International Scientific Organization
http://iscientific.org/
Chemistry International
www.bosaljournals.com/chemint/

Green synthesis of zinc oxide nanoparticles (ZnO-NPs) using *Ailanthus altissima* fruit extracts and antibacterial activity

Akl M. Awwad[1,*], Mohammad W. Amer[1], Nidà M. Salem[2] and Amany O. Abdeen[3]

[1]College of Science, Department of Chemistry, the University of Jordan, Amman, Jordan
[2]College of Agriculture, Department of Plant Protection, the University of Jordan, Amman, Jordan
[3]Royal Scientific Society, Amman, Jordan
*Corresponding author's E. mail: akl.awwad@yahoo.com

ARTICLE INFO

Article type:
Research article
Article history:
Received October 2019
Accepted December 2019
July 2020 Issue
Keywords:
Green synthesis
Zinc oxide nanoparticles
Ailanthus altissima fruits
Antibacterial activity

ABSTRACT

The green synthesis of nanoparticles using plants fruits aqueous extracts have been prepared for different applications. Recently, the green synthesis of zinc oxide nanoparticles have been a keen interest amongst researchers and scientist due to its simplicity, eco-friendliness, non-toxic, inexpensive and potential to perform as antibacterial agent. Thus, in this current work, the synthesis of zinc oxide nanoparticles using *Ailanthus altissima* fruits aqueous extract is reported. The green synthesized zinc oxide nanoparticles were characterized using scanning electron microscope (SEM), UV-Vis absorption spectroscopy and X-ray diffraction (XRD). The average size of the nanoparticles prepared was found to be ranging from 5 to 18 nm. The FT–IR analysis suggests that the obtained ZnO-NPs have been stabilized through the interactions of flavonoids, and phenolic compounds in the fruits extract. Synthesized ZnO-NPs reveals antibacterial activity against two bacterial strains, *Escherichia coli* and *Staphylococcus aureus*. It is concluded that the ZnO-NPs have high efficient antibacterial activity and considered as a potential additive to substitute toxic chemical and physical antibacterial materials.

Capsule Summary: Green synthesis of ZnO-NPs using *Ailanthus altissima* fruits aqueous extract and prepared ZnO-NPs showed promising antibacterial activity against *E. coli* and *S. aureus*.

Cite This Article As: A. M. Awwad, M. W. Amer, N. M. Salem and A. O. Abdeen. Green synthesis of zinc oxide nanoparticles (ZnO-NPs) using *Ailanthus altissima* fruit extracts and antibacterial activity. Chemistry International 6(3) (2020) 151-159. https://doi.org/10.5281/zenodo.3559520

INTRODUCTION

Zinc oxide nanoparticles (ZnO-NPs) with different morphological structures as antibacterial activity against bacteria micro fungus and virus was developed using various synthetic routes such as wet chemical (Narkiewicz et al., 2008), microemulsion (Yildirim, and Durucan, 2010), hydrothermal (Shao-Hwa et al., 2010), solvothermal (Shamhari et al., 2018), precipitation and co-precipitation route (Ghorbani et al., 2015; Katiyar et al., 2018), surfactant-assisted precipitation routes (Mahamuni et al., 2018), polyol chemistry (Mohan and Renjanadevi, 2016), conventional methods using surfactant (Mohan and Renjanadevi, 2016), Microwave-assisted combustion (Kooti and Sedeh, 2013), sonochemical method (Khanna et al., 2012), and sol-gel method (Hasnidawani et al., 2016; Chung et al., 2015; Al Abduullah et al., 2017). These methods have many disadvantages due to the difficulty of scale up the process, separation and purification of nanoparticles from the micro emulsions and energy requirements. Developing facile and green methods for synthesizing zinc oxide nanoparticles are of importance and still a challenge for materials researchers. According to the literature surveys, plants extracts have been suggested as valuable alternatives to chemical methods for synthesis of zinc oxide nanoparticles.

Recent research reported the synthesis of zinc oxide nanoparticles (ZnO-NPs) using different plant extracts such as *Tabernaemontana divaricata* green leaf extract (Raja et al., 2018), flower extract of *Nyctanthes arbor-tristis* (Jamdagni et al., 2018), *Azadirachta indica* leaf extract (Bhuyan et al., 2015), *Laurus nobilis* L. leaves aqueous extract (Fakharij et al., 2019), *Aloe barbadensis miller* leaf extract (Sangeetha et al., 2011), *Cassia alata* fresh leaves (Happy et al., 2019), leaf extracts of the *Costus pictus D. Don* medicinal plant (Suresh et al., 2018), aqueous extracts of *Aloe vera* gel/leaf and *Hibiscus sabdariffa* leaf (Mahendiran et al., 2017), *Hibiscus rosa-sinensis* leaf extract (Divya et al., 2013), *Ixora coccinea* leaf extract (Yedurkar et al., 2016), cherry extract (Mohammadi and Ghasemi, 2018), *Sesamum indicum* L. (Manokari et al., 2019), *Moringa oleifera* leaves (Matinise et al., 2017; Pal etal., 2018), *Pongamia pinnata* leaves (Sundrarajan et al., 2015), *Anisochilus carnosus* leaves (Anbuvannan et al., 2015), *Moringa Oleifera* seed (Rajeswari et al., 2018), *Ocimum basilicum* L. var. purpurascens Benth.-Lamiaceae leaves (Salam et al., 2014), *Plectranthus amboinicus* leaves (Fu and Fu, 2015), *Abutilon indicum* leaves (Ijaz et al., 2017), *Juglans regia* leaves (Asemani, and Anarjan, 2019), *Syzygium alternifolium flowers (*Yugandhar *et al., 2017), Atalantia monophylla* leaf extracts (Vijayakumar et al., 2018), leaf extract of *Glycosmis pentaphylla* (Vijayakumar et al., 2018), leaf extract of *Mentha pulegium* (Rad et al., 2019), *Lycopersicon esculentum* (tomato), *Citrus sinensis* (orange), *Citrus paradisi* (grapefruit) and *Citrus aurantifolia* (lemon) peels (Nava et al., 2017), plant extract of flower *Matricaria chamomilla* L., *olea europaea* leaves and *Lycopersicon esculentum* M. fruits (Ogunyemi et al., 2019), fruits of *Ananas Comosus* (Ahmad et al., 2019), *Ixora Coccinea* leaves (Yedurkar et al., 2016), *Ipomoea pescaprae* leaves (Venkateasan et al., 2017), *Corymbia citriodora* leaves (Zheng et al., 2015), tomato extract (Sutradhar and Saha, 2017), *Moringa Oleifera* Leaf Extract (Pal et al., 2018), *Boswellia ovalifoliolata* stem bark-extract (Supraja et al., 2016), root extract of *Zingiber officinale* (Raj and Jayalakshmy, 2015), extracts of *Allium sativum, Rosmarinus officinalis and Ocimum basilicum* (Stan et al., 2016), *trifolium pratense* flower extract (Renata and Długaszewska, 2015), *Punica granatum* fruit peels extract (Sukr et al., 2019), *Capsicum annuum* fruit extr*act (Lalithamba* et al., 2018), *Gooseberry* fruits extracts (Vennila, and Jesurani, 2017) and *Garcinia mangostana* fruit pericarp (Aminuzzaman et al., 2018).

In the present investigation, *Ailanthus altissima* fruits aqueous extract was used for the synthesis zinc oxide nanoparticles (ZnO-NPs), which were characterized by advanced techniques and antibacterial activity was also evaluated. The fruits of *Ailanthus altissima* grow in clusters, contain hundreds of seeds (Fig. 1A).

MATERIAL AND METHODS

Chemical and reagents

Zinc nitrate hexahydrate (Purum ≥98% $Zn(NO_3)_2.6H_2O$) was purchased from Sigma-Aldrich, Germany). De-ionized water was used in all experimental work. *Ailanthus altissima* fruits were collected from trees at Royal scientific Society, Jordan and washed with water to remove dust particles. Fruits were dried at ambient temperature for 7 days and then ground to obtain fine powder. The powder was then sieved with 350 mesh sieve.

Preparation of *Ailanthus altissima* fruits aqueous extract

Ailanths altissima fruits powder (10 g) were mixed with 1L de-ionized water and boiled for 10 min at 80 ^oC to obtain reddish aqueous extract and then left to cool at ambient temperature. Afterward, aqueous extract was obtained by filtration on Whitman's filter paper and kept for our research work.

Synthesis of zinc oxide nanoparticles (ZnONPs)

Zinc nitrate hexahydrate [$(ZnNO_3)_2.6H_2O$] 10 g was dissolved in 200 mL de-ionized water under stirring with magnetic bar at ambient temperature (27 ^oC). Afterward, an aqueous extract of *Ailanthus altissima* fruits was added drop by drop to zinc solution till the solution started changing from colorless color to reddish brown and the formation of suspended particles. The mixture was left overnight and filters to obtain the suspended particles, which dried in an oven at 80^{o}C for 4h. The powder obtained was subjected to analysis by X-ray diffraction (XRD) and scanning electron microscopy (SEM) (Fig. 1B).

Characterization techniques

Fourier infrared spectroscopy (FT-IR; IR Prestige-21, Shimadzu) was used to identify the different chemical functional groups present in the *Ailanthus altissima* fruits. FT-IR analyses also used to determine the functional groups are responsible for the reduction of zinc nitrate to zinc oxide nanoparticles. The analysis was carried out using KBr and the spectral range varying from 4,000 to 400 cm^{-1}. X-ray diffractometer, XRD-6000 (Shimadzu, Japan) equipped with Cu K α radiation source using Ni as filter at a setting of 30 kV/30mA. All XRD data were collected under the experimental conditions in the angular range $3^o \leq 2\theta \leq 50^o$. Scanning electron microscopy (SEM) analysis of synthesized ZnO nanoparticles was done by S-4500 SEM machine (Hitachi, Japan). Formation and stability of ZnO-NPs in sterile distilled water is confirmed using UV-vis spectrophotometer in a range of wavelength from 200 to 700 nm.

Fig. 1A: *Ailanthus altissima* fruits used for the green synthesis of ZnO-NPs

Fig. 1B: Schematic presentation of ZnO-NPs synthesis using *Ailanthus altissima* fruits extracts, analysis and antimicrobial activity

Antibacterial activity

Green synthesized ZnO-NPs using *Ailanthus altissima* fruits aqueous extract were studied for their antimicrobial activity against pathogenic bacteria by disc diffusion method; it was observed that ZnO-NPs have antibacterial activities at concentration of 2 μg/disc. Chloromphenical was used as a control antimicrobial agent.

RESULTS AND DISCUSSION

Optical properties of ZnO-NPs

The color of the reaction mixture changed from colorless to pale brown during reaction and from brown to white on heating to a temperature of 450°C using muffle furnace for 2h. Optical properties of ZnO-NPs using UV–vis spectrum were analyzed by measuring the UV–vis spectrum (Fig. 2), which clearly indicated that the intense characteristic absorption peaks were between 360 to 369 nm which confirmed the formation of ZnO-NPs.

FTIR analysis

FTIR measurement was carried out to identify the possible biomolecules in *Ailanthus altissima* fruits extract responsible for the reduction and capping processes leading to an efficient stabilization of ZnO-NPs. The FTIR spectrum showed the presence of bonds due to −OH stretching frequency around 3424 cm^{-1}. However, peaks at 2959 cm^{-1} and 2865 cm^{-1} are attributed to the asymmetric and symmetric stretching vibrations of $-CH_2$ group respectively. The peak at 1646 cm^{-1} results from the stretching bands of C=O functional groups.

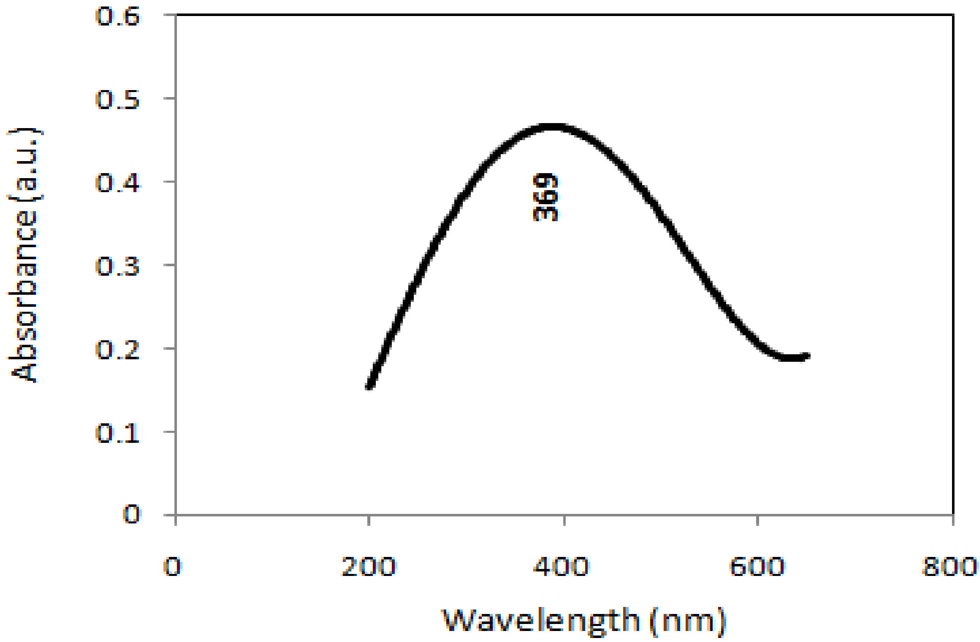

Fig. 2: UV-vis spectrum of ZnO-NPs synthesized via green route

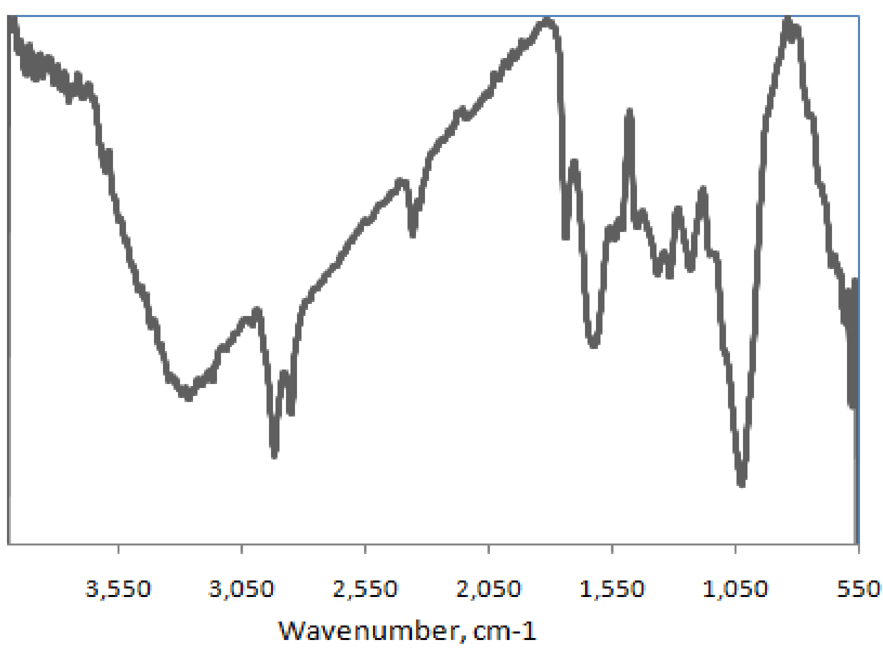

Fig. 3: FT-IR spectrum of *Ailanthus altissima* fruits extract (Y-axis = Transmittance, %)

The peak at 1758 cm^{-1} referred to the presence of stretching vibrations of non-ionic carboxylic acids or acid esters present in *A. altissima* fruits. The peak at 1367 cm^{-1} indicated the presence of C-O-H bending mode. The peak at around 1387 cm^{-1} present in ZnO signified amide band of the random coil of protein. The peak at 612 cm^{-1} indicates the stretching vibrations of ZnO-NPs. The region between 500 and 600 cm^{-1} is assigned for metal-oxygen bond. In addition to the bands of the biomolecules used as reducing and stabilization agents. The absorption peak at 584 cm^{-1} indicates the presence of ZnO-NPs (Fig. 3).

X-ray diffraction analysis

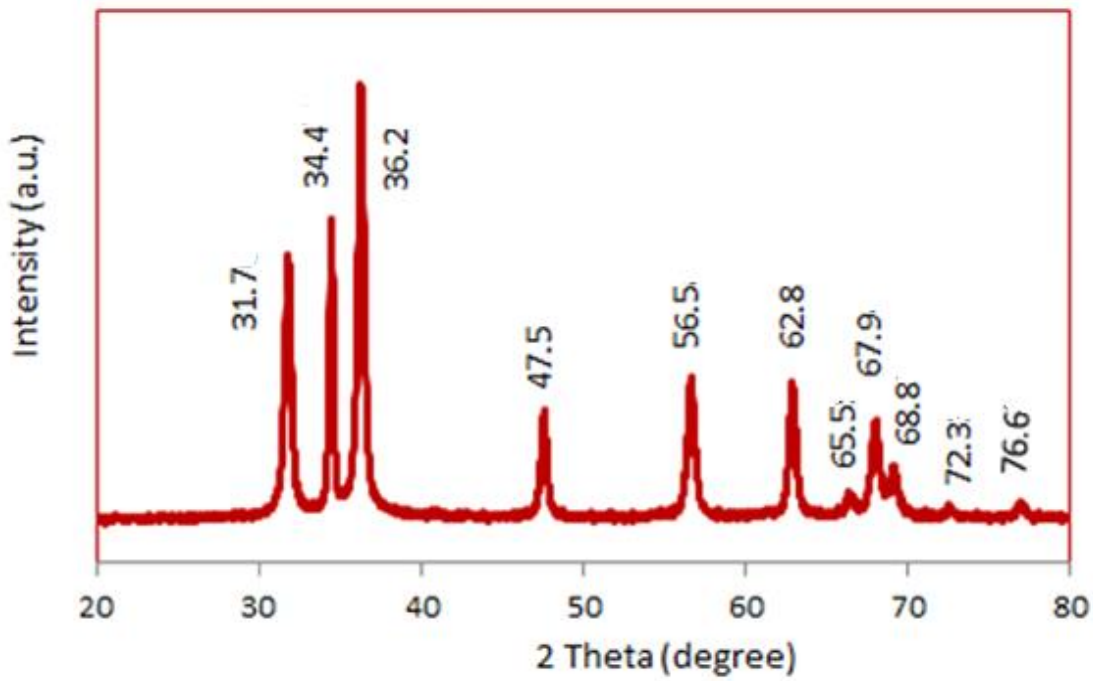

Fig. 4: XRD pattern of the ZnO-NPs synthesized using *Ailanthus altissima* fruits aqueous extract

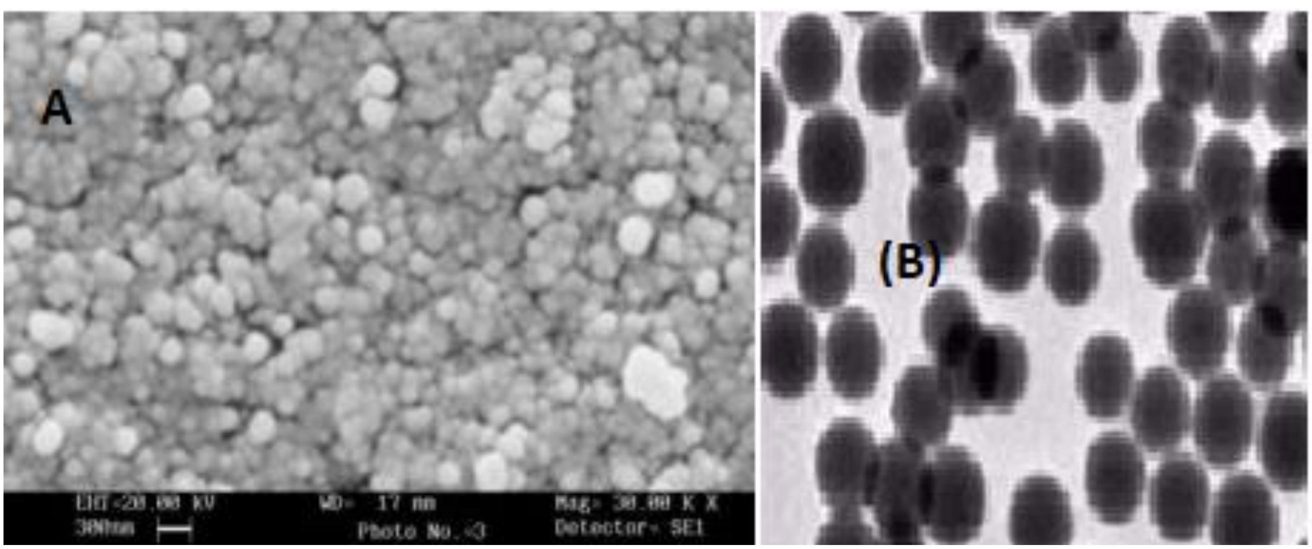

Fig. 5: Scanning electron microscopy (A-SEM) and Transmission electron microscopy (B-TEM) ZnO-NPs synthesized using *Ailanthus altissima* fruits aqueous extract

The X-ray diffraction (XRD) pattern of synthesized ZnO-NPs is illustrated in Fig. 4. The XRD pattern revealed the orientation and crystalline nature of zinc oxide nanoparticles. The peak position with 2θ values of 31.7°, 34.4°, 36.2°, 47.5°, 56.6°, 62.8°, 65.5°, 67.9°, 68.8°, 72.3° and 76.7° are indexed as (100), (002), (101), (102), (110), (103), (200), (112), (201) and (202) planes, which are in good agreement with those of powder ZnO obtained from the International Center of Diffraction Data card (JCPDS-36-1451) confirming the formation of a crystalline monoclinic structure. No extra diffraction peaks of other phases are detected, indicating the phase purity of ZnO-NPs. The average crystallite size of the *D* of synthesized nanoparticles was calculated using the well-known Scherrer formula as shown in Eq. 1.

$$D = 0.9\lambda/\beta\cos\theta \quad (1)$$

Where, λ is the wavelength of X-ray source (Cu-Kα line-0.1541 nm), β is the full width at half maximum (FWHM) in radians and θ is Bragg's diffraction angle. The calculated value of *D* was 24 nm.

SEM and TEM analysis of ZnO-NPs

The morphology of green synthesized ZnO-NPs during the synthesis process could be observed visually. The addition of *Ailanthus altissima* fruits aqueous extract to colourless zinc nitrate hexahydrate solution, changed to brown in about 10min. The completion of ZnO-NPs formation, takes 2h under magnetic bar stirring and at temperature 70-80^{o}C for 2h. The formation of ZnO-NPs was confirmed by UV-vis spectrum (Fig. 1) and morphology of synthesized ZnO-NPs as observed by SEM and TEM is presented in Fig. 5. The formed ZnO-NPs have spherical shape. The particle size of the synthesized ZnO-NPs by this green method showed the particle size range from 5-40 nm and with an average size of 20 nm.

Antibacterial activity of ZnO-NPs

Synthesized ZnO-NPs were tested by disk diffusion method using selected organisms such as Gram-negative bacteria *E. coli,* and Gram-positive bacteria *S. aureus.* As the concentration of ZnO-NPs increases, the zone of inhibition also increased against the bacteria strain. Zone of inhibition values determined for the treated ZnO-NPs (0.5mg/ml) were shown in Table 1. Zinc oxide nanoparticles have a significant growth inhibition effect against *S. aureus and E. coli bacteria*. This effect is resulted from high surface area of ZnO-NPs and their small particle size 12 nm. These findings are in line with previous studies that ZnO fabricated via green route, were highly active antimicrobial agents, i.e., *Acalypha fruticosa* L. leaf extract mediated synthesis of ZnO-NPs was performed and antimicrobial activities were tested against *Staphylococcus aureus, Bacillus subtilis, Proteus vulgaris, Pseudomonas aeruginosa, Candida albicans and Aspergillus niger* and ZnO prepared via green route showed excellent antimicrobial activity (Vijayakumar et al., 2019). Similalrly, *Medicago sativa* L. extract was used for the synthesis of ZnO-NPs and antimicrobial activity was evaluated against *Staphylococcus epidermidis* ATCC49461, *Lactococcus lactis* ATCC49032 and *Lactobacillus casei* ATCC334 and yeast (*Candida albicans* ATCC10231 and *Saccharomyces cerevisiae* MG012794). It was observed that the ZnO-NPs fabricated via green route were highly active against panel of strains (Król et al., 2019). Also, ZnO nanoparticles prepared via green route using *Raphanus sativus* root extract showed excellent on antimicrobial activity against MDR strain for wound healing applications (Kiran Kumar et al., 2019). Hence, the ZnO prepared via green route using *Ailanthus altissima* fruits aqueous extract could possibly be used as antimicrobial agent. In view of negative impact of conventional methods for the synthesis of nanoparticle, green synthesis is best alternative for the synthesis of NPs (Balwe et al., 2017; da Silva et al., 2019; Kumar Sur et al., 2018; Suresh et al., 2018).

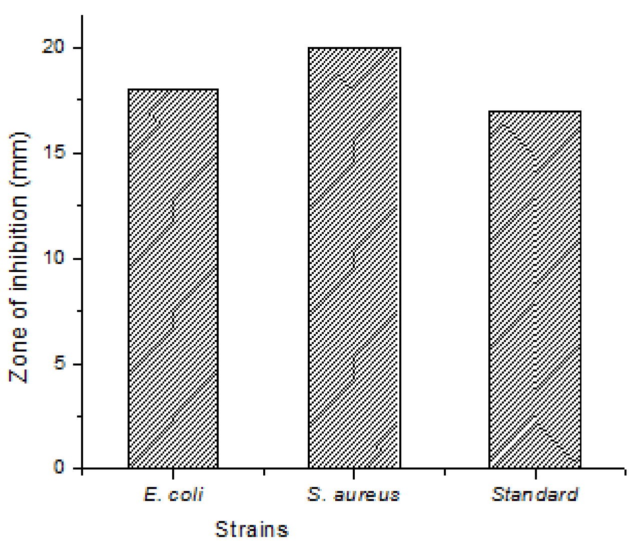

Fig. 5: Antimicrobial activity of the ZnO-NPs synthesized using *Ailanthus altissima* fruits aqueous extract

CONCLUSIONS

Green synthesis of ZnO-NPs using *Ailanthus altissima* fruits aqueous extract was investigated in present investigation. The main advantage of this synthesis is its simplicity, cost-effective synthetic route and large scale production of ZnO-NPs. The formation of ZnO-NPs was confirmed by SEM, TEM and XRD analysis. The synthesized nanoparticles were highly active as antibacterial agent against pathogenic bacteria like *E. coli* and *S. aureus* at a very low concentration. It is concluded based on results, that green synthesis using *Ailanthus altissima* fruits aqueous extract is an efficient synthesis route for ZnO-NPs at nano-scale, which can also be extended for the synthesis of other metal oxide NPs.

ACKNOWLEDGEMENTS

The authors are thankful to the University of Jordan and Royal Scientific Society, Amman, Jordan and Abdul Hameed Shoman Fund for Support of Scientific Research, Jordan.

REFERENCES

Ahmad, R.R., Harun, Z., Othman, M.H.D., Basri, H., Yunos, M.Z., Ahmad, A., Akhair, S.H.M., Rashid, A.Q.A., Azhar, F.H., Alias, S.S., Ainuddin, A.R., 2019. Biosynthesis of zinc oxide nanoparticles by using fruits extracts of *Ananas Comosus* and its antibacterial activity. Malaysian Journal of Fundamental and Applied Sciences 15, 268-273.

Al Abduullah, K., Awad, S., Zaraket, J., Salame, C., 2017. Synthesis of ZnO nanopowders by using sol-gel and studying their structural and electrical properties at different temperature. Energy Procedia 119, 565-570.

Aminuzzaman, M., Ying, L.P., Goh, W.-S. Watanabe A., 2018. Green synthesis of zinc oxide nanoparticles using aqueous extract of *Garcinia mangostana* fruit pericarp and their photocatalytic activity. Bulletin of Materials Science 41, 50.

Anbuvannan, M., Ramesh, M., Viruthaagiri, G., Shanmugam, N., Kannadasan, N., 2015. *Anisochilus carnosus* leaf extract mediated synthesis of zinc oxide nanoparticles for antibacterial and photocatalytic activities. Materials Science in Semiconductors Processing 39, 621-628.

Asemani, M., Anarjan, N., 2019. Green synthesis of copper oxide nanoparticles using *Juglans regia* leaf extract and assessment of their physico-chemical and biological properties. Green Processing and Synthesis 8, 557-567.

Balwe, S.G., Shinde, V.V., Rokade, A.A., Park, S.S., Jeong, Y.T., 2017. Green synthesis and characterization of silver nanoparticles (Ag NPs) from extract of plant Radix Puerariae: An efficient and recyclable catalyst for the construction of pyrimido[1,2-b]indazole derivatives under solvent-free conditions. Catalysis Communications 99, 121-126.

Bhuyan, T., Mishra, K., Khanuja, M., Prasad, R., 2015. Biosynthesis of zinc oxide nanoparticles from Azadirachta indica leaf extract for antibacterial and photocatyltic applications. Materials Science in Semiconductors Processing 32, 55-61.

Chung, Y.T., Ba-Abbad, M.M., Mohammad, A. W., Hairom, N.H.H., Benamor, A., 2015. Synthesis of minimal-size ZnO nanoparticles through sol–gel method: Taguchi design optimization. Materials and Design 87, 780-787.

da Silva, A.F.V., Fagundes, A.P., Macuvele, D.L.P., de Carvalho, E.F.U., Durazzo, M., Padoin, N., Soares, C., Riella, H.G., 2019. Green synthesis of zirconia nanoparticles based on Euclea natalensis plant extract: Optimization of reaction conditions and evaluation of adsorptive properties. Colloids and Surfaces A: Physicochemical and Engineering Aspects 583, 123915.

Divya, M.J., Sowmia, C., Joona, K., Dhanya, K. P., 2013. Synthesis of zinc oxide nanoparticle from *Hibiscus rosa-sinensis* leaf extract and investigation of its antimicrobial activity. Research Journal of Pharmaceutical, Biological and Chemical Sciences 4, 1137-1142.

Fakharij, S., Jamzad, M., Fard, H.K., 2019. Green synthesis of zinc oxide nanoparticles: A comparison. Journal Green Chemistry Letters and Reviews 12, 19-24.

Fu, L., Z. Fu, Z., 2015. *Plectranthus amboinicus* leaf extract–assisted biosynthesis of ZnO nanoparticles and their photocatalytic activity. Ceramics International 41, 2492-2496.

Ghorbani, H.R., Mehr, F.P., Pazoki, H., B. M. Rahmani, B.M., 2015. Synthesis of ZnO nanoparticles by precipitation method. Oriental Journal of Chemistry 31, 1219-1221.

Happy, A., Soumya, M., Kumar, S.V., Rajeshkumar, S., Sheba, R.D., Lakshmi, T., V. D. Nallaswamy, V.D., 2019. Phyto-assisted synthesis of zinc oxide nanoparticles using *Cassia alata* and its antibacterial activity against *Escherichia coli*. Biochemistry and Biophysics Reports 17, 208–211.

Hasnidawani, J.N., Azlina, H.N., Norita, H., Bonnia, N.N., Ratim, S., Ali, E.S., 2016. Synthesis of ZnO nanostructures using sol-gel method. Procedia Chemistry 19, 211-216.

Ijaz, F., Shahid, S., Khan, S.A., Ahmad, W., S. Zaman, S., 2017. Green synthesis of copper oxide nanoparticles using Abutilon indicum leaf extract: Antimicrobial, antioxidant and photocatalytic dye degradation activities. Tropical Journal of Pharmaceutical Research 16, 743-753.

Jamdagni, P., Khatri, P., J.S. Rana, J.S., 2018. Green synthesis of zinc oxide nanoparticles using flower extract of Nyctanthes arbor-tristis and their antifungal activity. Journal of King Saud University–Science 30, 168–175.

Katiyar, A., Kumar, N., Srivastava, A., 2018. Optical properties of ZnO nanoparticles synthesized by co-precipitation method using LiOH. Materials Today: Proceedings 5, 9144-9147.

Khanna, P.K., Kunal, K., Dhanabalan, K., Banerjee, S., Reji, N., Shinde, S.D., G.H. Jain, G.H., 2012. Sonochemical synthesis of ZnO nano-particles and their application in hydrogen sulphide gas sensing. Journal of Nanoscience and Nanotechnology 12, 2791-2796.

Kiran Kumar, A.B.V., Saila, E.S., Narang, P., Aishwarya, M., Raina, R., Gautam, M., Shankar, E.G., 2019. Biofunctionalization and biological synthesis of the ZnO nanoparticles: The effect of *Raphanus sativus* (white radish) root extract on antimicrobial activity against MDR strain for wound healing applications. Inorganic Chemistry Communications 100, 101-106.

Kooti, M., Sedeh, A.N., 2013. Microwave-assisted combustion synthesis of ZnO nanoparticle. Journal of Chemotherapy 4, 1–4.

Król, A., Railean-Plugaru, V., Pomastowski, P., Buszewski, B., 2019. Phytochemical investigation of *Medicago sativa* L. extract and its potential as a safe source for the synthesis of ZnO nanoparticles: The proposed mechanism of formation and antimicrobial activity. Phytochemistry Letters 31, 170-180.

Kumar Sur, U., Ankamwar, B., Karmakar, S., Halder, A., Das, P., 2018. Green synthesis of Silver nanoparticles using the plant extract of Shikakai and Reetha. Materials Today: Proceedings 5, 2321-2329.

Lalithamba, H.S., Raghavendra, M., Uma, K., Yatish, K.V., Mousumi, D., G. Nagendra, G., 2018. *Capsicum annuum* fruit extract: A novel reducing agent for the green synthesis of ZnO nanoparticles and their multifunctional applications. Acta Chimica Slovenica 65, 354-364.

Mahamuni, P.P., Patil, P.M., Dhanavade,M.J., Badiger, M.V., Shadija, P.G., Lokhande, A.C., Bohara, R.A., 2018. Synthesis and characterization of zinc oxide nanoparticles by using polyol chemistry for their antimicrobial and antibiofilm activity. Biochemistry and Biophysics Reports 12, 71-80.

Mahendiran, D., Subash, G., Arumai Selvan, D., Rehana, D., Senthil Kumar, R., Kalilur Rahiman, A., 2017. Biosynthesis of zinc oxide nanoparticles using plant extracts of *Aloe vera* and and *Hibiscus sabdariffa*: Phytochemical, antibacterial, antioxidant and anti-proliferative studies. Journal of Bionanoscience 7, 530–545.

Manokari, M., Latha, R., Priyadharshini, S., Cokul, R.M., Beniwal, P., M. S. Shekhawat, M.S., 2019. Green synthesis of zinc oxide nanoparticles from aqueous extracts of Sesamum indicum L. and their characterization. World News of Natural Sciences 23, 200-210.

Matinise, N., Fuku, X.G., Kaviyarasu, K., Mayedwa, N., Maaza, M., 2017. ZnO nanoparticles via *Moringa oleifera* green synthesis: Physical properties and mechanism of formation. Applied Surface Science 406, 339-347.

Mohammadi, F.M., Ghasemi, N., 2018. Influence of temperature and concentration on biosynthesis and characterization of zinc oxide nanoparticles using cherry extract. Journal of Nanostructure in Chemistry 8, 93-102.

Mohan, A. C., Renjanadevi, B., 2016. Preparation of zinc oxide nanoparticles and its characterization using scanning electron microscopy (SEM) and X-Ray diffraction (XRD). Procedia Technology 24, 761-766.

Narkiewicz, U., Sibera, D., Kuryliszyn-Kudelska, I., Kilanski, L., Dobrowolski, W., Romcevic, N., 2008. Synthesis by wet chemical method and characterization of nanocrystalline ZnO doped with Fe_2O_3. Acta Physica Polonica A 113, 1695-1700.

Nava, O.J., Soto-Robles, C.A., Gómez, C.M., Luque, P., Vilchis-Nestor, A.R., Castro-Beltrán, A., Olivas, A., 2017. Fruit peel extract mediated green synthesis of zinc oxide nanoparticles. Journal of Molecular Structure 1147, 1-6.

Ogunyemi, S.O., Abdallah, Y., Zhang, M., Fouad, H., Hong, X., Ibrahim, E., Masum, M.M.I., Hossain, A., Mo, J., Li, B., 2019. Green synthesis of zinc oxide nanoparticles using different plant extracts and their antibacterial activity against *Xanthomonas oryzae* pv. oryzae. Artificial Cells, Nanomedicine, and Biotechnology 47, 341-352.

Pal, S., Mondal, S., Maity, J., Mukherjee, R., 2018. Synthesis and characterization of ZnO nanoparticles using *Moringa Oleifera* leaf extract: Investigation of photocatalytic and antibacterial activity. International Journal of Nanoscience and Nanotechnology 14, 111-119.

Rad, S.S., Sani, A.M., Mohseni, S., 2019. Biosynthesis, characterization and antimicrobial activities of zinc oxide nanoparticles from leaf extract of *Mentha pulegium* (L.). Microbial Pathogenesis 131, 239-245.

Raj, L.F.A., Jayalakshmy E. 2015. Biosynthesis and characterization of zinc oxide nanoparticles using root extract of *Zingiber officinale*. Oriental Journal of Chemistry 31, 51–56.

Raja, A., Ashokkumar, S., Marthandam, R.P., Jayachandiran, J., Khatiwadae, C.P., Kaviyarasuf, K., Ramang, R.G., M. Swaminathanh, M., 2018. Eco-friendly preparation of zinc oxide nanoparticles using *Tabernaemontana divaricata* and its photocatalytic and antimicrobial activity. Journal of Photochemistry and Photobiology, B: Biology 181, 53-58.

Rajeswari, M., Agrawal, P., Roopa, G. S., Jain, A. Gupta, P.K., 2018. Green synthesis and characterization of multifunctional zinc oxide nanomaterials using extract of *Moringa oleifera* seed. Materials Today: Proceedings 5, 20996-21002.

Renata, D., Długaszewska, J., 2015. Biosynthesis and antibacterial activity of ZnO nanoparticles using *trifolium pratense* flower extract. Saudi Journal of Biological Sciences 23, 517–523.

Salam, H.A., Sivaraj, R., Venckatesh, R., 2014. Green synthesis and characterization of zinc oxide nanoparticles from *Ocimum basilicum* L. var. purpurascens Benth.-*Lamiaceae* leaf extract. Materials Letters 131, 16-18.

Sangeetha, G., Rajeshwari, S., R. Venckatesh, R., 2011. Green synthesis of zinc oxide nanoparticles by aloe *Barbadensis miller* leaf extract: Structure and optical properties. Materials Research Bulletin 46, 2560-2566.

Shamhari, N.M., Wee, B.S., Chin, S.F., Kok, K.Y., 2018. Synthesis and characterization of zinc oxide nanoparticles with small particle size distribution. Acta Chimica Slovenica 65, 578-585.

Shao-Hwa, H., Chuan, C.Y., Chyi-Ching, H., Cheng-Hsiung, P., Dah-Chuan, G., 2010. Analysis of growth parameters for hydrothermal synthesis of ZnO nanoparticles through a statistical experimental design method. Journal of Materials Science 45, 5309-5317.

Stan, M., Popa, A., Toloman, D., Dan, T. S., Vodnar, C., 2016. Antibacterial and antioxidant activities of ZnO nanoparticles synthesized using extracts of *Allium sativum, Rosmarinus officinalis* and *Ocimum basilicum*. Acta Metallurgica Sinica 29, 228–236.

Sukri, S.N.A.M., Shameli, K., Wong, M.-T. Teow, S.-Y., Chew, J., N. AfiniIsmail, N., 2019. Cytotoxicity and antibacterial activities of plant-mediated synthesized zinc oxide (ZnO) nanoparticles using *Punica granatum* (pomegranate) fruit peels extract. Journal of Molecular Structure 1189, 57-65.

Sundrarajan, M., Ambika, S., K. Bharathi, K., 2015. Plant-extract mediated synthesis of ZnO nanoparticles using *Pongamia pinnata* and their activity against pathogenic bacteria. Advanced Powder Technology 26, 1296-1299.

Supraja, N., Prasad, T., Krishna, T.G., David, E., 2016. Synthesis, characterization, and evaluation of the antimicrobial efficacy of *Boswellia ovalifoliolata* stem bark-extract-mediated zinc oxide nanoparticles. Applied Nanoscience 6, 581-590.

Suresh, J., Pradheesh, G., Alexramani, V., M. Sundrarajan, M., Ig Hong, S., 2018. Green synthesis and characterization of zinc oxide nanoparticle using insulin plant (*Costus pictus* D. Don) and investigation of its antimicrobial as well as anticancer activities. Advances in Natural Sciences: Nanoscience and Nanotechnology 9, 015008.

Suresh, J., Pradheesh, G., Alexramani, V., Sundrarajan, M., Hong, S.I., 2018. Green synthesis and characterization of hexagonal shaped MgO nanoparticles using insulin plant (*Costus pictus* D. Don) leave extract and its antimicrobial as well as anticancer activity. Advanced Powder Technology 29, 1685-1694.

Sutradhar, P., Saha, M., 2017. Green synthesis of zinc oxide nanoparticles using tomato (*Lycopersicon Esculentum*) extract and its photovoltaic application. Journal of Experimental Nanoscience 11, 314–27.

Venkateasan, A., Prabakaran, R., Sujatha, V., 2017. Phytoextract-mediated synthesis of zinc oxide nanoparticles using aqueous leaves extract of *Ipomoea pescaprae* (L). R. br revealing its biological properties and photocatalytic activity. Nanotechnology for Environmental Engineering 2, 8.

Vennila, S., Jesurani, Sr.S., 2017. Eco-friendly green synthesis and characterization of stable ZnO Nanoparticle using small Gooseberry fruits extracts. International Journal of ChemTech Research 10, 271-2745.

Vijayakumar S., Krishnakumar C., Arulmozhi P., Mahadevan S., Parameswari N., 2018. Biosynthesis, characterization and antimicrobial activities of zinc oxide nanoparticles from leaf extract of *Glycosmis pentaphylla* (Retz.) DC. Microbial Pathogenesis 116, 44-48.

Vijayakumar, S., Arulmozhi, P., Kumar, N., Sakthivel, B., Prathip Kumar, S., Praseetha, P.K., 2019. *Acalypha fruticosa* L. leaf extract mediated synthesis of ZnO nanoparticles: Characterization and antimicrobial activities. Materials Today: Proceedings https://doi.org/10.1016/j.matpr.2019.06.660.

Vijayakumar, S., Mahadevan, S., Arulmozhi, P., P.K. Praseetha, P.K., 2018. Green synthesis of zinc oxide nanoparticles using *Atalantia monophylla* leaf extracts: Characterization and antimicrobial analysis. Materials Science in Semiconductor Processing 82, 39-45.

Yedurkar, S., Maurya, C., Mahanwar, P., 2016. Biosynthesis of zinc oxide nanoparticles using *Ixora coccinea* leaf extract - A green approach. Open Journal of Synthesis Theory and Applications 5, 1-14.

Yildirim, O.A., Durucan, C., 2010. Synthesis of zinc oxide nanoparticles elaborated by microemulsion method. Journal of Alloys and Compounds 506, 944-949.

Yugandhar, P., Vasavi, T., Uma, P., Devi, M., Savithramma, N., 2017. Bioinspired green synthesis of copper oxide nanoparticles from Syzygium alternifolium (Wt.) Walp: characterization and evaluation of its synergistic antimicrobial and anticancer activity. Applied Nanoscience 7, 417-427.

Zheng, Y., Fu, L., Han, F., Wang, A., Cai, W., Yu, J., Peng, F., 2015. Green biosynthesis and characterization of zinc oxide nanoparticles using *Corymbia citriodora* leaf extract and their photocatalytic activity. Green Chemistry Letters and Reviews 8, 59–63.

Visit us at: http://bosaljournals.com/chemint/
Submissions are accepted at: editorci@bosaljournals.com