GREEN SYNTHESIS AND CHARACTERIZATION OF SILVER/SILVER OXIDE NANOPARTICLES USING AQUEOUS LEAVES EXTRACT OF ARTEMISIA HERBA-ALBA AS REDUCING AND CAPPING AGENTS

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Artemisia herba-alba is a medicinal plant, and its essential oil is used as an antiseptic and antispasmodic. In this study, green synthesis of silver/silver oxide (Ag/Ag₂O) nanoparticles was successfully synthesized from Artemisia Herba-Alba aqueous leaves extract. The effect of temperature, reaction time, the concentration of AgNO₃, the quantity of plant extract, and pH on the synthesis process of Ag/Ag₂O was optimized. More interesting, the results showed that only 5 min were required for reducing 1 mM AgNO₃ into Ag/Ag₂O NPs at room temperature. The crystalline nature of Ag/Ag₂O NPs with an average crystallize size of 10.7-36.8 nm. The green synthesizing Ag/Ag₂O NPs having in general a spherical morphology with particle/aggregate size less than 100 nm. The maximum UV-Vis absorption peak of Ag/Ag₂O NPs was observed at the range of 418- 435 nm giving optical band gaps of 2.05-2.30 eV. The TGA/DTA analysis shows significant organic contents (18 wt%) were physically and chemically adsorbed on the dry weight Ag/Ag₂O NPs. Artemisia herba-alba is a source of phytochemicals for effective and prompt fabrication of Ag/Ag₂O NPs with relevant insecticidal and anti-bactericidal activity against species of high public health importance.

Keywords: silver /silver oxide nanoparticles; Artemisia Herba-Alba; Silver nitrate AgNO3; Green Synthesis, XRD

1. Introduction

Green synthesis has as of late become a typical methodology for the development of nanoparticles (NPs) [1]. Green synthesis method utilized (biosynthesis) for getting nanoparticles through normally happening reagents like vitamins, sugars, plant extracts, biodegradable polymers, and microorganisms as reducing and capping agents [2]. However, the tweaking of the last properties is without a doubt the most repetitive and moving issue to be tackled before the far and wide utilization of metals and metal oxides NPs acquired by these routes [3]. Over the long decades, microorganisms such as bacteria [4-6], viruses [7], algae [8-11], fungi [12-15], yeast [13, 14], and especially plant extracts [16-19] have played a prominent role in the synthesis of metals and metal oxides NPs for specific applications, for example, bioimaging, drug delivery, and tissue engineering [19,20]. Plant extracts are also common in the green synthesis of metals and metal oxides NPs [22], as they act as a bio-reducing agent as well as a covering agent due to the presence of phytochemicals such as organic acids, flavonoids, alkaloids, phenolic compounds, and terpenoids [23-26].

Silver (Ag) and silver oxide (Ag₂O) NPs are wonderful materials and having great potential for

biomedical applications such as wound healing and cancer treatment [27]. To date, an assortment of synthetic, physical, and biological methods has been developed for the synthesis of Ag and Ag₂O with various morphologies for various applications They are additionally a [14],[28]. notable nanomaterial having tremendous applications in the field of oxidation catalysis [29-31], sensors [32-35], cancer cells [36], and photovoltaic cells [37]. There are numerous methods for the synthesis of Ag₂O, for example, photoreduction [38], wet precipitation [39-41], electrochemical synthesis [42–45], in additions to the green biosynthesis methods based on microorganisms [46, 47] and plant extracts [48-52]. Nonetheless, the physical and chemical methods are perilous, harmful, and costly [53, 54]. Despite the unique properties and wide range of applications reported for Ag and Ag₂O NPs, safety concerns have been raised over the usage of Ag and Ag₂O NPs because they pose cytotoxicity effects on the human cells [55].

Plant extract synthesis of Ag/Ag₂O NPs in an aqueous medium is advantageous for biological applications because the resulting particles can often be used directly [56], yet these techniques typically provide Ag NPs of low monodispersity, or with a size that is difficult to control [57]. Generally speaking, the aqueous synthesis of Ag NPs falls under the category of wet chemistry. This including

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the clustering and nucleation of Ag⁺ ions within a bulk solution in the presence of a reducing agent. To control particle size, capping and stabilizing agents such as trisodium citrate and polyvinylpyrrolidone (PVP) are typically used to slow and eventually stop the growth of the Ag NPs [58]. The formation of Ag₂O NPs instead of Ag can be performed by combining aqueous solutions of Ag⁺ ions and alkali hydroxide. This reaction does not afford appreciable amounts of AgOH due to the favorable energetics for the following (2 AgOH \rightarrow Ag₂O + H₂O, pK = 2.875). Recently, more attention has been given to the low-cost, non-toxic, simple, and eco-friendly synthesis of Ag and Ag₂O NPs from biological sources due to their antioxidant or reducing properties commonly liable for the reducing and stabilizing out of the synthesized nanoparticles.

Plant-extract synthesis seems to be the best route for large-scale Ag and Ag₂O NPs synthesis. Plant parts of Camellia Sinensis (green tea) [59-61], pine [62, 63], persimmon [64], ginkgo [65], magnolia [66], and Platanus [67] are being used for Ag and Ag₂O NPs synthesis. This technique made particles with a scatter size scope of 10 to 200 nm, yet it was likewise tracked down that the Ag NPs size could be constrained by fluctuating the reaction temperature. The speed at which the Ag NPs were reduced by the plant separate was similar to those of utilizing chemicals to reduce [68]. Thus, this route is considered as the best stage being liberated from harmful chemicals just as giving regular reducing and capping agents for the stabilization of the synthesized Ag and Ag₂O NPs. The use plant extraxt for the synthesis of Ag and Ag₂O NPs is ecofriendly and biocompatibility rout for pharmaceutical and biomedical applications as plant extracts do include toxic chemicals for the synthesis protocol.

The present work disclosed the green synthesis of Ag/Ag₂O NPs by using Artemisia Herba-Alba aqueous leaf extract. The synthesis route of the Ag/Ag₂O NPs was optimized based on the standard characterization techniques, including ultraviolet-visible spectrophotometry (UV-Vis or UV/Vis), Fourier-transform infrared spectroscopy (FTIR), X-ray powder diffraction (XRD), Scanning electron microscopy (SEM), and thermogravimetric differential thermal analysis and (TG–DTA) [69],[70]. This work also provides more information on the chemical composition of the Artemisia Herba-Alba aqueous leaf extract originated from Ain Zatoute -Biskra- (South East of Algeria) and investigates their chemical characteristics. Artemisia Herba-Alba, the white wormwood, is a lasting bush in the sort Artemisia that develops generally on the dry steppes of the Middle East (Desert of Egypt), North Africa (Tunisia, Morocco, and Algeria), Western Asia (Arabian Peninsula), and Southwestern Europe. Numerous reports attributed different natural and/or pharmacological activities of Artemisia Herba-Alba to specific segments of its fundamental oil and found that

varieties in oil structure were typically connected with considerable changes in movement, specifically the antimicrobial action [71, 72]. The antibacterial and the antispasmodic activity of Artemisia Herba-Alba fundamental oil has likewise been accounted for to have an enemy of antileishmaniasis activity [73].

2. Materials and Methods

2.1. Materials

Silver nitrate (AgNO₃, 98%, VTRS Laboratory), double distilled water, samples of Artemisia Herba-Alba were harvested in October 2018 from Ain Zatoute –Biskra- (South East of Algeria) used as received.

2.2. Preparation of Artemisia Herba-Alba Leaf extract

Leaves of Artemisia Herba-Alba were washed twice by distilled water, then were dried in the air for 5 days, the preparation of aqueous extract been by adding 500 mL of double distilled water to 50 grams of Artemisia Herba-Alba powder well (w/v ratio 1:10) and then kept under continuous stirring at 35°C for 24 h. The extract was filtered through Whatman filter paper to obtain the clear filtrate, which was used in Ag/Ag₂O NPs synthesis.

2.3. Biosynthesis of silver/silver oxide nanoparticles

Ag/Ag₂O NPs were synthesized by adding different ratio volume ratios 1 mL to 2.5 mL of leaf extract to 100 mL of 1 mM AgNO₃ aqueous solution in a 250 mL-Erlenmeyer flask. The mixture was kept under stirring 150 rpm at room temperature for 2 hours, the bio-reduction of Ag⁺ to Ag^o can be observed by a color change from yellow to reddishbrown brown after 5 minutes.

2.4. Characterisation of silver/silver oxide nanoparticles

Biosynthesis of Ag/Ag₂O NPs was analyzed by using UV-vis spectrometry (Shimadzu -1800). The UV-Vis measurements were recorded at room temperature in a wavelength region of 300 to 900 nm. The reaction time and stability of the Ag/Ag₂O NPs formation were followed by UV-vis spectrometry using quartz cells and double distilled water as a blank solution. Attenuated total reflection-Fourier transform infrared (ATR-FTIR) spectroscopy measurements of leaf extract and green synthesis Ag/Ag₂O NPs were performed by (Nicolet iS5, Thermo Fisher Scientific), to identify the functional groups carried out in the range of 4000 to 400 cm⁻¹.

Crystalline structure and crystallite size of the synthesized Ag/Ag₂O NPs was obtained using an X-ray diffractometer (XRD, Rigaka Miniflex 600) and CuK radiation with a wavelength of 0.15406 nm in the angular 20 range 10° 2 0<80°. Particle size

and morphology of the synthesis Ag/Ag₂O NPs were examined by using (SEM-TESCAN VEGA 3) at an accelerating voltage of 10 KV. Thermogravimetric and differential thermal analysis (TG–DTA) of the silver/silver oxide nanoparticles was studied were performed with a TG apparatus (Netzsch STA 449 F1). Ag/Ag₂O NPs of about 10 mg were heated from 10 to 700 C at a heating/cooling rate of 10 °C/min and a flow rate of 30 mL/min in the air atmosphere.

3. Results and discussion

Silver NPs were formed by reducing Ag + to Ag⁰ using leaf extract of Artemisia Herba-Alba. However, the reaction parameters such as pH, the ratio of [Ag+] to extracted sample, and a period can significantly affect the reduction process and lead to the formation of Ag₂O as a co-product. Silver/Silver Oxide NPs were formed by reducing Ag⁺ to Ag⁰ using leaf extract of Artemisia Herba-Alba. However, the reaction parameters such as pH, the ratio of [Ag+] to extracted sample, and a time frame can significantly affect the reduction process and lead to the formation of Ag₂O as a co-product. The plant extract-mediated synthesis of Ag NPs hypothesized that the presence of bioactive compounds, such as polyphenols (flavonoids) have a hydroxyl (-OH) and ketonic (-C=O) groups that bind to the bulk metal Ag⁺ ion cluster them to a few nanometres size. The formation of Ag/Ag₂O NPs could be mediated by the presence of OH-. This contributes the OH- group to Ag⁺ and results in the formation of highly unstable Ag-OH, which is readily oxidized to Ag₂O upon drying and leads to the formation of the Ag/Ag₂O NPs

3.1. UV-Vis Spectroscopy

Visual observation shows the color changed from light yellow to brown within 5 minutes, after a while the color becomes dark brown and this indicates might be the excitation of surface plasmon resonance (SPR). The formation of Ag/Ag₂O NPs was confirmed by observing an absorption peak in the visible range from 418 to 435 due to SPR at different AgNO₃ concentrations (Figure 1) and different volumes of leaf extract (1.0, 1.5, 2.0, and 2.5 mL) to 100 mL of 1 mM AgNO₃ (Figure 2). The change in the peak intensity is due to the change in the amount of the leaf extract. This may be due to the high number of Ag/Ag₂O NPs formed resulting from the reduction of AgNO₃.

The optimization of the reaction time for Ag/Ag₂O NPs formation was followed at room temperature that in the first 24 hours is shown in Fig. 3, the reaction rate was fast, to start decreasing after that until it becomes very slow after seven days. Which indicated that most Ag₊ ions were consumed for Ag/Ag₂O NPs synthesis. If we estimate that the formation of Ag/Ag₂O NPs stopped after a week, 89.4% of Ag/Ag₂O NPs formed in 24 hours.



Fig.1 - UV–Vis absorption spectrum of Ag/Ag₂O NPs synthesized using different 100 mL AgNO₃ precursor concentration with 1.0% leaf extract (v/v).



Fig. 2 - UV–Vis absorption spectrum of Ag/Ag₂O NPs synthesized from 100 ml of 1 mM AgNO₃ with different volume ratio of Artemisia Herba-Alba leaf extract (v/v):1%, 1.5%, 2%, and 2.5%.



Fig. 3 - UV-vis spectrum absorption of Ag/Ag₂O NPs at different time intervals at room temperature (100 ml of 1 mM AgNO₃ and 1ml Artemisia Herba-Alba leaf extract).

The estimated optical band gap (Eg) of Ag/Ag_2O NPs is calculated using the Tauc relation Eq.(1) [74]:

$$(\alpha hv) = A(hv - E_g)^n \qquad (1)$$

Where α is the absorption coefficient, A is constant, hv is the energy of light and n is a constant depending on the nature of the electron transition, E_g is optical band gap energy. Additionally, Figure 3 and Figure 4 show the Tauc plot of $(\alpha hv)^2$ versus hv at different concentrations and different rapport, respectively. We have obtained the energy gap from the intersection of the edge of the linear part of absorption with the energy axis. When $(\alpha hv)^2$ is zero, the photon energy is Eg. The results are listed in Table 1. a (Eg) estimation of Ag/Ag₂O NPs with a different volume ratio of leaf extract was found to be in the range 2.05-2.30 eV. The Bandgap (Eg) slightly decreases from 2.29 to 2.32 eV with increasing the AgNO₃ concentration from 2mM to 5mM with 1.0% of leaf extract.



Fig. 4 - Bandgap (Eg) estimation from Tauc's relation of the prepared Ag/Ag_2O NPs with 100 mL of AgNO₃ of concentrations with 1.0% of leaf extract.

Table 1 The optical bandgap of the Ag/Ag₂O NPs prepared from different volume ratio of leaf extract (v/v): 1.0%, 1.5%, 2.0%, and 2.5% to 100 mL of 1 mM AgNO₃

volume ratio	Optical band gap E _g (eV)	Precursor concentra- tion	Optical band gap E _g (eV)
1.0%	2.30	2mM	2.29
1.5%	2.27	3 mM	2.32
2.0%	2.21	4 mM	2.28
2.5%	2.05	5 mM	2.31

3.2. Fourier transform infrared spectroscopy

FTIR analysis was done to distinguish the nature of the functional groups (reducing and stabilizing biomolecules) in the Artemisia Herba-Alba extract. The resultant FTIR spectrum (Figure 5 and Figure 6) has displayed a few absorption bands that relate to the functional groups of the biomolecules existing in the plant extract. Three main absorption peaks were observed, the broad peak centered at 3340 cm⁻¹ is assigned to O–H stretching vibrations [75, 76], the intense peak at 1650 cm⁻¹ is due to C=O stretching and N–H bending vibrations of the primary amides group which is commonly found in the protein [77]. Besides, the peak located at 650 cm⁻¹ corresponds to C–H bending vibrations out of plane [78].



Fig. 5 - Bandgap (Eg) estimation from Tauc's relation of the prepared Ag/Ag₂O from 100 mL of 1 mM AgNO3 with different volume ratio of leaf extract (v/v): 1.0%, 1.5%, 2.0%, and 2.5%.



Fig. 6 - FTIR Spectra of Artemisia Herba-Alba extract and the prepared Ag/Ag₂O NPs solution prepared at 100 mL of Ag NO₃ of different concentrations (2, 3, 4, and 5 mM AgNO₃) and 1 mL of Artemisia Herba-Alba extract.

The FTIR spectra of AgO NPs synthesized at different precursor concentrations and different (precursor to extract volume ratios) are shown in (Fig. 5) and (Fig. 6) respectively. Comparing the FTIR spectra of AgO NPs with the Artemisia Herba-Alba extract in (Fig. 5) reveals a distinguished decrease in the band's intensity at 3340 cm⁻¹ and 1650 cm⁻¹ which may indicate that both of the OH group and the proteins presented in Artemisia herba-alba extract have served as bio-reducing and capping agents for AgO NPs synthesis [24].

3.3. X-Ray Diffraction

XRD patterns of the biosynthesized Ag/Ag₂O NPs prepared from 100 mL AgNO₃ solution of different concentrations (2, 3, 4, and 5 mM AgNO₃) and different volume ratios (Leaf extract: AgNO3 solution of 1.0, 1.5, 2.0, 2.5% V/V) are shown in Fig.7 and Fig.8 respectively. A number of Bragg reflection peaks were observed in all the XRD patterns located at 20 values of 38.16°, 44.34°, 64.57°, and 77.60° corresponding to (111), (200), (220), and (311) planes of metallic face-centered cubic structure (JCPDS 04-0783) of Ag NPs [79, 80]. Whereas the diffraction peaks at 2θ values of 26.90°, 32.69°, 37.94°, 54.9°, 65.54° and 69° related to (110), (111), (200), (220), (311) and (222) planes of face-centered cubic structure (JCPDS 01-076-1393) of crystalline Ag₂O [81]. Noteworthy that the prepared Ag/Ag₂O NPs with the lowest volume ratio of extract to AgNO₃ solution (1:100) shown in Figure 9 exhibited only one phase of metallic Ag NPs with no additional peaks of Ag₂O phase. The higher contraction of the leaf extracts the higher binding between polyphenols of the extract (hydroxyl, ketonic) to the Ag+ ions. This contributes the OH⁻ group to Ag⁺ and results in the formation of highly unstable Ag-OH, which is readily oxidized to Ag₂O upon drying and leads to the formation of the Ag/Ag₂O NPs [82].



Fig. 7 - FTIR Spectra of Artemisia Herba-Alba extract and the prepared Ag/Ag_O NPs solution prepared at 100 mL of 1 mM AgNO₃ and 1.0, 1.5, 2.0, and 2.5 mL of the asprepared Artemisia Herba-Alba extract.

The crystallite size of the synthesized nanoparticles was estimated selecting the peak of highest intensity situated at 2θ value of 38.16° using the Scherrer formula Eq (1):

$$D = \frac{k\lambda}{\beta \cos \theta}$$
(1)

Where D is the crystalline size (nm), β is the full width at half maximum of the diffraction peak (FWHM) of the most intense diffraction peak, λ the X-ray wavelength (1.5406 Å) and θ is the Bragg angle of diffraction [83]. The effect of both precursor



Fig .8 -XRD patterns of the prepared Ag/Ag₂O NPs solution prepared at 100 mL of Ag NO₃ of different concentrations (2, 3, 4, and 5 mM AgNO₃) and 1 mL of Artemisia Herba-Alba extract.



Fig. 9 - XRD patterns of the prepared Ag/Ag₂O NPs solution prepared at 100 mL of 1 mM AgNO₃ and 1.0, 1.5, 2.0, and 2.5 mL of the as-prepared Artemisia Herba-Alba extract.

concentration and volume ratio on crystallite size of Ag/Ag₂O NPs are shown in Table 2.

Table 2 shows that the crystallite size is affected by both precursor concentration and volume ratio. Increasing the precursor concentration has irregularly affected the Ag and Ag₂O NPs crystallite size. On the other hand, Increasing the volume ratio of leaf extract to 1 mM AgNO₃ solution from 1:100 to 2.5:100 has decreased the crystallite size of Ag from 20.25 to 10.67 and Ag₂O crystals from 36.79 nm to 12.23 nm.

3.4. Scanning Electron Microscopy

Particle size and morphology of Ag/Ag_2O NPs were studied using the SEM (Figure 10). The particle size of the prepared Ag/Ag_2O NPs have a tight size distribution with an average size of 150-250 nm with a spherical shape. The particle size distribution increases with decreases with increasing the AgNO₃ from 2-5 mM. Most of the

Table 2

ffect of AgNO ₃ precursor concentration and volume ratio of leaf extract to AgNO ₃ solution on the crystallite size of Ag and Ag ₂ O NPs.

AgNO₃ Concentration	Extract/AgNO ₃ solution Volume Ratio (ml/ml)	Crystallite size of Ag (nm)	Crystallite size of Ag₂O (nm)
2 mM	1.0/100	14.95 ± 1.05	36.79 ± 1.45
3 mM	1.5/100	10.67 ± 1.38	16.55 ± 0.61
4 mM	2.0/100	20.25 ± 0.82	12.35 ± 1.12
5 mM	2.5/100	10.79 ± 1.27	12.23 ± 0.56

Ag/Ag₂O NPs were aggregated to form foam like a bunch of particles, and however, individual particles were also observed. The spherical shape of Ag/Ag₂O NPs because of the equivalent growth rate

alongside all nucleation directions where the sphere has the littlest surface area per unit volume contrasted with different shapes.









Fig. 10 continues on next page

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Fig. 10 - SEM images of the prepared Ag/Ag₂O NPs solution prepared at 100 mL of Ag NO₃ of different concentrations ((a,b) 2 mM, (c,d) 3 mM, (e,f) 4 mM, and (g,h) 5 mM. AgNO₃) and 1 mL of Artemisia Herba-Alba extract.



Fig. 11 - TGA and DTA profiles the prepared Ag/Ag_2O NPs solution prepared at 100 mL of $AgNO_3$ of different concentrations 2 mM $AgNO_3$ and 1 mL of Artemisia Herba-Alba extract.

3.5. Thermal Analysis and Organic Contents

Figure 11 shows a thermogravimetric analysis (TGA/DTA) performed to assess the purity of Ag/Ag₂O NPs in the powder form. Data extracted from TGA/DTA analysis was used to estimate the organic contents adsorbed on the surface of the Ag/Ag₂O NPs and their thermal stability for

oxidation in the air in the temperature range from 25 to 700 [84]. To confirm the stability of Ag/Ag₂O NPs, thermogravimetric analysis was performed under a nitrogen atmosphere at a heating rate of 10 °C.min⁻¹. Further weight loss was observed during heating from 300 to 700 °C. The first weight of about 2wt% occurs at about 140 °C due to loss

of physically adsorbed water (moisture). The second weight loss (18wt%) in the temperature range 350-680 \C is due to the oxidation and degradation of the organic and liberation of CO₂ and H₂O [85]. Significant weight loss is observed in the heating step at 300-350 \C due to the elimination of the organic part [86].

4.Conclusion

This study describes a green, simple, and eco-friendly method for the synthesis of Ag/Ag₂O NPs using Artemisia Herba-Alba aqueous leaf extract as a reducing and capping agent. The formation of Ag/Ag₂O NPs and influence of different AgNO₃ concentrations and addition of different volumes of leaf extract to AgNO₃ solution was studied by ultraviolet-visible (UV-Vis) spectroscopy, Fourier transforms infrared spectroscopy (FTIR), scanning electron spectroscopy (SEM), and X-ray diffraction (XRD) and thermal analysis (TGA/DTA). The formation of Ag/Ag₂O NPs was confirmed by observing an absorption peak in the visible range from 418 to 435 nm due to SPR at different AgNO₃ concentrations. The results have shown that the crystallite size of Ag/Ag₂O NPs can be significantly influenced by the precursor concentration and volume ratio. Increasing the volume ratio of leaf extract to 1 mM AgNO₃ solution from 1:100 to 2.5:100 (v/v) has decreased the crystallite size of Ag from 20.25 to 10.67 and Ag₂O crystals from 36.79 nm to 12.23 nm. The Ag/Ag₂O NPs were found to be less than 100 nm in size with spherical shapes. The TGA/DTA analysis shows significant organic contents (18 wt %) were physically and chemically adsorbed on the dry weight Ag/Ag₂O NPs. The purposed procedure is green and viable because it's simple, fast, low cost, and friendly to the environment compared to other wet chemistry methods.

Conflict of interest

The authors declare that they have no conflict of interest. Acknoledgment

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REFERENCES

- [1] A. Barhoum, G. Van Assche, A. S. H. Makhlouf, H. Terryn, K. Baert, M.-P. Delplancke, S. M. El-Sheikh and H. Rahier, *A green, simple chemical route for the synthesis of pure nanocalcite crystals, Cryst. Growth Des.*,2015, **15**(2).
- [2] A. Barhoum, M. Rehan, H. Rahier, M. Bechelany and G. Van Assche, Seed-Mediated Hot-Injection Synthesis of Tiny Ag Nanocrystals on Nanoscale Solid Supports and Reaction Mechanism, ACS Appl. Mater. Interfaces, 2016, 8(16).
- [3] A. Barhoum, H. Rahier, M. Benelmekki and G. Van Assche, Chapter 20 - Recent Trends in Nanostructured Particles: Synthesis, Functionalization, and Applications, in Micro Nano Technol., 2018, A. Barhoum and A. S. B. T.-F. of N. Hamdy Makhlouf, Eds., Elsevier.

- [4] S. Saeed, A. Iqbal and M. A. Ashraf, Bacterial-mediated synthesis of silver nanoparticles and their significant effect against pathogens, Environ. Sci. Pollut. Res., 2020, 27(30), 37347.
- [5] N. Feroze, B. Arshad, M. Younas, M. I. Afridi, S. Saqib and A. Ayaz, Fungal mediated synthesis of silver nanoparticles and evaluation of antibacterial activity, Microsc. Res. Tech., 2020, 83(1), John Wiley & Sons, Ltd, 72.
- [6] M. A. Huq, Green Synthesis of Silver Nanoparticles Using Pseudoduganella eburnea MAHUQ-39 and Their Antimicrobial Mechanisms Investigation against Drug Resistant Human Pathogens, in Int. J. Mol. Sci. ,2020, 21(4).
- [7] A. Anandaradje, V. Meyappan, I. Kumar and N. Sakthivel, Microbial Synthesis of Silver Nanoparticles and Their Biological Potential, in Nanoparticles Med., 2020, Springer Singapore, Singapore.
- [8] P. Balaraman, B. Balasubramanian, D. Kaliannan, M. Durai, H. Kamyab, S. Park, S. Chelliapan, C. T. Lee, V. Maluventhen, et al., *Phyco-synthesis of Silver Nanoparticles Mediated from Marine Algae Sargassum myriocystum and Its Potential Biological and Environmental Applications, Waste and Biomass Valorization*,2020, **11**(10), 5255.
- [9] R. Fatima, M. Priya, L. Indurthi, V. Radhakrishnan and R. Sudhakaran, *Biosynthesis of silver nanoparticles* using red algae Portieria hornemannii and its antibacterial activity against fish pathogens, *Microb.* Pathog., 2020, **138**, 103780.
- [10] T. N. V. K. V Prasad, V. S. R. Kambala and R. Naidu, Phyconanotechnology: synthesis of silver nanoparticles using brown marine algae Cystophora moniliformis and their characterisation, J. Appl. Phycol.,2013, 25(1), 177.
- [11] K. Govindaraju, V. Kiruthiga, V. G. Kumar and G. Singaravelu, Extracellular Synthesis of Silver Nanoparticles by a Marine Alga, Sargassum Wightii Grevilli and Their Antibacterial Effects, in J. Nanosci. Nanotechnol., 9(9).
- [12] Y.-K. Jo, B. H. Kim and G. Jung, Antifungal Activity of Silver Ions and Nanoparticles on Phytopathogenic Fungi, Plant Dis., 2009, 93(10), Scientific Societies, 1037.
- [13] N. Durán, P. D. Marcato, G. I. H. De Souza, O. L. Alves and E. Esposito, Antibacterial Effect of Silver Nanoparticles Produced by Fungal Process on Textile Fabrics and Their Effluent Treatment, in J. Biomed. Nanotechnol., 3(2).
- [14] N. Vigneshwaran, N. M. Ashtaputre, P. V Varadarajan, R. P. Nachane, K. M. Paralikar and R. H. Balasubramanya, *Biological synthesis of silver nanoparticles using the fungus Aspergillus flavus*, *Mater. Lett.*,2007, **61**(6), 1413.
- [15] M. Gajbhiye, J. Kesharwani, A. Ingle, A. Gade and M. Rai, Fungus-mediated synthesis of silver nanoparticles and their activity against pathogenic fungi in combination with fluconazole, Nanomedicine Nanotechnology, Biol. Med., 2009, 5(4), 382.
- [16] H. Yousaf, A. Mehmood, K. S. Ahmad and M. Raffi, Green synthesis of silver nanoparticles and their applications as an alternative antibacterial and antioxidant agents, Mater. Sci. Eng. C,2020, 112, 110901.
- [17] J. Y. Song and B. S. Kim, Rapid biological synthesis of silver nanoparticles using plant leaf extracts, Bioprocess Biosyst. Eng., 2008, 32(1), 79.
- [18] L. Castillo-Henríquez, K. Alfaro-Aguilar, J. Ugalde-Álvarez, L. Vega-Fernández, G. Montes de Oca-Vásquez and J. R. Vega-Baudrit, Green Synthesis of Gold and Silver Nanoparticles from Plant Extracts and Their Possible Applications as Antimicrobial Agents in the Agricultural Area, in Nanomater. ,2020, 10(9).
- [19] R. H. Ahmed and D. E. Mustafa, Green synthesis of silver nanoparticles mediated by traditionally used medicinal plants in Sudan, Int. Nano Lett., 2020, 10(1), 1.

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- [20] R. Rasouli, A. Barhoum and H. Uludag, A review of nanostructured surfaces and materials for dental implants: Surface coating, patterning and functionalization for improved performance, in Biomater. Sci.,2018, 6(6), Royal Society of Chemistry.
- [21] R. Rasouli, A. Barhoum, M. Bechelany and A. Dufresne, Nanofibers for Biomedical and Healthcare Applications, Macromol. Biosci., 2019, 19(2).
- [22] A. Bouafia, S. E. Laouini, M. L. Tedjani, G. A. Ali and A. Barhoum, Green biosynthesis and physicochemical characterization of Fe 3 O 4 nanoparticles using Punica granatum L. fruit peel extract for optoelectronic applications, Text. Res. J., 2021, SAGE Publications Ltd STM, 004051752110066.
- [23] A. Bouafia, S. E. Laouini and M. R. Ouahrani, A Review on Green Synthesis of CuO Nanoparticles using Plant Extract and Evaluation of Antimicrobial Activity, Asian J. Res. Chem., 2020, 13(1), A & V Publications, 65.
- [24] T. M. Laid, K. Abdelhamid, L. S. Eddine and B. Abderrhmane, Optimizing the biosynthesis parameters of iron oxide nanoparticles using central composite design, J. Mol. Struct., 2021, **1229**, 129497.
- [25] A. Bouafia and S. E. Laouini, Plant-Mediated Synthesis of Iron Oxide Nanoparticles and Evaluation of the Antimicrobial Activity: A Review, Mini. Rev. Org. Chem., 2020, 17, 1.
- [26] J. A. A. Abdullah, L. Salah Eddine, B. Abderrhmane, M. Alonso-González, A. Guerrero and A. Romero, Green synthesis and characterization of iron oxide nanoparticles by pheonix dactylifera leaf extract and evaluation of their antioxidant activity, Sustain. Chem. Pharm., 2020, **17**, 100280.
- [27] M. Rehan, A. Barhoum, T. A. Khattab, L. Gätjen and R. Wilken, Colored, photocatalytic, antimicrobial and UVprotected viscose fibers decorated with Ag/Ag<inf>2</inf>CO<inf>3</inf> and Ag/Ag<inf>3</inf>PO<inf>4</inf> nanoparticles, Cellulose,2019, 26(9).
- [28] M. Rehan, T. A. Khattab, A. Barohum, L. Gätjen and R. Wilken, Development of Ag/AgX (X = Cl, I) nanoparticles toward antimicrobial, UV-protected and self-cleanable viscose fibers, Carbohydr. Polym.,2018, 197, Textile Industries Research Division, National Research Centre, 33 El-Buhouth Street, Dokki, Cairo 12622, Egypt; Fraunhofer Institute for Manufacturing Technology and Applied Materials Research (IFAM), Wiener Street 12, D-28359 Bremen, Germany. Electronic, 227.
- [29] K. Muthu, S. Rajeswari, B. Akilandaeaswari, S. M. Nagasundari and R. Rangasamy, Synthesis, characterisation and photocatalytic activity of silver nanoparticles stabilised by Punica granatum seeds extract, Mater. Technol.,2020, Taylor & Francis, 1.
- [30] M. Bhagat, R. Anand, R. Datt, V. Gupta and S. Arya, Green Synthesis of Silver Nanoparticles Using Aqueous Extract of Rosa brunonii Lindl and Their Morphological, Biological and Photocatalytic Characterizations, J. Inorg. Organomet. Polym. Mater., 2019, 29(3), 1039.
- [31] S. Marimuthu, A. J. Antonisamy, S. Malayandi, K. Rajendran, P.-C. Tsai, A. Pugazhendhi and V. K. Ponnusamy, Silver nanoparticles in dye effluent treatment: A review on synthesis, treatment methods, mechanisms, photocatalytic degradation, toxic effects and mitigation of toxicity, J. Photochem. Photobiol. B Biol.,2020, 205, 111823.
- [32] J. Li, D. Kuang, Y. Feng, F. Zhang, Z. Xu, M. Liu and D. Wang, Green synthesis of silver nanoparticles– graphene oxide nanocomposite and its application in electrochemical sensing oftryptophan, Biosens. Bioelectron.,2013, **42**, 198.
- [33] C. K. Tagad, S. R. Dugasani, R. Aiyer, S. Park, A. Kulkarni and S. Sabharwal, Green synthesis of silver nanoparticles and their application for the development of optical fiber based hydrogen peroxide sensor, Sensors Actuators B Chem., 2013, 183, 144.

- [34] M. R. Bindhu, M. Umadevi, G. A. Esmail, N. A. Al-Dhabi and M. V. Arasu, Green synthesis and characterization of silver nanoparticles from Moringa oleifera flower and assessment of antimicrobial and sensing properties, J. Photochem. Photobiol. B Biol., 2020, 205, 111836.
- [35] F. A. Qais, A. Shafiq, I. Ahmad, F. M. Husain, R. A. Khan and I. Hassan, Green synthesis of silver nanoparticles using Carum copticum: Assessment of its quorum sensing and biofilm inhibitory potential against gram negative bacterial pathogens, Microb. Pathog.,2020, 144, 104172.
- [36] A. M. Sawy, A. Barhoum, S. A. Abdel Gaber, S. M. El-Hallouty, W. G. Shousha, A. A. Maarouf and A. S. G. Khalil, Insights of doxorubicin loaded graphene quantum dots: Synthesis, DFT drug interactions, and cytotoxicity, Mater. Sci. Eng. C,2021, 122.
- [37] P. Sutradhar and M. Saha, Green synthesis of zinc oxide nanoparticles using tomato (Lycopersicon esculentum) extract and its photovoltaic application, J. Exp. Nanosci., 2016, 11(5), Taylor & Francis, 314.
- [38] M. M. Said, M. Rehan, S. M. El-Sheikh, M. K. Zahran, M. S. Abdel-Aziz, M. Bechelany and A. Barhoum, *Multifunctional Hydroxyapatite/Silver Nanoparticles/Cotton Gauze for Antimicrobial and Biomedical Applications*, in *Nanomater.*,2021, **11**(2).
- [39] Z. Khan, S. A. Al-Thabaiti, A. Y. Obaid and A. O. Al-Youbi, Preparation and characterization of silver nanoparticles by chemical reduction method, Colloids Surfaces B Biointerfaces, 2011, 82(2), 513.
- [40] S. Iravani, H. Korbekandi, S. V Mirmohammadi and B. Zolfaghari, Synthesis of silver nanoparticles: chemical, physical and biological methods., Res. Pharm. Sci.,2014, 9(6), 385.
- [41] K. C. Song, S. M. Lee, T. S. Park and B. S. Lee, Preparation of colloidal silver nanoparticles by chemical reduction method, Korean J. Chem. Eng., 2009, 26(1), 153.
- [42] A. Prokopalo, Electrochemical synthesis of silver nanoparticles in solutions of rhamnolipid, Micro Nano Lett., 2020, 15(12), Institution of Engineering and Technology, 802.
- [43] M. Mehdi, M. Akhtar, S. Abro, Z. Qamar, M. M. Nauman, S. Aziz, Z. U. Khan, M. Sufiyan, M. Bin Waseem, et al., *Electrochemical synthesis of AgNP and mechanical performance of AgNP-EG coatings on soft elastomer, J. Elastomers Plast.*,2019, **52**(7), SAGE Publications Ltd STM, 609.
- [44] L. T. Tran, H. V. Tran, H. Thi Minh Dang, C. D. Huynh and T. A. Mai, Silver Nanoparticles Decorated Polyaniline Nanowires-Based Electrochemical DNA Sensor: Two-step Electrochemical Synthesis, J. Electrochem. Soc.,2020, 167(8), The Electrochemical Society, 87508.
- [45] L. Jiang, I. Santiago and J. Foord, High-Yield Electrochemical Synthesis of Silver Nanoparticles by Enzyme-Modified Boron-Doped Diamond Electrodes, Langmuir,2020, 36(22), American Chemical Society, 6089.
- [46] R. Singh, U. U. Shedbalkar, S. A. Wadhwani and B. A. Chopade, Bacteriagenic silver nanoparticles: synthesis, mechanism, and applications, Appl. Microbiol. Biotechnol., 2015, 99(11), 4579.
- [47] D. Garibo, H. A. Borbón-Nuñez, J. N. D. de León, E. García Mendoza, I. Estrada, Y. Toledano-Magaña, H. Tiznado, M. Ovalle-Marroquin, A. G. Soto-Ramos, et al., Green synthesis of silver nanoparticles using Lysiloma acapulcensis exhibit high-antimicrobial activity, Sci. Rep.,2020, 10(1), 12805.
- [48] V. Morales-Lozoya, H. Espinoza-Gómez, L. Z. Flores-López, E. L. Sotelo-Barrera, A. Núñez-Rivera, R. D. Cadena-Nava, G. Alonso-Nuñez and I. A. Rivero, Study of the effect of the different parts of Morinda citrifolia L. (noni) on the green synthesis of silver nanoparticles and their antibacterial activity, Appl. Surf. Sci.,2021, 537, 147855.

- [49] M. M. H. Khalil, E. H. Ismail, K. Z. El-Baghdady and D. Mohamed, Green synthesis of silver nanoparticles using olive leaf extract and its antibacterial activity, Arab. J. Chem., 2014, 7(6), 1131.
- [50] M. A. Awad, E. M. Al Olayan, M. I. Siddiqui, N. M. Merghani, S. S. A. Alsaif and A. S. Aloufi, Antileishmanial effect of silver nanoparticles: Green synthesis, characterization, in vivo and in vitro assessment, Biomed. Pharmacother.,2021, 137, 111294.
- [51] M. S. Jabir, Y. M. Saleh, G. M. Sulaiman, N. Y. Yaseen, U. I. Sahib, Y. H. Dewir, M. S. Alwahibi and D. A. Soliman, Green Synthesis of Silver Nanoparticles Using Annona muricata Extract as an Inducer of Apoptosis in Cancer Cells and Inhibitor for NLRP3 Inflammasome via Enhanced Autophagy, in Nanomater. 2021, 11(2).
- [52] M. G. Tsegay, H. G. Gebretinsae, J. Sackey, M. Maaza and Z. Y. Nuru, Green synthesis of khat mediated silver nanoparticles for efficient detection of mercury ions, Mater. Today Proc., 2021, 36, 368.
- [53] S. J. Lee, T. Begildayeva, S. Yeon, S. S. Naik, H. Ryu, T. H. Kim and M. Y. Choi, *Eco-friendly synthesis of lignin* mediated silver nanoparticles as a selective sensor and their catalytic removal of aromatic toxic nitro compounds, Environ. Pollut.,2021, 269, 116174.
- [54] N. C. Pomal, K. D. Bhatt, K. M. Modi, A. L. Desai, N. P. Patel, A. Kongor and V. Kolivoška, Functionalized Silver Nanoparticles as Colorimetric and Fluorimetric Sensor for Environmentally Toxic Mercury Ions: An Overview, J. Fluoresc., 2021,.
- [55] K. Tan, A. Barhoum, S. Pan and M. Danquah, Risks and Toxicity of Nanoparticles and Nanostructured Materials, in Emerg. Appl. Nanoparticles Archit. Nanostructures,2018,.
- [56] S. E. Laouini, A. Bouafia, A. V Soldatov, H. Algarni, M. L. Tedjani, G. A. M. Ali and A. Barhoum, Green Synthesized of Ag/Ag2O Nanoparticles Using Aqueous Leaves Extracts of Phoenix dactylifera L. and Their Azo Dye Photodegradation, Membranes (Basel).,2021, 11(7), 468.
- [57] A. Barhoum, jaison jeevanandam, A. Rastogi, pieter samyn, Y. Boluk, A. Dufresne, M. K. Danquah and M. Bechelany, *Plant Celluloses, Hemicelluloses, Lignins,* and Volatile Oils for the Synthesis of Nanoparticles and Nanostructured Materials, Nanoscale,2020, Royal Society of Chemistry (RSC).
- [58] A. Karatutlu, A. Barhoum and A. Sapelkin, Theories of Nanoparticle and Nanostructure Formation in Liquid Phase, in Emerg. Appl. Nanoparticles Archit. Nanostructures Curr. Prospect. Futur. Trends, 2018, Elsevier Inc.
- [59] W. R. Rolim, M. T. Pelegrino, B. de Araújo Lima, L. S. Ferraz, F. N. Costa, J. S. Bernardes, T. Rodigues, M. Brocchi and A. B. Seabra, Green tea extract mediated biogenic synthesis of silver nanoparticles: Characterization, cytotoxicity evaluation and antibacterial activity, Appl. Surf. Sci.,2019, 463, 66.
- [60] W. Zhang and W. Jiang, Antioxidant and antibacterial chitosan film with tea polyphenols-mediated green synthesis silver nanoparticle via a novel one-pot method, Int. J. Biol. Macromol.,2020, 155, 1252.
- [61] D. Arumai Selvan, D. Mahendiran, R. Senthil Kumar and A. Kalilur Rahiman, Garlic, green tea and turmeric extracts-mediated green synthesis of silver nanoparticles: Phytochemical, antioxidant and in vitro cytotoxicity studies, J. Photochem. Photobiol. B Biol.,2018, 180, 243.
- [62] P. Velmurugan, S.-M. Lee, M. lydroose, K.-J. Lee and B.-T. Oh, Pine cone-mediated green synthesis of silver nanoparticles and their antibacterial activity against agricultural pathogens, Appl. Microbiol. Biotechnol., 2013, 97(1), 361.
- [63] M. J. Sweet and I. Singleton, Soil contamination with silver nanoparticles reduces Bishop pine growth and ectomycorrhizal diversity on pine roots, J. Nanoparticle Res., 2015, 17(11), 448.

- [64] K. Ramachandraiah, N. T. B. Gnoc and K. B. Chin, Biosynthesis of Silver Nanoparticles from Persimmon Byproducts and Incorporation in Biodegradable Sodium Alginate Thin Film, J. Food Sci.,2017, 82(10), John Wiley & Sons, Ltd, 2329.
- [65] F. Wang, W. Zhang, X. Tan, Z. Wang, Y. Li and W. Li, Extract of Ginkgo biloba leaves mediated biosynthesis of catalytically active and recyclable silver nanoparticles, Colloids Surfaces A Physicochem. Eng. Asp.,2019, 563, 31.
- [66] I.-M. Chung, R. Malathy, R. Priyadharshini, V. Hemapriya, S.-H. Kim and M. Prabakaran, *Inhibition of mild steel corrosion using Magnolia kobus extract in sulphuric acid medium, Mater. Today Commun.*,2020, 25, 101687.
- [67] S. Shende, K. A. Joshi, A. S. Kulkarni, C. Charolkar, V. S. Shinde, V. S. Parihar, R. Kitture, K. Banerjee, N. Kamble, et al., *Platanus orientalis Leaf Mediated Rapid Synthesis of Catalytic Gold and Silver Nanoparticles, J. Nanomed. Nanotechnol.*,2018, **09**(02), 2.
- [68] S. Wei, Y. Wang, Z. Tang, H. Xu, Z. Wang, T. Yang and T. Zou, A novel green synthesis of silver nanoparticles by the residues of Chinese herbal medicine and their biological activities, RSC Adv.,2021, 11(3), The Royal Society of Chemistry, 1411.
- [69] A. Barhoum, M. L. García-Betancourt, H. Rahier and G. Van Assche, Physicochemical Characterization of Nanomaterials: Polymorph, Composition, Wettability, and Thermal Stability, in Emerg. Appl. Nanoparticles Archit. Nanostructures Curr. Prospect. Futur. Trends,2018, Elsevier Inc.
- [70] A. Barhoum and M. Luisa García-Betancourt, Physicochemical Characterization of Nanomaterials: Size, Morphology, Optical, Magnetic, and Electrical Properties, in Emerg. Appl. Nanoparticles Archit. Nanostructures Curr. Prospect. Futur. Trends,2018, Elsevier Inc.
- [71] R. Singh, C. Hano, G. Nath and B. Sharma, Green Biosynthesis of Silver Nanoparticles Using Leaf Extract of Carissa carandas L. and Their Antioxidant and Antimicrobial Activity against Human Pathogenic Bacteria, in Biomol. ,2021, 11(2).
- [72] E. Benassai, M. Del Bubba, C. Ancillotti, I. Colzi, C. Gonnelli, N. Calisi, M. C. Salvatici, E. Casalone and S. Ristori, Green and cost-effective synthesis of copper nanoparticles by extracts of non-edible and waste plant materials from Vaccinium species: Characterization and antimicrobial activity, Mater. Sci. Eng. C,2021, 119, 111453.
- [73] H. I. AlMohammed, A. Khudair Khalaf, A. E. Albalawi, A. D. Alanazi, P. Baharvand, A. Moghaddam and H. Mahmoudvand, *Chitosan-Based Nanomaterials as Valuable Sources of Anti-Leishmanial Agents: A Systematic Review*, in *Nanomater.*, 2021, **11**(3).
- [74] W. H. Strehlow and E. L. Cook, Compilation of Energy Band Gaps in Elemental and Binary Compound Semiconductors and Insulators, J. Phys. Chem. Ref. Data, 1973, 2(1), American Institute of Physics, 163.
- [75] A. Bouafia, S. E. Laouini, A. Khelef, M. L. Tedjani and F. Guemari, Effect of Ferric Chloride Concentration on the Type of Magnetite (Fe₃O₄) Nanoparticles Biosynthesized by Aqueous Leaves Extract of Artemisia and Assessment of Their Antioxidant Activities, J. Clust. Sci.,2021, **32**(4), 1033.
- [76] A. Bouafia and S. E. Laouini, Green synthesis of iron oxide nanoparticles by aqueous leaves extract of Mentha Pulegium L.: Effect of ferric chloride concentration on the type of product, Mater. Lett., 2020, 265, 127364.
- [77] A. M. Auti, N. P. Narwade, N. M. Deshpande and D. P. Dhotre, *Microbiome and imputed metagenome study of crude and refined petroleum-oil-contaminated soils: Potential for hydrocarbon degradation and plant-growth promotion, J. Biosci.*,2019, 44(5), 114.

- 352 Yassine Belaiche, Abdelhamid Khelef, Salah Eddine Laouini, Abderrhmane Bouafia, Mohammed Laid Tedjani, Ahmed Barhoum Green synthesis and characterization of silver/silver oxide nanoparticles using aqueous leaves extract of Artemisia Herba – Alba as reducing and capping agents
- [78] D. Arif, M. B. K. Niazi, N. Ul-Haq, M. N. Anwar and E. Hashmi, Preparation of antibacterial cotton fabric using chitosan-silver nanoparticles, Fibers Polym.,2015, 16(7), 1519.
- [79] R. I. Priyadharshini, G. Prasannaraj, N. Geetha and P. Venkatachalam, Microwave-Mediated Extracellular Synthesis of Metallic Silver and Zinc Oxide Nanoparticles Using Macro-Algae (Gracilaria edulis) Extracts and Its Anticancer Activity Against Human PC3 Cell Lines, Appl. Biochem. Biotechnol.,2014, 174(8), Springer, 2777.
- [80] Y. Meng, A sustainable approach to fabricating ag nanoparticles/PVA hybrid nanofiber and its catalytic activity, Nanomaterials,2015, 5(2), Multidisciplinary Digital Publishing Institute, 1124.
- [81] A. Rajabi, M. J. Ghazali, E. Mahmoudi, S. Azizkhani, N. H. Sulaiman, A. W. Mohammad, N. M. Mustafah, H. Ohnmar and A. S. Naicker, *Development and antibacterial application of nanocomposites: Effects of molar ratio on Ag2O–CuO nanocomposite synthesised via the microwave-assisted route, Ceram. Int.*,2018, 44(17), Elsevier, 21591..

- [82] S. Ravichandran, V. Paluri, G. Kumar, K. Loganathan and B. R. Kokati Venkata, A novel approach for the biosynthesis of silver oxide nanoparticles using aqueous leaf extract of Callistemon lanceolatus (Myrtaceae) and their therapeutic potential, J. Exp. Nanosci.,2016, 11(6), Taylor & Francis, 445
- [83] J. I. Langford, X-ray diffraction procedures for polycrystalline and amorphous materials by H. P. Klug and L. E. Alexander, J. Appl. Crystallogr., 1975, 8(5), 573.
- [84] S. Küünal, S. Kutti, P. Rauwel, M. Guha, D. Wragg and E. Rauwel, *Biocidal properties study of silver* nanoparticles used for application in green housing, Int. Nano Lett., 2016, 6(3), 191.
 [85] K. Harish and K. Manisha, Synthesis and
- [85] K. Harish and K. Manisha, Synthesis and characterization of silveroxide nanoparticles by sol-gel method, Int J Adv Res Sci Eng,2018, 7(3), 632.
- [86] M. Khalil and F. Z. Alqahtany, Comparative Studies of the Synthesis and Physical Characterization of ZnO Nanoparticles Using Nerium oleander Flower Extract and Chemical Methods, J. Inorg. Organomet. Polym. Mater., 2020, 30(9), 3750.