	~10 nm	Antimicrobial activity	[49]

Plant	Precursor	Size of the nanoparticles	Applications	Reference
Green and black tea leaves	Copper (II) sulfate ($CuSO_4$)	26-40 nm	Antibacterial, antifungal and aflatoxin B1 adsorption activity	[50]
Quisqualis indica	Copper acetate ($Cu(CH_3COO)_2$)	100 nm	Anti tumour and cytotoxic activities	[51]
Tinospora cordifolia	Copper (I I) nitrate trihydrate $Cu(NO_3)_2.3H_2O$	~6-8 nm	Photocatalytic, antioxidant, antibacterial properties	[52]
Adhatoda vasica	Copper sulfate pentahydrate ($CuSO_4.5H_2O$)	7-11 nm	Antimicrobial activity	[53]
Cynodon dactylon	Copper (II) nitrate trihydrate ($Cu(NO_3)^2 \cdot 3H_2O$)		Antibacterial activity	[54]
Hibiscus cannabinus	Copper (II) nitrate trihydrate ($Cu(NO_3)^2 \cdot 3H_2O$)	350-600 nm	Antibacterial activity	[55]
Green tea leaves	Cupric sulfate ($CuSO_4.5H_2O$)	500-900 nm	Development of latent fingerprints	[56]
Zingiber officinalis	Copper (II) sulfate ($CuSO_4$)	20-100 nm	Antibacterial activity	[57]
Citrofortunella microcarpa	Copper (II) nitrate trihydrate ($Cu(NO_3)^2 \cdot 3H2O$)	54-68 nm	Dye degradation	[58]
Curcuma longa	Copper acetate Dihydrate $Cu(CO_2CH_3)_2 \cdot 2H_2O$	5-20 nm	Antimicrobial activity	[59]
Cynomorium coccineum	Copper (II) sulfate ($CuSO_4$)		Printing cotton and antimicrobial activity	[60]
Cynomorium coccineum	Copper (II) sulfate ($CuSO_4$)	~14.2 nm	Wastewater treatment	[61]
Calotropis gigantea	Cupric nitrate $Cu(NO_3)^2$	~20 nm	Fabrication of Dye sensitized solar cells	[62]
Pogestemon benghalensis	Copper acetate monohydrate ($Cu(CH_3COO)2 \cdot H_2O$)	10-100 nm	Treatment of esophageal cancer	[63]
Euphorbia maculata	Copper (II) sulfate pentahydrate ($CuSO_4 \cdot 5H_2O$	~18 nm	Degradation of organic pollutants	[64]
Ficus carica	Copper (I I) chloride ($CuCl_2$)	60-80 nm	Degradation of toxic organic dye	[65]
Zea mays	Copper (II) acetate monohydrate ($Cu(C_2H_3O_2)_2.H_2O$)	10-26 nm	Industrial textile effluent treatment	[66]
Sugarcane juice	Copper nitrate ($Cu(NO_3)_2$)	~84.4 nm	Antibacterial activity	[67]
Carica papaya	Cupric sulfate ($CuSO_4.5H_2O$)	~140 nm	Photocatalytic dye degradation	[68]
Capparis spinosa	Copper (II) sulfate ($CuSO_4$)	17-41 nm	Antinociceptive effect	[69]
Ficus religiosa	Cupric sulfate ($CuSO_4.5H_2O$)	577 nm	Anticancer activity	[70]
Acalypha indica	Copper (II) sulfate ($CuSO_4$)	26-30 nm	Antimicrobial and anticancer activity	[71]
Ruellia tuberosa	Copper (II) sulfate ($CuSO_4$)	83.23 nm	Antibacterial activity and dye degradation	[72]

7. SYNTHESIS BY ALGAE

Few papers reported synthesis of copper nanoparticles (Table 1) using algae. Algal route provided nontoxic and inexpensive means of nanoparticles formation. One report method used *Anabaena cylindrica* for algal facilitated synthesis, which had an application for drinking water treatment at proposed dose [81]. Brown seaweed *Sargassum polycystum* from marine sources have been used for copper nanoparticle synthesis which showed up an effective antimicrobial and anti-cancerous activities [82].

8. CHARACTERIZATION OF NANOPARTICLES

Nanoparticles are classically characterized by their shape, size, surface area and dispersity nature. The common techniques used for characterizing NPs are: UV-Visible spectrophotometry, Fourier transform infrared spectroscopy (FTIR), X ray diffraction (XRD), scanning electron microscope (SEM), transmission electron microscope (TEM), energy dispersive X ray spectroscopy (EDX) and atomic force microscopy (AFM).

9. VISUAL COLOUR AND UV-VISIBLE ANALYSIS

The formation of metallic NPS from respective metallic salts provide specific peaks at different absorptions which is monitored using UV-Visible spectrophotometry. The characterization of copper nanoparticles begins with visual colour change which works on principle of surface plasmon resonance (SPR). The combined oscillation of the free conduction band electrons which are present in the metal oxides, excited by the incident UV radiation is the reason for surface plasmon absorption [83]. As the size of particles increases, the colour change occurs; from dark to light in case of copper. The varying colour changes are due to LSPR (localized surface plasmon resonance) that NPs exhibit which lies in the visible region of electromagnetic spectrum. Here, a particular portion of wavelength in the visible region will be absorbed while another portion gets reflected and hence the emitted wavelength would reflect its own colour. The UV-Visible spectroscopy measures the absorbance of these colour changes [84]. When fruit juice of *Citrus medica* was mixed with aqueous copper sulphate solution, initial blue colour changed to light yellow and further became colourless which indicated the formation of copper NPs [41].

10. FOURIER TRANSFORM INFRARED SPECTROSCOPY (FTIR)

FTIR is a surface chemical analytical technique that measures the transmittance versus wavenumber of light. The nature of the functional groups and how it helps in bio reduction can be approximately evaluated using FTIR spectroscopy. The FTIR spectrum of newly green synthesised NPs will be compared with existing data to get information of the functional involved in bio reduction. There would be several active agents acting as capping and reduction agents. In case of plants it can be proteins, polysaccharides, terpenoids and flavonoids. The IR peaks were observed at 3480 cm^{-1}, 1725 cm^{-1}, 1590 cm^{-1} and 1300cm^{-1} for the functional groups OH, C=O, C=C and aromatic C-O vibrations respectively for the Cu NPs synthesised from *Plantago asiatica* leaf extract [85]. Similarly peaks at 3400–3500, 1680, 1450, and 1050–1270 cm^{-1} are observed in FTIR spectrum of *Rheum palmatum* root extract that correspond to the free OH in molecule and OH group forming hydrogen bonds, carbonyl group (C=O), stretching C=C aromatic ring, and C–OH stretching vibrations, respectively. This proved that the presence of phenolics in extract are responsible for the reduction of metal ions and nanoparticle formation [86].

11. X-RAY DIFFRACTION (XRD)

The X-ray diffraction (XRD) system is used to analyse the structure of crystalline materials. The energetic X-rays can penetrate deep into the materials and provide information. If the NPs are not crystalline (without clearly defined shape), this technique can't be used to identify sample structure. It's is based on Scherrer's equation that determines the size of crystallites in the form of powder. The equation is as follows:

$$D = \frac{BK\lambda}{\cos\theta}$$

where, D = coherent diffraction domain size, λ = the wavelength of the X-ray source applied, β = the full width at half maxima (rad) (2θ), θ = the Bragg angle and K = the shape constant [87]. Hasheminya et al. reported the XRD pattern showing three characteristic peaks at (111), (200), (220). These characteristic peaks indicated planes of copper NPs with face centred cubic (FCC) structure [88]. From the XRD studies, substituting the values in the equation, Yugandhar et al. found that average size of particles of copper oxide NPs synthesised from fruit extract of *Syzygium alternifolium* was 17.5 nm [89].

12. ELECTRON MICROSCOPE

Scanning electron microscopy (SEM) focuses on the sample's surface and hence gives information about the topography and morphology of the NPs. It produces three dimensional (3D) images. Also, these techniques allow to measure the average size of the particles. Vishveshvar et al. confirmed that CuO NPS synthesised by *Ixiro coccinea* plant leaves had spherical shape with the average size of 300nm that has the tendency to agglomerate [83]. Similarly, Aziz et al. found the CuO NPs synthesised from mint leaves extract to show irregular shapes with variation of size nearly nanosheets shape different from the usual spherical shapes [90].

Transmission electron microscopy (TEM) has greater magnification and resolution than SEM. It gives details about the internal composition, more accurate information about size, shape, crystallography of NPs, but produce flat (2D) images. Naika et. al observed spherical CuO NPs with size in the range 5-10nm in the TEM images after green synthesis of copper NPs with *Gloriosa superba* extract [91]. Similarly, Ismail et al. conducted *Portulaca oleracea* mediated biosynthesis of copper NPs and noticed TEM images at two extract concentration to understand the utility of extract as stabilizing agent. It shows that when the extract concentration increases (from 1mL to 3mL) the size of NPs decreases (from 14nm to about 7-10nm) along with acquiring spherical shaped CuNPs [92]. Energy dispersive X-ray spectroscopy (EDX) is also an analytical technique used for characterization. Here, the property of each element having unique atomic structure making a unique set of peaks on X-ray spectrum which used for analysis. Vijay kumar et al. conducted *Aloe vera* leaf extract mediated biosynthesis of CuO NPs and the EDX analysis revealed the chemical composition of NPs having atomic percent of 54% for copper and 45% for oxygen [44].

13. APPLICATIONS

Due to their unique properties, nanoparticles are widely used in various fields such as agriculture, cosmetic industry, drug delivery, wastewater treatment and dye degradation. Nowadays green synthesised NPs are much preferred in medical based applications. These NPs exhibit high differential uptake efficiency in the target cells over normal cells through preventing them from prematurely interacting with the biological environment, enhanced permeation and retention effect in disease tissues and improving their cellular uptake, resulting in decreased toxicity [93]. One of the major drawbacks of chemotherapy and radiotherapy is that the drugs would kill even the healthy cells along with the cancerous cells. But the nanomedicines don't cause any such harmful effects. Thus, the use of the NPs for cancer treatment is gaining importance in recent years [94]. Nagajyothi et al. synthesised copper NPs using black bean extract and the result proved that CuO NPs can induce apoptosis and supress proliferation of HeLa cells at 0.5 and 1 mg/ml concentrations which was further studied. Thus, it would pave a way for discovery of novel anticancer drug against human cervical carcinoma cells treatment [95] . The copper NPs that were synthesised from *Aspergillus niger* strain STA9 by Noor et al. were found to exhibit an anti-cancerous effect when tested on human hepatocellular carcinoma cell line (Huh-7) and it decreased the cell viability at a concentration of 20 mM. Also, it showed anti-diabetic activity which makes it an effective candidate for further medical applications [78]. Green synthesised CuO NPs also showed their potential against variety of cancer cell lines including prostate cancer cell lines [96], human colon cancer cell lines (HCT-116) [97] and many more.

In addition to this, copper NPs have been found to have a wide range of antimicrobial activity against pathogens [41,42,88]. The mode of action is in different manner such as inactivating the enzymes, generating hydrogen peroxide, membrane damage and binding with DNA molecules of the microbes thus interrupting the double stranded structure are a few to be mentioned. The detailed information is provided in the review article by Avinash P. Ingle [98]. The antimicrobial activity of copper NPs recommended their possible application in food preservation field especially preventing microbial contamination to fresh cut, ready to eat fruits and vegetables [99]. Copper NPs are also used in food processing as well as packing [100].

Wastewater released from the textile industry are detrimental to the aquatic species. The presence of dyes decreases the sunlight penetration and oxygen dissolution in water. So, it has to be properly treated before releasing to water source. Nanoparticles have played an efficient role in degrading the organic dyes used in textile, paper, plastic etc. Sharma et al. synthesised copper NPs from *Tinospora cordifolia* and the catalytic degradation ability of synthesized nanoparticle was studied using various dyes such as reactive dye, direct dye, eosin yellowish and safranin [43] .The CuO NPs also showed degradation of nile blue and reactive yellow 160 as well [101]. Similarly, many more lab scale experiments were carried out proving copper nanoparticles as a potential agent for dye degradation [3,102,103].

14. CONCLUSION

This review is focused mainly on copper nanoparticles, their synthesis and applications. Copper replaced other metal nanoparticles such as silver and gold which was in great demand due to its ease of availability and low cost. Green synthesis was more focused as its more reliable, eco-friendly and easier when compared to the conventional methods. A huge variety of plants and peel extracts have been successfully used for green synthesis. The bioactive compounds were responsible for both reduction as well as stabilization of copper NPs. Thus, formed NPs were then characterised using several analytical tools- UV-Visible spectroscopy, SEM, TEM etc. All these synthesised NPs are said to have potential applications in various fields which opens up a new future for nanotechnology.

AVAILABILITY OF DATA AND MATERIALS

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

ACKNOWLEDGEMENTS

We would like to thank Fr. Jobi Xavier, Head of the Department of Lifesciences, Christ (Deemed to be University), Bangalore, Karnataka, India for providing us the with the opportunity and requirements needed for the accomplishment of the research project.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Lewis Oscar F, Vismaya S, Arunkumar M, Thajuddin N, Dhanasekaran D, Nithya C. Algal Nanoparticles: Synthesis and Biotechnological Potentials. In: Thajuddin N, Dhanasekaran D, editors. Algae - Organisms for Imminent Biotechnology [Internet]. InTech; 2016. [cited 2020 Jun 14]. Available:http://www.intechopen.com/books/algae-organisms-for-imminent-biotechnology/algal-nanoparticles-synthesis-and-biotechnological-potentials
2. TCP, Sharma SK, Kennedy M. Nanoparticles in household level water treatment: An overview. Separation and Purification Technology. 2018;199:260–70.
3. Mohamed Bechir Ben Hamida, Jalel Belghaieb, Nejib Hajji. Heat and mass transfer enhancement for falling film absorption process in vertical plate absorber by adding Copper nanoparticles, Arabian Journal for Science and Engineering. 2018;43(9):4991-5001. https://doi.org/10.1007/s13369-018-3252-9
4. Ben Hamida MB, Belghaieb J, Hajji N. Numerical study of heat and mass transfer enhancement for bubble absorption process of ammonia-water mixture without and with nanofluids. Thermal Science. 2018;22(6):3107-3120.
5. Paper 3: Massoudi MD, Ben Hamida MB, Mohammed HA, Almeshaal MA. MHD Heat Transfer in W-Shaped Inclined Cavity Containing a Porous Medium Saturated with Ag/Al2O3 Hybrid Nanofluid in the Presence of Uniform Heat Generation/ Absorption. Energies. 2020;13(13):3457.
6. Sajid M, Płotka-Wasylka J. Nanoparticles: Synthesis, characteristics, and applications in analytical and other sciences. Microchemical Journal. 2020;154:104623.
7. Jabli M, Al-Ghamdi YO, Sebeia N, Almalki SG, Alturaiki W, Khaled JM, et al. Green synthesis of colloid metal oxide nanoparticles using Cynomorium coccineum: Application for printing cotton and evaluation of the antimicrobial activities. Materials Chemistry and Physics. 2020;249:123171.
8. Alshammari A, Kalevaru VN, Martin A. Metal Nanoparticles as Emerging Green Catalysts. In: Larramendy ML, Soloneski S, editors. Green Nanotechnology - Overview and Further Prospects [Internet]. InTech; 2016.

[Cited 2020 Jun 14]
Available:http://www.intechopen.com/books/green-nanotechnology-overview-and-further-prospects/metal-nanoparticles-as-emerging-green-catalysts

9. Abdolhoseinzadeh A, Sheibani S. Enhanced photocatalytic performance of Cu_2O nano-photocatalyst powder modified by ball milling and ZnO. Advanced Powder Technology. 2020; 31(1):40–50.
10. Lozhkomoev AS, Kazantsev SO, Pervikov AV, Fomenko AN, Gotman I. New approach to production of antimicrobial Al2O3-Ag nanocomposites by electrical explosion of two wires. Materials Research Bulletin. 2019;119:110545.
11. Blosi M, Albonetti S, Dondi M, Martelli C, Baldi G. Microwave-assisted polyol synthesis of Cu nanoparticles. J Nanopart Res. 2011;13(1):127–38.
12. Khodashenas B, Ghorbani HR. Synthesis of copper nanoparticles : An overview of the various methods. Korean J Chem Eng. 2014;31(7):1105–9.
13. Mohamed Bechir Ben Hamida, Charrada K. Natural Convection Heat Transfer in an Enclosure Filled with an Ethylene Glycol-Copper Nanofluid Under Magnetic Fields, Numerical Heat Transfer, Part A: Applications: An International Journal of Computation and Methodology, 2014;67: 902–920.
14. Ahmed Kadhim Hussein MAY. Bakier Mohamed Bechir Ben Hamida, Sivasankaran S. Magneto-hydrodynamic natural convection in an inclined T-shaped enclosure for different nanofluids and subjected to a uniform heat source, Alexandria Engineering Journal, 2016;55: 2157-2169.
15. Paper 10: Mohamed Bechir Ben Hamida and Charrada K. Heat generation/ absorption effect on natural convection heat transfer in a square enclosure filled with a ethylene glycol - copper nanofluid under magnetic field. American Journal of Modern Energy, 2015; 1 (1):1-16.
16. Biswas A, Bayer IS, Biris AS, Wang T, Dervishi E, Faupel F. Advances in top–down and bottom–up surface nanofabrication: Techniques, applications & future prospects. Advances in Colloid and Interface Science. 2012;170(1–2):2–27.
17. Mohamed EA. Green synthesis of copper & copper oxide nanoparticles using the extract of seedless dates. Heliyon. 2020; 6(1):03123.
18. Liu Q, Zhou D, Yamamoto Y, Ichino R, Okido M. Preparation of Cu nanoparticles with NaBH4 by aqueous reduction method. Transactions of Nonferrous Metals Society of China. 2012;22(1):117–23.
19. Begletsova N, Selifonova E, Chumakov A, Al-Alwani A, Zakharevich A, Chernova R, et al. Chemical synthesis of copper nanoparticles in aqueous solutions in the presence of anionic surfactant sodium dodecyl sulfate. Colloids and Surfaces A: Physicochemical and Engineering Aspects. 2018;552:75–80.
20. Seetha J, Mallavarapu U mahesh, Akepogu P, Mesa A, Gollapudi VR, Natarajan H, et al. Biosynthesis and study of bimetallic copper and silver nanoparticles on cellulose cotton fabrics using *Moringa oliefiera* leaf extraction as reductant. Inorganic and Nano-Metal Chemistry. 2020;10:1–8.
21. Thiruvengadam M, Chung I-M, Gomathi T, Ansari MA, Gopiesh Khanna V, Babu V, et al. Synthesis, characterization and pharmacological potential of green synthesized copper nanoparticles. Bioprocess Biosyst Eng. 2019;42(11): 1769–77.
22. Nayantara Kaur P. Biosynthesis of nanoparticles using eco-friendly factories and their role in plant pathogenicity: a review. Biotechnology Research and Innovation. 2018;2(1):63–73.
23. Chandra H, Kumari P, Bontempi E, Yadav S. Medicinal plants: Treasure trove for green synthesis of metallic nanoparticles and their biomedical applications. Biocatalysis and Agricultural Biotechnology. 2020;24:101518.
24. Nath D, Banerjee P. Green nanotechnology – A new hope for medical biology. Environmental Toxicology and Pharmacology. 2013;36(3):997–1014.
25. Rajeshkumar S, Menon S, Venkat Kumar S, Tambuwala MM, Bakshi HA, Mehta M, et al. Antibacterial and antioxidant potential of biosynthesized copper nanoparticles mediated through *Cissus arnotiana* plant extract. Journal of Photochemistry and Photobiology B: Biology. 2019;197:111531.
26. Vidovix TB, Quesada HB, Januário EFD, Bergamasco R, Vieira AMS. Green synthesis of copper oxide nanoparticles using *Punica granatum* leaf extract applied

to the removal of methylene blue. Materials Letters. 2019;257:126685.

27. Kaur P, Thakur R, Chaudhury A. Biogenesis of copper nanoparticles using peel extract of *Punica granatum* and their antimicrobial activity against opportunistic pathogens. Green Chemistry Letters and Reviews. 2016;9(1):33–8.
28. Zangeneh MM, Ghaneialvar H, Akbaribazm M, Ghanimatdan M, Abbasi N, Goorani S, et al. Novel synthesis of *Falcaria vulgaris* leaf extract conjugated copper nanoparticles with potent cytotoxicity, antioxidant, antifungal, antibacterial, and cutaneous wound healing activities under in vitro and in vivo condition. Journal of Photochemistry and Photobiology B: Biology. 2019;197: 111556.
29. Chand Mali S, Raj S, Trivedi R. Biosynthesis of copper oxide nanoparticles using *Enicostemma axillare* (Lam.) leaf extract. Biochemistry and Biophysics Reports. 2019;20:100699.
30. Sasidharan D, Namitha TR, Johnson SP, Jose V, Mathew P. Synthesis of silver and copper oxide nanoparticles using *Myristica fragrans* fruit extract: Antimicrobial and catalytic applications. Sustainable Chemistry and Pharmacy. 2020;16: 100255.
31. Devipriya D, Roopan SM. Cissus quadrangularis mediated ecofriendly synthesis of copper oxide nanoparticles and its antifungal studies against *Aspergillus niger*, *Aspergillus flavus*. Materials Science and Engineering: C. 2017;80:38–44.
32. Patel BH, Channiwala MZ, Chaudhari SB, Mandot AA. Biosynthesis of copper nanoparticles; its characterization and efficacy against human pathogenic bacterium. Journal of Environmental Chemical Engineering. 2016;4(2):2163–9.
33. Rajeshkumar S, Rinitha G. Nanostructural characterization of antimicrobial and antioxidant copper nanoparticles synthesized using novel *Persea americana* seeds. OpenNano. 2018;3:18–27.
34. Sriramulu M, Shanmugam S, Ponnusamy VK. Agaricus bisporus mediated biosynthesis of copper nanoparticles and its biological effects: An *In-vitro* study. Colloid and Interface Science Communications. 2020;35: 100254.
35. Roy K, Ghosh CK, Sarkar CK. Degradation of toxic textile dyes and detection of hazardous Hg 2+ by low-cost bioengineered copper nanoparticles synthesized using Impatiens balsamina leaf extract. Materials Research Bulletin. 2017;94:257–62.
36. Rosbero TMS, Camacho DH. Green preparation and characterization of tentacle-like silver/copper nanoparticles for catalytic degradation of toxic chlorpyrifos in water. Journal of Environmental Chemical Engineering. 2017;5(3):2524–32.
37. Reddy KR. Green synthesis, morphological and optical studies of CuO nanoparticles. Journal of Molecular Structure. 2017;1150: 553–7.
38. Rehana D, Mahendiran D, Kumar RS, Rahiman AK. Evaluation of antioxidant and anticancer activity of copper oxide nanoparticles synthesized using medicinally important plant extracts. Biomedicine & Pharmacotherapy. 2017;89: 1067–77.
39. Singh A, Singh NB, Hussain I, Singh H. Effect of biologically synthesized copper oxide nanoparticles on metabolism and antioxidant activity to the crop plants *Solanum lycopersicum* and *Brassica oleracea* var. botrytis. Journal of Biotechnology. 2017;262:11–27.
40. Shiravand S, Mahmoudvand H, Ebrahimi K. Biosynthesis of copper nanoparticles using aqueous extract of *Capparis spinosa* fruit and investigation of its antibacterial activity. mpj. 2017;21(4): 866–71.
41. Shende S, Ingle AP, Gade A, Rai M. Green synthesis of copper nanoparticles by *Citrus medica* Linn. (Idilimbu) juice and its antimicrobial activity. World J Microbiol Biotechnol. 2015;31(6):865–73.
42. Rajesh KM, Ajitha B, Reddy YAK, Suneetha Y, Reddy PS. Assisted green synthesis of copper nanoparticles using *Syzygium aromaticum* bud extract: Physical, optical and antimicrobial properties. Optik. 2018;154:593–600.
43. Sharma P, Pant S, Poonia P, Kumari S, Dave V, Sharma S. Green Synthesis of Colloidal Copper Nanoparticles Capped with *Tinospora cordifolia* and its application in catalytic degradation in textile dye: An ecologically sound approach. J Inorg Organomet Polym. 2018;28(6):2463–72.
44. Kumar PPNV, Shameem U, Kollu P, Kalyani RL, Pammi SVN. Green

Synthesis of Copper Oxide Nanoparticles Using Aloe vera Leaf Extract and Its Antibacterial Activity Against Fish Bacterial Pathogens. BioNanoSci. 2015;5(3):135–9.

45. Lee H-J, Song JY, Kim BS. Biological synthesis of copper nanoparticles using *Magnolia kobus* leaf extract and their antibacterial activity: Biological synthesis of copper nanoparticles using *Magnolia kobus* leaf extract. J Chem Technol Biotechnol; 2013.
46. AHER HR. Green synthesis of copper nanoparticles using syzygium cumin, leaf extract, characterization and antimicrobial activity. Chem Sci Trans [Internet]. 2019; 8(1).
[Cited 2020 Jun 14]
Available:http://www.e-journals.in/abstract.asp?Totarticle=1552
47. Khani R, Roostaei B, Bagherzade G, Moudi M. Green synthesis of copper nanoparticles by fruit extract of *Ziziphus spina-christi* (L.) Willd.: Application for adsorption of triphenylmethane dye and antibacterial assay. Journal of Molecular Liquids. 2018;255: 541–9.
48. Prakash S, Elavarasan N, Venkatesan A, Subashini K, Sowndharya M, Sujatha V. Green synthesis of copper oxide nanoparticles and its effective applications in Biginelli reaction, BTB photodegradation and antibacterial activity. Advanced Powder Technology. 2018;9(12):3315–26.
49. Tovar-Corona A, Lobo-Sánchez MA, Herrera-Perez JL, Zanella R, Rodriguez-Mora JI, Vázquez-Cuchillo O. Green synthesis of copper (0) nanoparticles with cyanidine-O-3-glucoside and its strong antimicrobial activity. Materials Letters. 2018;211:266–9.
50. Muhammad Asif Asghar, Erum Zahir, Syed Muhammad Shahid, Muhammad Naseem Khan, Muhammad Arif Asghar, Javed Iqbal, et al. Iron, copper and silver nanoparticles: Green synthesis using green and black tea leaves extracts and evaluation of antibacterial, antifungal and aflatoxin B1 adsorption activity. LWT. 2018;90:98–107.
51. Mukhopadhyay R, Kazi J, Debnath MC. Synthesis and characterization of copper nanoparticles stabilized with Q*uisqualis indica* extract: Evaluation of its cytotoxicity and apoptosis in B16F10 melanoma cells. Biomedicine & Pharmacotherapy. 2018;97: 1373–85.
52. Udayabhanu, Nethravathi PC, Pavan Kumar MA, Suresh D, Lingaraju K, Rajanaika H, et al. *Tinospora cordifolia* mediated facile green synthesis of cupric oxide nanoparticles and their photocatalytic, antioxidant and antibacterial properties. Materials Science in Semiconductor Processing. 2015;33:81–8.
53. Bhavyasree PG, Xavier TS. Green synthesis of Copper Oxide/Carbon nanocomposites using the leaf extract of *Adhatoda vasica* Nees, their characterization and antimicrobial activity. Heliyon. 2020;6(2):03323.
54. Suresh S, Ilakiya R, Kalaiyan G, Thambidurai S, Kannan P, Prabu KM, et al. Green synthesis of copper oxide nanostructures using *Cynodon dactylon* and *Cyperus rotundus* grass extracts for antibacterial applications. Ceramics International. 2020;46(8):12525–37.
55. Kalaiyan G, Suresh S, Thambidurai S, Prabu KM, Kumar SK, Pugazhenthiran N, et al. Green synthesis of hierarchical copper oxide microleaf bundles using *Hibiscus cannabinus* leaf extract for antibacterial application. Journal of Molecular Structure. 2020;1217:128379.
56. Bhagat DS, Suryawanshi IV, Gurnule WB, Sawant SS, Chavan PB. Greener synthesis of CuO nanoparticles for enhanced development of latent fingerprints. Materials Today: Proceedings. 2020;2214785320339365.
57. Varghese B, Kurian M, Krishna S, Athira TS. Biochemical synthesis of copper nanoparticles using *Zingiber officinalis* and *Curcuma longa*: Characterization and antibacterial activity study. Materials Today: Proceedings. 2020;25:302–6.
58. Rafique M, Shafiq F, Ali Gillani SS, Shakil M, Tahir MB, Sadaf I. Eco-friendly green and biosynthesis of copper oxide nanoparticles using *Citrofortunella microcarpa* leaves extract for efficient photocatalytic degradation of Rhodamin B dye form textile wastewater. Optik. 2020; 208:164053.
59. Jayarambabu N, Akshaykranth A, Venkatappa Rao T, Venkateswara Rao K, Rakesh Kumar R. Green synthesis of Cu nanoparticles using *Curcuma longa* extract and their application in antimicrobial activity. Materials Letters. 2020;259: 126813.
60. Jabli M, Al-Ghamdi YO, Sebeia N, Almalki SG, Alturaiki W, Khaled JM, et al.

Green synthesis of colloid metal oxide nanoparticles using *Cynomorium coccineum*: Application for printing cotton and evaluation of the antimicrobial activities. Materials Chemistry and Physics. 2020;249:123171.

61. Sebeia N, Jabli M, Ghith A. Biological synthesis of copper nanoparticles, using *Nerium oleander* leaves extract: Characterization and study of their interaction with organic dyes. Inorganic Chemistry Communications. 2019;105:36–46.
62. Sharma JK, Akhtar MS, Ameen S, Srivastava P, Singh G. Green synthesis of CuO nanoparticles with leaf extract of *Calotropis gigantea* and its dye-sensitized solar cells applications. Journal of Alloys and Compounds. 2015;632:321–5.
63. Zou X, Cheng S, You B, Yang C. Bio-mediated synthesis of copper oxide nanoparticles using Pogestemon benghalensis extract for treatment of the esophageal cancer in nursing care. Journal of Drug Delivery Science and Technology. 2020;58:101759.
64. Pakzad K, Alinezhad H, Nasrollahzadeh M. Green synthesis of Ni@Fe_3O_4 and CuO nanoparticles using *Euphorbia maculata* extract as photocatalysts for the degradation of organic pollutants under UV-irradiation. Ceramics International. 2019;45(14):17173–82.
65. Usman M, Ahmed A, Yu B, Peng Q, Shen Y, Cong H. Photocatalytic potential of bio-engineered copper nanoparticles synthesized from *Ficus carica* extract for the degradation of toxic organic dye from waste water: Growth mechanism and study of parameter affecting the degradation performance. Materials Research Bulletin. 2019;120:110583.
66. Nwanya AC, Razanamahandry LC, Bashir AKH, Ikpo CO, Nwanya SC, Botha S, et al. Industrial textile effluent treatment and antibacterial effectiveness of Zea mays L. Dry husk mediated bio-synthesized copper oxide nanoparticles. Journal of Hazardous Materials. 2019;375: 281–9.
67. Angeline Mary AP, Thaminum Ansari A, Subramanian R. Sugarcane juice mediated synthesis of copper oxide nanoparticles, characterization and their antibacterial activity. Journal of King Saud University - Science. 2019;31(4):1103–14.
68. Sankar R, Manikandan P, Malarvizhi V, Fathima T, Shivashangari KS, Ravikumar V. Green synthesis of colloidal copper oxide nanoparticles using *Carica papaya* and its application in photocatalytic dye degradation. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy. 2014;121:746–50.
69. Mahmoudvand H, Khaksarian M, Ebrahimi K, Shiravand S, Jahanbakhsh S, Niazi M, et al. Antinociceptive effects of green synthesized copper nanoparticles alone or in combination with morphine. Annals of Medicine and Surgery. 2020;51: 31–6.
70. Sankar R, Maheswari R, Karthik S, Shivashangari KS, Ravikumar V. Anticancer activity of *Ficus religiosa* engineered copper oxide nanoparticles. Materials Science and Engineering: C. 2014;44:234–9.
71. Sivaraj R, Rahman PKSM, Rajiv P, Narendhran S, Venckatesh R. Biosynthesis and characterization of *Acalypha indica* mediated copper oxide nanoparticles and evaluation of its antimicrobial and anticancer activity. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy. 2014;129: 255–8.
72. Vasantharaj S, Sathiyavimal S, Saravanan M, Senthilkumar P, Gnanasekaran K, Shanmugavel M, et al. Synthesis of ecofriendly copper oxide nanoparticles for fabrication over textile fabrics: Characterization of antibacterial activity and dye degradation potential. Journal of Photochemistry and Photobiology B: Biology. 2019;191:143–9.
73. Salunke BK, Sawant SS, Lee S-I, Kim BS. Microorganisms as efficient biosystem for the synthesis of metal nanoparticles: current scenario and future possibilities. World J Microbiol Biotechnol. 2016;32(5): 88.
74. Issazadeh K, Jahanpour N, Pourghorbanali F, Raeisi G, Faekhondeh J. Heavy metals resistance by bacterial strains. 2013;4.
75. Varshney R, Bhadauria S, Gaur MS, Pasricha R. Characterization of copper nanoparticles synthesized by a novel microbiological method. JOM. 2010;62(12): 102–4.
76. Din MI, Rehan R. Synthesis, Characterization, and Applications of

Copper Nanoparticles. Analytical Letters. 2017;50(1):50–62.

77. Noman M, Shahid M, Ahmed T, Niazi MBK, Hussain S, Song F, et al. Use of biogenic copper nanoparticles synthesized from a native Escherichia sp. as photocatalysts for azo dye degradation and treatment of textile effluents. Environmental Pollution. 2020 ;257: 113514.
78. Noor S, Shah Z, Javed A, Ali A, Hussain SB, Zafar S, et al. A fungal based synthesis method for copper nanoparticles with the determination of anticancer, antidiabetic and antibacterial activities. Journal of Microbiological Methods. 2020; 174:105966.
79. Honary S, Barabadi H, Gharaei E, Naghibi F. Green synthesis of copper oxide nanoparticles using *Penicillium aurantiogriseum, Penicillium citrinum and Penicillium waksmanii*. 2012;7.
80. Salvadori MR, Ando RA, Oller Do Nascimento CA, Corrêa B. Bioremediation from wastewater and extracellular synthesis of copper nanoparticles by the fungus *Trichoderma koningiopsis*. Journal of Environmental Science and Health, Part A. 2014;49(11):1286–95.
81. Bhattacharya P, Swarnakar S, Ghosh S, Majumdar S, Banerjee S. Disinfection of drinking water via algae mediated green synthesized copper oxide nanoparticles and its toxicity evaluation. Journal of Environmental Chemical Engineering. 2019;7(1):102867.
82. Ramaswamy SVP, Narendhran S, Sivaraj R. Potentiating effect of ecofriendly synthesis of copper oxide nanoparticles using brown alga: Antimicrobial and anticancer activities. Bull Mater Sci. 2016; 39(2):361–4.
83. Vishveshvar K, Aravind Krishnan MV, Haribabu K, Vishnuprasad S. Green Synthesis of Copper Oxide Nanoparticles Using *Ixiro coccinea* Plant Leaves and its Characterization. BioNanoSci. 2018;8(2): 554–8.
84. Sun L, Chen P, Lin L. Enhanced Molecular Spectroscopy via Localized Surface Plasmon Resonance. In: Stauffer MT, editor. Applications of Molecular Spectroscopy to Current Research in the Chemical and Biological Sciences [Internet]. InTech; 2016.
[Cited 2020 Jun 14].
Available:http://www.intechopen.com/books/applications-of-molecular-spectroscopy-to-current-research-in-the-chemical-and-biological-sciences/enhanced-molecular-spectroscopy-via-localized-surface-plasmon-resonance
85. Nasrollahzadeh M, Momeni SS, Sajadi SM. Green synthesis of copper nanoparticles using *Plantago asiatica* leaf extract and their application for the cyanation of aldehydes using K4Fe(CN)6. Journal of Colloid and Interface Science. 2017;506:471–7.
86. Bordbar M, Sharifi-Zarchi Z, Khodadadi B. Green synthesis of copper oxide nanoparticles/clinoptilolite using Rheum palmatum L. root extract: High catalytic activity for reduction of 4-nitro phenol, rhodamine B, and methylene blue. J Sol-Gel Sci Technol. 2017;81(3):724–33.
87. Hargreaves JSJ. Some considerations related to the use of the Scherrer equation in powder X-ray diffraction as applied to heterogeneous catalysts. Catalysis, Structure & Reactivity. 2016;2(1–4):33–7.
88. Hasheminya S-M, Dehghannya J. Green synthesis and characterization of copper nanoparticles using *Eryngium caucasicum* Trautv aqueous extracts and its antioxidant and antimicrobial properties. Particulate Science and Technology. 2019;1–8.
89. Yugandhar P, Vasavi T, Jayavardhana Rao Y, Uma Maheswari Devi P, Narasimha G, Savithramma N. Cost Effective, Green Synthesis of Copper Oxide Nanoparticles Using Fruit Extract of *Syzygium alternifolium* (Wt.) Walp., Characterization and Evaluation of Antiviral Activity. J Clust Sci. 2018;29(4):743–55.
90. Wisam J. Aziz, Muslim A. Abid, Emad H. Hussein. Biosynthesis of CuO nanoparticles and synergistic antibacterial activity using mint leaf extract. Materials Technology. 2020;35(8):447–51.
91. Naika HR, Lingaraju K, Manjunath K, Kumar D, Nagaraju G, Suresh D, et al. Green synthesis of CuO nanoparticles using *Gloriosa superba* L. extract and their antibacterial activity. Journal of Taibah University for Science. 2015;9(1):7–12.
92. Ismail MIM. Green synthesis and characterizations of copper nanoparticles. Materials Chemistry and Physics. 2020; 240:122283.
93. Wang S, Su R, Nie S, Sun M, Zhang J, Wu D, et al. Application of nanotechnology in improving bioavailability and bioactivity

of diet-derived phytochemicals. The Journal of Nutritional Biochemistry. 2014; 25(4):363–76.

94. Bhatia S. Nanoparticles types, classification, characterization, fabrication methods and drug delivery applications. In: Natural Polymer Drug Delivery Systems [Internet]. Cham: Springer International Publishing. 2016;33–93. [cited 2020 Jun 14]. Available:http://link.springer.com/10.1007/978-3-319-41129-3_2
95. Nagajyothi PC, Muthuraman P, Sreekanth TVM, Kim DH, Shim J. Green synthesis: In-vitro anticancer activity of copper oxide nanoparticles against human cervical carcinoma cells. Arabian Journal of Chemistry. 2017 Feb;10(2):215–25.
96. Prasad PR, Kanchi S, Naidoo EB. *In-vitro* evaluation of copper nanoparticles cytotoxicity on prostate cancer cell lines and their antioxidant, sensing and catalytic activity: One-pot green approach. Journal of Photochemistry and Photobiology B: Biology. 2016;161:375–82.
97. Gnanavel V, Palanichamy V, Roopan SM. Biosynthesis and characterization of copper oxide nanoparticles and its anticancer activity on human colon cancer cell lines (HCT-116). Journal of Photochemistry and Photobiology B: Biology. 2017;171:133–8.
98. Ingle AP, Duran N, Rai M. Bioactivity, mechanism of action, and cytotoxicity of copper-based nanoparticles: A review. Appl Microbiol Biotechnol. 2014;98(3): 1001–9.
99. Saravanakumar K, Sathiyaseelan A, Mariadoss AVA, Xiaowen H, Wang M-H. Physical and bioactivities of biopolymeric films incorporated with cellulose, sodium alginate and copper oxide nanoparticles for food packaging application. International Journal of Biological Macromolecules. 2020;153:207–14.
100. Copper nanoparticles could protect food from bacteria [Internet]. Science Daily; 2013. Available:https://www.sciencedaily.com/releases/2013/07/130724101546.htm. Accessed 14 June 2020.
101. Singh J, Kumar V, Kim K-H, Rawat M. Biogenic synthesis of copper oxide nanoparticles using plant extract and its prodigious potential for photocatalytic degradation of dyes. Environmental Research. 2019;177:108569.
102. Sinha T, Ahmaruzzaman M. Green synthesis of copper nanoparticles for the efficient removal (degradation) of dye from aqueous phase. Environ Sci Pollut Res. 2015;22(24):20092–100.
103. Sebeia N, Jabli M, Ghith A, Saleh TA. Eco-friendly synthesis of Cynomorium coccineum extract for controlled production of copper nanoparticles for sorption of methylene blue dye. Arabian Journal of Chemistry. 2020;13(2): 4263–74.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/59435