

Green synthesis of Zinc Oxide Nanoparticles Using Eucalyptus Mellidora Leaf Extract and Evaluation of its Antimicrobial Effects

B. Rafiee (MSc)^{*1}, S. Ghani (MSc)², D. Sadeghi (PhD)³, M. Ahsani (BSc)⁴

1. Young Researchers and Elite Club, Arak Branch, Islamic Azad University, Arak, I.R.Iran

2. Department of Biotechnology, School of Advanced Technologies in Medicine, Shahid Beheshti University of Medical Sciences, Tehran, I.R.Iran

3. Biology Research Center, Faculty and Research Institute of Basic Sciences, Imam Hossein University of Technology, Tehran, I.R.Iran

4. Department of Horticulture, Faculty of Agriculture, Arak University, Arak, I.R.Iran

J Babol Univ Med Sci; 20(10); Oct 2018; PP: 28-35

Received: Mar 25th 2018, Revised: Sep 5th 2018, Accepted: Sep 16th 2018.

ABSTRACT

BACKGROUND AND OBJECTIVE: Green production of nanoparticles is an environmentally friendly method in which natural solvents are used. Green nanoparticle synthesis methods have priority over chemical and physical methods due to the reduction of cost, time and energy. The purpose of this study was to biosynthesize zinc oxide nanoparticles and evaluate the antibacterial activity of these nanoparticles.

METHODS: In this experimental study, the extract of *Eucalyptus melliodora* was combined at a ratio of 1: 1 with 0. 1 M zinc sulfate and kept at room temperature for 15 minutes. Synthesis of zinc oxide nanoparticles was confirmed by spectrophotometric methods, mean diameter of nanoparticles measurement, X-ray diffraction and electron microscopy (SEM). Then, the MIC of zinc oxide nanoparticles was measured on standard strains of *Staphylococcus aureus* 1431PTCC, *Bacillus cereus* 1015PTCC, *Escherichia coli* 1399PTCC and *Pseudomonas aeruginosa* 1571PTCC.

FINDINGS: The absorption peak of ZnO NPs was observed at 350 nm. The SEM showed ZnO nanoparticles was spherical shape of size ranging from 30 to 50 nm. The highest MIC was observed for *Pseudomonas aeruginosa* with 0. 0019 mg / ml and the lowest MIC for *Bacillus cereus* with 0. 62 mg / ml. Also, in comparison with ZnO nanoparticles, *Eucalyptus* extract and Zinc sulfate had the most antimicrobial activity for zinc oxide nanoparticles and their MIC had significant difference in the effect on the bacteria tested ($p < 0. 05$).

CONCLUSION: The results of this study showed biological nanoparticles of ZnO and aqueous extract of *Eucalyptus* as well as zinc sulfate have antimicrobial properties, but the most antimicrobial effects were observed by ZnO NPs.

KEY WORDS: Anti-Bacterial Activity, Green synthesis, Zinc Oxide Nanoparticles.

Please cite this article as follows:

Rafiee B, Ghani S, Sadeghi D, Ahsani M. Green synthesis of Zinc Oxide Nanoparticles Using Eucalyptus Mellidora Leaf Extract and Evaluation of its Antimicrobial Effects. J Babol Univ Med Sci. 2018;20(10):28-35.

*Corresponding Author: B. Rafiee (MSc)

Address: Young Researchers and Elite Club, Arak Branch, Islamic Azad University, Arak, I.R.Iran

Tel: +98 86 33412251

E-mail: rafiee.17b@gmail.com

Introduction

Nanotechnology has witnessed significant progress in the field of nanomaterials and the use of methods and new materials have been developed and discovered new ways for concerns about environmental pollution by nanoparticles through chemical methods and their products, therefore they require green chemical methods which are healthy, non-toxic and environmentally friendly (2,1). The nanoparticles synthesized biologically plays an important role in modern medicine because of the modern characteristics and environmental sustainability (3). The use of living microorganisms such as fungi, bacteria, yeast, actinomycetes and macro organisms such as plants, algae as an intermediate in the synthesis of nanoparticles of mineral composition, can be another way besides the physical and chemical methods for nano-particle production (4), for example the synthesis of iron nanoparticles by *Bacillus megatrium* bacteria (5). In general, biochemical methods of nanoparticle production are paramount importance to physical and chemical methods due to lower costs, energy and time. This method does not require the use of toxic solvents and hazardous materials for the environment. Green production of nanoparticles is a friendly nature in which the solvents normally used in the production and assembly of nanoparticles using green chemistry in 1990 were considered and, over time, the use of green plants to produce bio-nanoparticles offer a thrill opportunity and is widely known (6). Therefore, plants and plant products are much more interested in the production of nanoparticles, moreover, nanoparticles produced by medicinal plants with lower risk can be used in some cases, such as drug transfer. Research has also shown that nanoparticles produced by plants are made faster than nanoparticles derived from the activity of other organisms and are more stable (7), the shape and size of nanoparticles made by plants differ from nanoparticles derived from other organisms, so the advantage of plant production of nanoparticles compared with other methods such as use of bacteria, algae, yew and fungi are reliability and safety of plant methods and they are more healthier, cheaper and more renewable (8). These include the biosynthesis of silver

nanoparticles by the plant, as well as the biosynthesis of gold nanoparticles using Iranian clover seeds (10, 9). World-class nanoparticles, with their exciting and unique features can be used in areas such as diagnosis, nano-medicine and antimicrobial properties. So that nanotechnology is also in place to solve the antibiotics resistance problem (11-13). One of the most important nanoparticles is zinc oxide used industrially in most countries (14). Zinc nanoparticles in food packaging, in biosensors, in the imaging of cells and in the treatment of cancer, in cosmetics, in water and sewage treatment, as well as zinc oxide metal nanoparticles, are also antimicrobial and have been used for many uses in the last two decades (20-15). Zinc oxide nanoparticles are used to combat gram-negative and gram-positive bacteria, and also as an antifungal agent (22, 21). The mechanism of antimicrobial action of zinc oxide is similar to that of other nanoparticles, and acts mainly through the destruction of the bacterial wall (19). In principle, the mechanism of toxic effects of nanoparticles is not well known, but recent research has shown these toxic effects are mediated by high contact levels of nanoparticles, their permeability to cells and organisms, membrane damage, DNA damage, inflammation in cells, and changes in related cellular interactions (23). Therefore, the aim of this study was to study the green synthesis of ZnO nanoparticles using *Eucalyptus Melidoura* leaf extract and also to investigate the antimicrobial activity of zinc oxide nanoparticles against a number of common gram-negative bacteria (*Staphylococcus aureus*, *Bacillus cereus*, *Escherichia coli* strains and *Pseudomonas aeruginosa*). The aim of this study was to synthesize zinc oxide nanoparticles in green and to investigate the antibacterial activity of these nanoparticles.

Methods

Synthesis of ZnO nanoparticles using *Eucalyptus Melidoura* extract: In order to prepare the *Eucalyptus Melidoura* extract, the *Eucalyptus Melidoura* leaves were collected from Dezful's Medicinal Garden, then extracted by boiling method, and finally, 0.45 microns' filters were used to sterilize the extract of the plant. The

sulfate solution was then prepared at 0.1 molar and filtered with filter paper. The extracts were then combined with a 1: 1 ratio of zinc sulfate, and the nanoparticles were synthesized at room temperature over a period of 15 minutes.

Specification of zinc oxide nanoparticles using spectrophotometry (Uv-vis): The absorption spectra of nanoparticles were performed by a spectrophotometer (Uv-visSERIES8000CECIL). The zinc nanoparticle absorbance was investigated at a wavelength of 200-700 nm.

Measurement of the Dynamic Light Scattering (Zeta potential) and the Poly Dispersity Index (DLS) and the Zeta potential representing the stability of the nanoparticles, as well as (PDI) from the ZetaSizer (Manufacturing company Malvern-England).

X-Ray Diffraction: A solution containing zinc nanoparticles was centrifuged three times at 20,000 rpm, then the supernatant was discarded and the precipitate dried in the oven. Finally, dried powder was investigated for X-ray diffraction analysis of crystalline nanoparticles.

Scanning Electron Microscopy: The shape and size of the zinc oxide nanoparticles were examined using the HITACHI S-4500 SEM device. So that 15 µl of ZnO nanoparticles were sprayed onto SEM special grains and examined after drying.

Determine the antibacterial properties

Disc diffusion method: To study antibacterial properties, standard strains of *Staphylococcus aureus* 1431 PTCC, *Bacillus cereus* 1015PTCC as gram-positive bacteria and *Escherichia coli* 1399PTCC, *Pseudomonas aeruginosa* 1571PTCC were used as gram-negative bacteria. 100 µl of each bacterium with a concentration of half MacFarland's was cultured on a Muller hinton agar medium. For each of the four bacteria, four plates containing a 6 µl impregnated disc from a zinc oxide nanoparticle suspension, a 6 µl diluted solution of 0.1 molar zinc sulfate and a 6 µl disk eucalyptus extract were used. After 24 hours, the non-growth halo diameter was measured and recorded as an antibacterial property index of the specimens. These tests were repeated three times to prevent the occurrence

of errors in all stages of operation, and the results were recorded.

Tube dilution method: The minimum concentration of bacterial growth inhibitory (MIC) in Tryptic Soy Broth (TSB) culture media was loaded into 4 set of 10 tubes containing 1 ml sterile TSB environment, into a tube of 1 ml of a Zinc sulfate nanoparticle solution was added. After stirring 1 ml from the first tube into the second tube, then 1 ml from the second tube was added to the third tube, and then until the last tube, and finally 1 ml was poured out of the last tube. All tubes were added 1 ml active bacteria suspension, which was standardized in accordance with the half-MacFarland tube. All tubes were placed in a suitable temperature incubator for 24 hours. After 24 hours, due to the opacity in the tubes, the MIC was determined. These tests were repeated three times to prevent the occurrence of errors in all stages of operation, and the results were recorded.

Results

Spectrophotometer (UV-Vis): In the analysis of zinc nanoparticles with a spectrophotometric Uv-vis, absorption peak of zinc nanoparticles was observed at nm350 wavelengths, which indicated the presence of nanoparticles of zinc in the reaction solution (Fig. 1). The maximum absorption peak of zinc nanoparticles is at 400-300 nm (24).

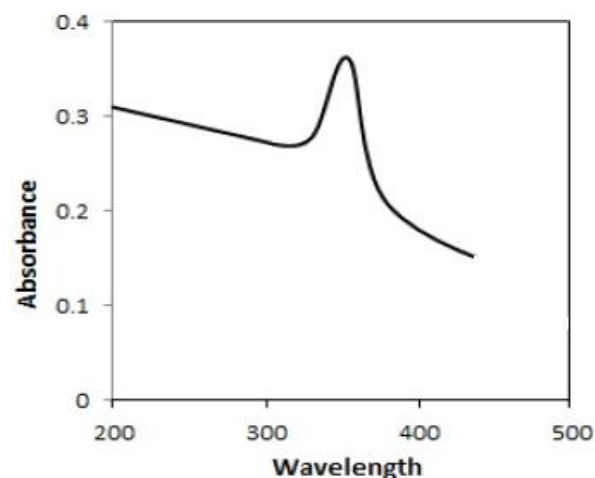


Figure 1. Uv-vis absorption spectra of zinc nanoparticles

The average size of nanoparticle diameter (DLS), zeta potential, and dispersion index of nanoparticles (PDI): In this study, using a zeta-synthesizer device in the range of 8PH, the mean diameter of nanoparticles synthesized were in the range of 37 nm (Fig. 2), also (PDI) was equal to 0.43, indicating a high uniformity of the colloidal solution of the synthesized nanoparticles. Moreover, the zeta potential was recorded as 19.6-millivolt, indicating a very stable zinc nanoparticle (Fig. 3).

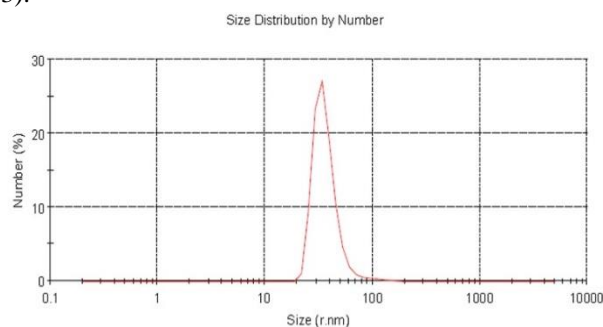


Figure 2. Diagram of average diameter of Zn nanoparticles

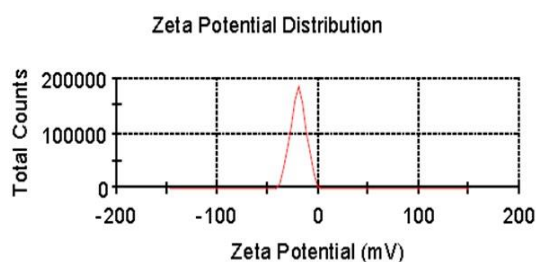


Figure 3. Zeta Potential Chart of Zn Nanoparticles

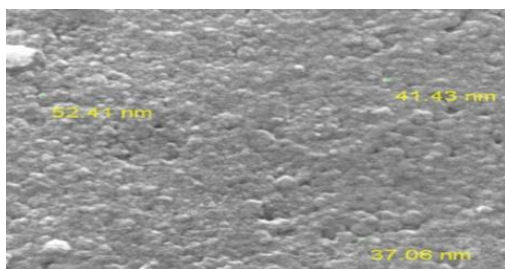


Figure 4. XRD pattern of zinc oxide nanoparticles

X-ray diffraction (XRD): XRD analysis was performed to prove zinc nanoparticles formation. The spectrum obtained from the x-ray editing at the angle θ has peaks (100-002-101-102-110-103-200-112-201) (Fig. 4) which conforms to the X-ray diffraction pattern (ZnO) and no other phase is observed (Fig. 2).

Scanning Electron Microscope (SEM): Images (SEM), Zn nanoparticles are shown in Fig. 3. This is used to confirm the morphology and size of nanoparticles. According to SEM images, nanoparticles were spherical and the size of nanoparticles was between 30-50 nm (Fig. 4).

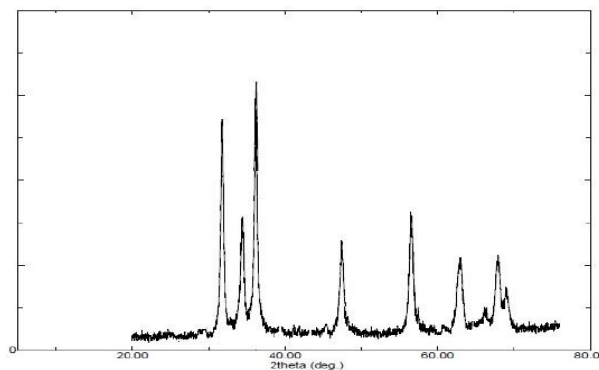


Figure 4. SEM image of spherical nanoparticles of zinc oxide

Disc diffusion: Most antimicrobial activity of zinc oxide nanoparticles was on *Pseudomonas aeruginosa* with a diameter of inhibition zone of 30 ml and the least antimicrobial activity was on *Bacillus cereus* with a diameter of inhibition zone of 20 ml (Table 1). According to the results, the antimicrobial properties of zinc nanoparticles were greater than the antimicrobial activity of the eucalyptus extract and zinc sulfate.

Minimum inhibitory concentration (MIC): Results of antimicrobial activity of zinc nanoparticles showed that the highest antimicrobial effect on *Pseudomonas aeruginosa* with 0.0019 MIC / mg / ml and the least antimicrobial activity on *Bacillus cereus* with 0.062 mg/ml MIC (Table 2).

Statistical analysis: All statistical tests used in this study were Kruskal Wallis. The evaluation index was mesian in Kroschal Wallis and based on Chi-square (χ^2) and $p < 0.05$ was considered significant. As for the diameter of the non-growth halos, three antimicrobial compounds were evaluated for effect on the diameter of non-growth halo on the four different microorganisms which there was a significant difference between them (Table 1). In the case of statistical analysis (MIC), the three groups of antimicrobial agents had a significant difference in the effect on all four microorganisms, and zinc sulfate had significantly lower MIC in all four types of microorganisms (Table 2).

Table 1. The results of measuring the diameter of the non-growth halo

Table 1: The Results of measuring the diameter of the non-growth halo											
Bacteria	Repeat	diameter of the non-growth halo (mm)									Statistical analysis
		Eucalyptus Extract			Zinc oxide nanoparticles			Zinc sulfate			
		First	Second	Third	First	Second	Third	First	Second	Third	
Bacillus cereus		6.5	7	7	20	20	20	13.7	14	14	chi-squared=7.579 with 2 d.f. probability=0.0226
Pseudomonas aeruginosa		17.8	18.2	18	30	29.5	30	14.8	14.8	15	chi-squared=7.200 with 2 d.f. probability=0.0273
Staphylococcus aureus		15	15.2	15	24.6	25	25	15.7	15.8	16	chi-squared=7.200 with 2 d.f. probability=0.0273
Escherichia coli		11.8	12	12	27.5	28	28	16	16.2	16	chi-squared=7.200 with 2 d.f. probability=0.0273
Total											X2= 7.538 with 2 d.f.p=0.0231

Table 2. Results of MIC measurements

Table 2: Results of MIC measurements											
		Minimum inhibitory concentration from growth (mg/ml)									
Bacteria	Repeat	Eucalyptus on mg/ml	Extract based		Zinc nanoparticle based on mg/ml			Zinc sulfate based on mg/ml			Statistical analysis
		Third	Second	First	Third	Second	First	Third	Second	First	X2(p-value)
1	Bacillus cereus	0.062	0.062	0.062	0.0078	0.0078	0.0078	0.015	0.015	0.015	Chi-squared =7.23 with 2 d.f. probability=0.027
2	Pseudomonas aeruginosa	0.0039	0.0039	0.0039	0.0019	0.0019	0.0019	0.015	0.015	0.015	chi-squared = 7.200 with 2 d.f. probability =0.0273
3	Staphylococcus aureus	0.0039	0.0039	0.0039	0.0039	0.0019	0.0019	0.015	0.015	0.015	chi-squared =7.200 with 2 d.f. probability=0.0273
4	Escherichia coli	0.0078	0.0078	0.0078	0.0039	0.0019	0.0019	0.015	0.015	0.015	chi-squared =7.24 with 2 d.f. probability =0.0275
Total											X2 = 8.297 with 3 d.f. p=0.0403

Discussion

In this study, it was found that the aqueous extract of Eucalyptus leaves has the ability to produce zinc oxide nanoparticles from zinc sulfate, and it was found that these zinc oxide nanoparticles have antimicrobial activity and, in comparison with the aqueous extract of eucalyptus meliodura and zinc sulfate have more antimicrobial effects. The results of study of Pantidos et al. on the biological synthesis of metal nanoparticles by bacteria, fungi and herbs showed that green nanoparticle synthesis methods require less energy and cost (25). In a study by Mohamed et al., Iron nanoparticles were

synthesized by Alternaria fungus (26). In another study by Awwad et al., a green and easy method for the synthesis of magnetic nanoparticles was used (27). Raut et al. used a basal extract of ZnO nanoparticles to study the size of nanoparticles with SEM, such that the size of the nanoparticles synthesized was about 11 to 25 nm and the shape of the nanoparticles was hexagonal (28), while zinc oxide nanoparticles synthesized in our study has a size range of 30 to 50 nm and is a spherical shape. In another similar study by Yedurkar et al., using zinc acetate and Ixora Coccinea leaf extract, nanoparticles of zinc oxide were measured, the size of nanoparticles was

measured to be 80 to 130 nm, and the shape of the nanoparticles was spherical (29), which is different in size compared with our study but in terms of nanoparticle shape were similar. In another study by Bhumi et al., using zinc acetate and extract of *Catharanthus roseus* leaves, nanoparticles of zinc oxide were synthesized in the range of 23 to 57 nm in spherical shape, in addition the antimicrobial properties of zinc oxide nanoparticles was evaluated on *Pseudomonas*, *Streptococcus*, *Escherichia coli* and *Bacillus thuringiensis* bacteria, which had the highest antimicrobial effect on *Pseudomonas* and the lowest antimicrobial activity on *Escherichia coli* (30), however, our study showed the highest effect on *Pseudomonas aeruginosa* and the least effect was observed on *Staphylococcus aureus*, but in general the antimicrobial strength of ZnO nanoparticles was higher in our research based on the diameter of the non-growth zone than the above research.

In another study by Niranjana Bala et al., using Zinc acetate and extract of *Hibiscus subdariffa* leaves, zinc oxide nanoparticles were made, with size in the range of 12 to 46 nm (30), which was partially similar to the size of synthesized nanoparticles in our study. In addition, the antimicrobial effects of zinc oxide nanoparticles on *Staphylococcus aureus* and *Escherichia coli* was investigated which proved that the antimicrobial effects are in line with our research results.

In another study by Awwad et al., using zinc sulfate and olive leaves extract, biosynthesis of zinc oxide nanoparticles was performed, which revealed that nanoparticles form as Nano sheets and Nano flowers of about 500 nm (32), which in our study, this was not observed, and the nanoparticles were spherical at about 30 to 50 nanometers.

On the other hand, in another study, using *Costus pictus* leaves extracts, nanoparticles of zinc oxide were synthesized. The results of the electron microscope showed that nanoparticles with a mean size of 40 nm with hexagonal and bar geometric shapes. Also, these zinc oxide nanoparticles have antimicrobial effects on *Staphylococcus aureus*, *Escherichia coli* and *Bacillus subtilis* bacteria (33), which are in line with our study, but there is not a significant relation between the shape

of nanoparticles, which is undoubtedly related to the plant species and the compounds found in the plant extract.

Another study zinc oxide nanoparticle was made using *Parthenium hysterophorus* leaf extract which had a size range of 16-45 nm, which were spherical, pseudo spherical and cylindrical forms and had antimicrobial effects against *Staphylococcus aureus*, *Escherichia coli*, *Bacillus subtilis*, and *Klebsiella pneumoniae* (34), which is consistent with our study. In another study in Iran by Motakef-Kazemi et al., zinc oxide nanoparticles were made using parsley extract that had a nanoparticle diameter of about 50 nm in spherical shape, and the DLS analysis of the nanoparticles had a peak of 50 nm, and in terms of the antimicrobial effect of nanoparticles Zinc has an antimicrobial ability against *Escherichia coli* (35), which has largely been matched by our study. In another study by Upadhyaya et al., zinc oxide nanoparticles were synthesized using *Lawsonia inermis* extract and the results of SEM showed that the nanoparticles have a hexagonal shape with a size of 100 nm (36), which is different from our study. It is remarkable that it is unquestionably related to the construction technique and the type of plant used, as well as to the type of its basic material which is nitric oxide. It should be noted that in various researches in the world biosynthesis of zinc oxide nanoparticles was performed by different herbal extracts from Aloe Vera leaves, red clover plants and ginger rhizome (36).

In this study, zinc oxide nanoparticles were made using the *Eucalyptus Meliodora* aqueous extracts which showed the highest antibacterial effect on *Pseudomonas aeruginosa* and had the least effect on *Bacillus cereus*. On the other hand, the antimicrobial activity of ZnO nanoparticles, *Eucalyptus* aqueous extract and Zinc sulfate was also compared with Zinc oxide nanoparticles that the most antibacterial effect on all tested bacteria was seen by zinc oxide nanoparticles.

Acknowledgment

Hereby, we would like to thank the Young Researchers Club of Arak for support of this research.

References

1. Nagati V, Koyyati R, Donda MR, Alwala J, Kundle KR, Padigya PR. Green Synthesis and characterization of Silver nanoparticles from *Cajanus cajan* leaf extract and its antibacterial activity. *Int J Nanomater Biostruc*. 2012; 2(3): 39-43.
2. Atta AM, Al-Lohedan HA, Ezzat AO. Synthesis of silver nanoparticles by green method stabilized to synthetic human stomach fluid. *Molecules*. 2014;19(5):6737-53.
3. Poovizhi J, Krishnaveni B. Synthesis, characterization and antimicrobial activity of zinc oxide nanoparticles synthesized from *calotropis procera*. *Int J Pharmaceut Sci Drug Res*. 2015; 7(5): 425-431.
4. Karimi J, Mohsenzadeh S. Plant synthesis of silver nanoparticles by *Achillea wilhelmsii* Pharmaceutical plant. *Razi Journal of Medical Sciences*. 2013; 20(111): 64-9.
5. Ghani S, Rafiee B, Sadeghi D, Ahsani M. Biosynthesis of Iron Nano-Particles by *Bacillus Megaterium* and Its Anti-Bacterial Properties. *J Babol Univ Med Sci*. 2017;19(7):13-19. [In Persian]
6. Supraja S, Mohammed AS, Chakravarthy N, Jayaprakash PA, Elumalai S, Kalimuthu K, et al. Green synthesis of silver nanoparticles from *Cynodon Dactylon* leaf extract. *Int J Chem Tech Res*. 2013; 5(1):271-7.
7. Ramesh P, Rajendran A, Meenakshisundaram M. Green synthesis of zinc oxide nanoparticles using flower extract *cassia auriculata*. *J NanoSci NanoTechnol*. 2014; 2(1): 41-5.
8. Chandran SP, Chaudhary M, Pasricha R, Ahmad A, Sastry M. Synthesis of gold nanotriangles and silver nanoparticles using aloe vera plant extract. *Biotechnol Prog*. 2006; 22(2):577-83.
9. Abbasifar A, Ghani S, Ahsani Irvani M, Rafiee B, Valizade Kaji B, Akbari A. Antibacterial activity of silver nanoparticles synthesized by using extracts of *hedera helix*. *Zahedan J Res Med Sci*. 2017;19(1):e5920.
10. Khatami M, Soltaninejad M, Kaikavoosi K. Biosynthesis of gold nanoparticles using persian clover seed extracts. *Qom Univ Med Sci J*. 2016;10(2):23-30. [In Persian]
11. Jamdagni P, Khatri P, Rana JS. Nanoparticles based DNA conjugates for detection of pathogenic microorganisms. *Int Nano Lett*. 2016; 6(3):139-46.
12. Bobo D, Robinson KJ, Islam J, Thurecht KJ, Corrie SR. Nanoparticle-based medicines: a review of FDA-approved materials and clinical trials to date. *Pharm Res*. 2016;33(10): 2373-87.
13. Ahmed S, Ahmad M, Swami BL, Ikram S. A review on plants extract mediated synthesis of silver nanoparticles for antimicrobial applications: a green expertise. *J Adv Res*. 2016; 7(1):17-28.
14. Handy RD, von der Kammer F, Lead JR, Hassellöv M, Owen R, Crane M. The ecotoxicology and chemistry of manufactured nanoparticles. *Ecotoxicology*. 2008;17(4):287-314.
15. Han W, Yu Y, Li NT, Wang LB. Application and safety assessment for nano-composite materials in food packaging. *Chin Sci Bull*. 2011;56(12):1216-25.
16. Zhao M, Huang J, Zhou Y, Chen Q, Pan X, He H, Ye Z. A single mesoporous ZnO/Chitosan hybrid nanostructure for a novel free nanoprobe type biosensor. *Biosens Bioelectron*. 2013;43(1):226-30.
17. Serpone N, Dondi D, Albini A. Inorganic and organic UV filters: Their role and efficacy in sunscreens and sun care products. *Inorganica Chim Acta* 2007;360(3):794-802.
18. Bhande RM, Khobragade CN, Mane RS, Bhande S. Enhanced synergism of antibiotics with zinc oxide nanoparticles against extended spectrum β -lactamase producers implicated in urinary tract infections. *J Nanopart Res*. 2013;15(1):1-13.
19. Chen T, Zhao T, Wei D, Wei Y, Li Y, Zhang H. Core-shell nanocarriers with ZnO quantum dots-conjugated Au nanoparticle for tumor-targeted drug delivery. *Carbohydr Polym*. 2013;92(2):1124-32.
20. Reeves JF, Davies SJ, Dodd NJ, Jha AN. Hydroxyl radicals (OH) are associated with titanium dioxide (TiO₂) nanoparticle-induced cytotoxicity and oxidative DNA damage in fish cells. *Mutat Res*. 2008;640(1-2):113-22.
21. Zhang L, Jiang Y, Ding Y, Daskalakis N, Jeuken L, Povey M, et al. Mechanistic investigation into antibacterial behaviour of suspensions of ZnO nanoparticles against *E. Coli*. *J Nanopart Res*. 2010;12(5):1625-36.

- 22.Sanaeimehr Z, Javadi I, Namvar F. Antiangiogenic and antiapoptotic effects of green-synthesized zinc oxide nanoparticles using *Sargassum muticum* algae extraction. *Cancer Nanotechnol.* 2018;9(1):3.
- 23.Jagtap UB, Bapat VA. Green synthesis of silver nanoparticles using *Artocarpus heterophyllus* lam. Seed extract and its antibacterial activity. *Indust Crop Pro.* 2013;46:132-7.
- 24.Pantidos N, Horsfall LE. Biological synthesis of metallic nanoparticles by bacteria, fungi and plants. *J Nanomed Nanotechnol.* 2014;5(5):1-10.
- 25.MohamedYM, Azzam AM, Amin BH, Safwat NA. Mycosynthesis of iron nanoparticles by *Alternaria alternata* and its antibacterial activity. *African J of Biotechnol.* 2015;14(4):1234-41.
- 26.Awwad AM, Salem NM. A Green and facile approach for synthesis of magnetite nanoparticles. *Nanosci Nanotechnol.* 2012; 2(6):208-13.
- 27.Raut PS, Thorat V, Thakre R. Green Synthesis of Zinc Oxide (ZnO) Nanoparticles Using *Ocimum Tenuiflorum* Leaves. *Int J Sci Res.* 2015;17(5):1225-8.
- 28.Yedurkar S, Maurya Ch, Mahanwar P. Biosynthesis of zinc oxide nanoparticles using *ixora coccinea* leaf extract—a green approach. *Open J Synth Theory Appl.* 2016;5(1):1-14.
- 29.Bhumi G, Savithramma N. Biological Synthesis of Zinc oxide Nanoparticles from *Catharanthus roseus* (L.) G. Don. Leaf extract and validation for antibacterial activity. *Int J Drug Dev Res.* 2014; 6(1):208-14.
- 30.Bala N, Saha S, Chakraborty M, Maiti M, Das S, Basub R, Nandyc P. Green synthesis of zinc oxide nanoparticles using *Hibiscus subdariffa* leaf extract: effect of temperature on synthesis, anti-bacterial activity and anti-diabetic activity. *RSC Adv.* 2015; 5(7):4993.
- 31.Awwad AM, Albiss B, Ahmad AL. Green synthesis, characterization and optical properties of zinc oxide nanosheets using *Olea europea* leaf extract. *Adv Mat Lett.* 2014; 5(9):520-4.
32. Suresh J, Pradheesh G, Alexramani V, Sundrarajan M, Hong S. 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. *Adv Nat Sci: Nanosci. Nanotechnol.* 2018;9: 015008.
- 33.Datta A, Patra C, Bharadwaj H, Kaur S, Dimri N, Khajuria R. Green synthesis of zinc oxide nanoparticles using *parthenium hysterophorus* leaf extract and evaluation of their antibacterial properties. *J Biotechnol Biomater.* 2017; 7:271.
34. Hajiashrafi Sh, Motakef Kazemi N. Green synthesis of zinc oxide nanoparticles using parsley extract. *Nanomed Res J.* 2018;3(1): 44-50.
- 35.Upadhyaya H, Shome S, Sarma R, Tewari S, Bhattacharya M, Panda S. Green Synthesis, Characterization and Antibacterial Activity of ZnO Nanoparticles. *Am J Plant Sci.* 2018;9: 1279-91.