ORIENTAL JOURNAL OF CHEMISTRY
An International Open Access, Peer Reviewed Research Journal
www.orientjchem.org
ISSN: 0970-020 X
CODEN: OJCHEG
2025, Vol. 41, No.(1):
Pg. 144-151

Antimicrobial Properties of Silver Nanoparticles Biogenically Fabricated using some Medicinal Plants from the Arabian Peninsula: (A-Review)

SALEH H. SALMEN

Department of Botany and Microbiology, College of Science, King Saud University,
P.O. Box 2455, Riyadh-11451, Saudi Arabia.
*Corresponding author E-mail: ssalmen@ksu.eda.sa

http://dx.doi.org/10.13005/ojc/410117

(Received: September 10, 2024; Accepted: January 24, 2025)

ABSTRACT

Nanoparticles can be readily synthesized using environmentally friendly techniques from a wide range of plants. Silver nanoparticles (AgNPs) are particularly useful because their unique biological, physical and chemical properties make them ideal as antibacterial, antiviral, antifungal as well as anticancer activities. Several methods are available for producing AgNPs, but the biological approach, also known as the green method is particularly useful. A wide range of extracts from flowers, fruits, leaves, stems, bark, seeds and roots can be used to synthesize AgNPs. Such biological synthesis has a number of advantages over chemical and physical approaches, notably a marked reduction in the use of hazardous production pathways. Here, the biogenic synthesis and antimicrobial effects of AgNPs obtained from medicinal plant extracts, obtained from the Arabian Peninsula is reviewed.

Keywords: Silver nanoparticles, Biogenic synthesis, Medicinal plants, Antimicrobial activity, Arabian Peninsula.

INTRODUCTION

Nanotechnology, using materials with a scale size smaller than 100 nm, is an increasingly important area of science. The approach utilizes substances on a molecular level and the resultant organic or inorganic nanoparticles (NPs) can be used in a wide range of applications. Examples of inorganic NPs include semi-conductor NPs, such as ZnO, ZnS, and can also be synthesized from Co, Fe, and Ni; fullerenes, quantum dots, while carbon nanotubes provide excellent examples of organic NPs[1].

Due to their remarkable properties and practical adaptability, gold and silver NPs are of particular interest. Compared to larger particles with the same chemical composition, AgNPs exhibit significant biological effects, catalytic activity, and atomic behavior, largely as a result of their large surface zone[2]. AgNP fabrication is particularly important because of its potential wide-spread application for the development of biological sensors[3-4], plasmonics[5], DNA sequencing[6], optoelectronics[7], Surface-Enhanced Raman Scattering[8], energy generation[9], clean water

technology[10], biomedical applications[11] and finally information storage[12,13].

A number of methods have been widely used to fabricate AgNPs, including the 1) the hydrothermal method, 2) chemical vapor deposition, 3) the sol–gel method, 4) microwave-assisted combustion and finally, 5) thermal decomposition[14-16]. The biogenic fabrication (referred to as green synthesis) of AgNPs involves the use of biological materials such as plant extracts and microorganisms (e.g., fungi, bacteria and algae) as reducing agents. The antimicrobial activity of the resultant products has been widely investigated[17-18]. AgNPs are made by green synthesis when several biomolecules, including flavonoids, aldehydes, ketones, tannins, polyphenols, carboxylic acids; the protein component of plant extracts and microbes being the agent which oxidizes Ag+ to Ag0.

Here, I review the biogenic fabrication, and use as antimicrobials, of AgNPs obtained from a wide range of medicinal plants sampled from the Arabian Peninsula. The mechanisms of antibacterial inhibition and the characteristics of the developed AgNPs are also discussed.

Characterization of AgNPs

The most common and frequently used techniques to study the characterization of AgNPs are a) ultraviolet-visible spectroscopy (UV-Vis), which is commonly used as an indicator of the fabrication of AgNPs[19-20], b) energy dispersive spectroscopy (EDS), which is used to examine the structure of AgNPs, Fourier-transform infrared spectroscopy, c) (FTIR) which is conducted to observe functional groups within active compounds present in the synthesized AgNPs and d) scanning (SEM) and transmission electron (TEM) microscopy; Raman Spectroscopy can also be carried out determine the shape and size diameters of nanoparticles[21].

The potential of synthesized AgNPs as antibacterial agents can be assessed using agar and well and disc diffusion technique, used to measure bacterial inhibition zones in agar and the minimal inhibitory concentration (MIC), which determines the lowest antibiotic concentration sufficient for inhibiting the growth of a test-bacterium.

Antibacterial mechanisms of AgNPs

Although the exact means by which AgNPs inhibit bacteria remains unclear, a number of antibacterial effects have been demonstrated[22]. Toxic silver ions are continuously released from AgNPs[23], and have an affinity for sulfur proteins and by electrostatic attraction, can themselves to both the cytoplasmic membrane and cell wall. This may cause the bacterial envelope to rupture following increased cytoplasmic membrane permeability[24]. Respiratory enzymes may also become inactive after the absorption of free silver ions into cells, producing reactive oxygen species while inhibiting the synthesis of adenosine triphosphate[25]. The production of reactive oxygen likely aides the decomposition of cell membranes and alteration of the cell's DNA. Since sulfur and phosphorus are essential components of DNA, interactions between silver ions and these elements can disrupt DNA replication, inhibit cell division, or eventually cause bacteria death. Furthermore, by denaturing ribosomes in the cytoplasm, silver ions can prevent the formation of new proteins[26]. AgNPs have antibacterial effects in addition to the ability of silver ions' ability to kill bacteria. For example, when AgNPs bond to the cell surface, they cause the accumulation of weakened pits in the cell wall. Denaturation of the cell membrane might thereby result from the accumulated AgNPs. Because they are nano-sized, AgNPs may also pass through bacterial cell walls and negatively impact the structure of the cell membrane[27]. Meikle *et al.,* (2020)[28] demonstrated that AgNPs are likely to affect *Gram-negative* bacteria because these bacteria have a thinner cell wall than *Gram-positive* species. It is well established therefore, that AgNPs smaller than 10 nm have the potential to immediately alter a cell's permeability, penetrate bacterial cells, and damage cells[29].

Applications of AgNPs

AgNPs show significant antibacterial activity against a number of *Gram-positive* and *Gram-negative* bacteria[30], Recently, for examples, AgNPs which are tolerant to high temperatures have been used instead of organic and inorganic acids, by the food packaging sector in order to kill microbes and thereby extend the shelf life of preserved foods[31]. AgNPs are also used in agriculture to generate bio-fertilizers that can regulate plant utilization and maintain soil fertility by avoiding nutrient loss[32]. Applications of AgNPs in medicine include, amongst

others, their involvement in cancer therapy, dental science and technology and, medical imaging[33].

Biogenic synthesis of AgNPs from plant parts

AgNP manufacturing techniques are classified as physical, chemical, or biological[34]. They utilize two methods in the fabrication process: a top-down approach where the appropriate bulk material is reduced into nano-particles, the other a bottom-up approach in which nanoparticles are synthesized chemically or biologically by a procedure where atoms self-assemble into new nuclei, which then form onto nanoscale particles[35-36]. This review focuses on the biological method, particularly using a variety of plant parts for the synthesis of AgNPs (Fig. 1). Saudi Arabia, having a wide range of such useful plants (Fig. 2) is well-placed amongst Arab states, to exploit this technology.

Synthesis from plant leaves

Several leaf extracts obtained the Arabian Peninsula have been utilized in the fabrication of AgNPs. For example, leaf extracts of *Aloe vera*, *Portulaca oleracea* and *Cynodon dactylon* have been used to produce AgNPs with bactericidal activity against *Gram-positive* bacteria including, *E. faecalis, S. aureus, B. cereus* and *B. subtilis*, as well as *Gram-negative* species such as *E. coli, S. typhi, P. aeruginosa, A. baumannii* and *Shigella* sp.[37]. Indigofera oblongifolia leaf extract mediated AgNPs with spherical in shape and size (8–25 nm), have antibacterial effects against *S. pyogenes, B. subtilis, S. aureus E. coli* and *S. typhimurium*[38]. Antibacterial AgNPs with a particle size of between 24 and 50 nm have also been produced using *Sisymbrium irio* leaf extract[39]. *Aloe fleurentiniorum*, *Artemisia sieberi*, *Calotropis procera* and *Capparis spinosa* leaves extract were found to be capable of the biosynthesis of spherical, antibacterial AgNPs of notably small diameters ranging from 8 to 27 nm[40-42]. AgNPs fabricated using *Alhagi graecorum* leaf extract also exhibited antifungal activity and cytotoxic effects[43]. Rizwana, *et al.,* (2021)[44] also showed that spherical AgNPs, having an average size of 68.71 nm, exhibit antifungal and antibacterial properties. Spherical biogenic AgNPs with an average size of >37 nm have also been synthesized using *Cissus rotundifolia* and show antimicrobial effects against some microbes such as *K. pneumonia, E. coli, S. aureus, B. cereus, Aspergillus* and *C. albicans*. Not surprisingly, the antibacterial effects of AgNPs have been shown to be dose related[45]. The antibacterial effect of *Brassica oleracea* mediated AgNPs have been shown to be maximal against *S. epidermidis* with 14.33 ± 0.57 mm and *P. aeruginosa* with 12.0 ± 0.20 mm inhibition zone; these. AgNPs also exhibited antioxidant and anticancer properties[46].

An antifungal effect was found in *Portulaca oleracea* extract that mediated green AgNPs with a spherical shape and size of 69.09 nm. These AgNPs showed a relatively stronger antifungal activity than the standard AgNPs against all of the tested fungal species[47]. Spherical in shape with an average size from 27 to 32 nm AgNPs were also bio-fabricated using Catha edulis and these biogenic AgNPs showed marked inhibitory effects against both sensitive and multi-drug resistance *S. aureus* and *E. coli* bacteria. The findings of this study demonstrated that AgNPs are more effective than the antifungal drugs, which are typically used to treat oral infections caused by *C. albicans*[48]. Catha edulis leaves extract have also been used for AgNPs synthesis of spherical particles[49]; their antimicrobial properties were not however, evaluated. Recently, Ocimum basilicum leaf derived AgNPs of nanoparticle size from 8 to 52 nm were shown to possess marked antibacterial activity against *E. coli.*[50]

The inhibitory effects of AgNPs biosynthesized from *Rhazya stricta* aqueous extract were shown to be effective reported against numerous plant pathogenic fungi, including *Drechslera halodes*, *Macrophomina phaseolina*, *Drechslera tetramera, Curvularia australiensis* and *Alternaria alternate*[51]. Aloe vera gel extract was used to synthesis of AgNPs with sizes 50–100 nm which proved to be[52]. Antibacterial and antifungal activities were also produced by green AgNPs synthesized by extracts from the leaves of *Phoenix Dactylifera* L. The resultant AgNPs had a spherical shape with diameters between 40 and 50 nm and antibacterial activity was reporte[53]. *Myrtus communis* plant extracts have been used to fabricated biogenic AgNPs with a spherical shape and an average diameter of circa 15 nm[54]. Synthesized AgNPs using this plant demonstrated significant inhibitory activity against *E. coli* and methicillin-resistant *S. aureus*, suggesting that they may be used in the future as an effective antibacterial agent. Alharbi *et al.,* (2023)[55] recently produced very small particles (4–7 nm) AgNPs using *Senna alexandrina*

that were shown to inhibit some important multidrug-resistant pathogens (MDRPs), including *A. baumanii/ haemolyticus*, *S. epidermidis, E. coli* and Methicillin-resistant *Staphylococcus aureus* (MRSA), as well as having the potential to inhibit breast cancer cells (MCF-7 cells). *Ochradenus arabicus* leaves were used to fabricate spherical biogenic AgNPs with an average diameter was 6–27 nm. Antibacterial activity was seen against *S. aureus, E. coli, S. mutans* and *P. aeruginosa* that *P. aeruginosa*[56].

Synthesis from stems, roots and seeds

Qanash *et al.,* (2023)[57] used the stems and leaves mint plant to produce AgNPs and to assess the antioxidant activities and antimicrobial of AgNPs compared to mint extract alone. The average diameter of the formed AgNPs was determined to be 17.77 nm and synthesized AgNPs was shown to be spherical in nature. When compared to the synthesized AgNPs, which exhibited a zone of inhibition of 33, 25, 30, 32, 32, and 27 mm against *B. subtilis, E. faecalis, E. coli, P. vulgaris*, and *C. albicans*.,

Masoud., *et al.,* (2019)[58] used the plants, *Ziziphus spina-Christi* (sidr), *Salvadora persica* (arak), *Allium cepa* (onion), *Allium sativum* (garlic), *Mentha spicata* (mint) and *Zingiber officinale* (ginger) to synthesisze biogenic AgNPs. AgNPs and tetracycline were evaluated for their individual and combination effects against *S. aureus* and *K. pneumonia*. The mean particle size has been determined to be 30-60 nm for sidr, 50-120 nm for onion and 15-25 nm for ginger extract. Extracts of sidr, onion and ginger contributed to produce AgNPs, however extracts of, garlic, arak and mint were unable to convert silver ions into AgNPs. AgNPs synthesized from ginger had the highest individual and combined activity against the bacteria that were examined, followed by AgNPs synthesized from sidr and then onion. AgNPs considerably boosted the activity of tetracycline against *S. aureus* and *K. pneumonia*. Recently, biogenic spherical AgNPs have been fabricated using *Caralluma subulata* aqueous extract with an average diameter was 8–26 nm. AgNPs were used against 19 bacterial isolates as antibacterial agents and inhibited both *Gram-positive* and *Gram-negative* bacteria as well as some fungi[59]. Biogenically generated AgNPs obtained from the *Caralluma subulata* plant showed promise for important bio-applications, including the treatment of contaminated water. According to Oves *et al.,*[60], *Phoenix dactylifera* root hair extract can be used to biofabricate spherical AgNPs with an average diameter of 15–40 nm. Additionally, it was shown that synthesized AgNPs inhibited the growth of *C. albicans* and *E. coli* on solid medium, with zones of inhibition of 22 and 20 mm, respectively. Date seed (*Phoenix dactylifera*) extract also mediated AgNPs the production of spherical particles with diameter at 7–37 nm. Antibacterial activity of AgNPs also was confirmed against pathogenic bacteria, including *E. coli, S. aureus* and *S. epidermidis.*[61]

Synthesis from flowers

Recently, *Hibiscus sabdariffa* flower extract has been shown to mediate the green synthesis of AgNPs that recorded 72.30 nm in diameter. The antibacterial potential of biogenic AgNPs was confirmed against some pathogenic bacteria such as *Methicillin-resistant S. aureus, E. cloacae, E. coli* and *K. pneumoniae* strains with relative inhibition zone diameters of 14.54±0.15 mm, 12.82 ±0.36 mm, 21.69±0.12 mm and 18.35±0.24 mm, respectively. It was also shown that *E. coli* was particularly susceptible to the biogenic AgNPs. Additionally, the patterns of synergistic interactions between biogenic AgNPs and the antibiotic fosfomycin were assessed in this study, with *K. pneumonia* showing the greatest synergistic pattern, with an approximate synergistic percentage of 64.22%[62]. Flowers extract of *Abelmoschus esculentus* were also used to fabricated biogenic AgNP. The resultant green synthesized AgNPs were spherical and had a size range of 5.52 to 31.96 nm., with an average size of 16.19 nm. Antibacterial activity was confirmed against *Gram-positive* pathogens like *S. epidermidis*, *S. aureus, B. subtilis* and *S. pyogenes* and the *Gram-negative* pathogens like *E. coli*, *K. pneumoniae*, *P. aeruginosa*, *S. typhimurium*, *P. vulgaris* and *S. sonnei*. The antimicrobial activity varied according to the species of bacteria, with the biogenic AgNPs inhibitory effect being most marked against *Gram-negative* bacteria[63].

Synthesis from fruits and peels

Oves *et al.,* (2022)[64] described the green synthesis of AgNPs using Conocarpus lancifolius fruits extract. The particles size of the synthesized AgNPs was between 21 and 173 nm; these showed antimicrobial effects against bacteria such as *S. aureus* (inhibition zones of 18 mm) and *S. pneumonia* (inhibition zones of 24 mm) and fungal

pathogen *A. flavus* and *R. stolonifera*. Following a 24-h exposure, the nanomaterials showed potential anticancer activity against MDA MB-231 cells and were nontoxic. *Phoenix dactylifera* fruits extract-mediated biogenic spherical AgNPs have been synthesized with diameters ranging from 20 to 100 nm and showed antimicrobial effects against *E. coli*, *S. aureus P. aeruginosa, E. faecalis* and *Candida albicans*[65,66]. Biosynthesis of AgNPs using pomegranate peel extract was confirmed by Saad *et al.,* (2021)[67] who reported biological effects for AgNPs that included antioxidant effects, cytotoxic activities and significant antibacterial properties. Citrus limon waste peels extract has also been used to fabricated biogenic AgNPs that had average size of 59.74 nm[68]. An extract of *Anthemis pseudocotula* was also used for biosynthesis of AgNPs which showed biological effects such as antibiofilm activity and the antimicrobial against several *Gram-negative* and *Gram-positive* bacteria, including *E. coli, S. aureus, P aeruginosa* and *A. baumannii* (MDR-AB), MRSA bacteria and the pathogenic yeast, *C. albicans*. It has also been shown that AgNPs, of diameter 0.039 mg/mL have the ability to inhibit *Gram-negative* bacteria from forming biofilms[69].

Table 1: Plant parts which mediate the green synthesis of AgNPs and their biological properties

No	Plants	Part of plant	Shape and size (nm)	Biological activity	Region	References
1	Aloe vera, *Portulaca oleracea* and *Cynodon dactylon*	Leaves	N/R	Bactericidal	Riyadh-Saudi Arabia	37
2	*Indigofera oblongifolia*	Leaves	Spherical 8-25	Antibacterial	Shabwah, South of Yemen	38
3	*Sisymbrium irio*	Leaves	24-50	Antibacterial	Al Zulfi-Saudi Arabia	39
4	*Aloe fleurentiniorum*	Leaves	Spherical 8-27	Antibacterial	South of Yemen	40
5	*Artemisia sieberi Calotropis procera*	Leaves	Spherical 10-14	Antibacterial	Riyadh-Saudi Arabia	41
6	*Capparis Spinosa*	Leaves	Spherical 13	Antibacterial	Riyadh-Saudi Arabia	42
7	Alhagi graecorum	Leaves	Spherical 22-36	Antifungal, Cytotoxic effect	Baghdad-Iraq	43
8	*Trigonella foenum-graecum* L.	Leaves	Spherical 68.71	Antibacterial, Antifungal	Qaseem-Saudi Arabia	44
9	*Cissus rotundifolia*	Leaves	Spherical >37	Antibacterial	Al Baha, Saudi Arabia	45
10	*Brassica oleracea*	leaves	Spherical 20	Antibacterial, Anticancerand Antioxidant	Riyadh-Saudi Arabia	46
11	*Portulaca oleracea*	leaves	Spherical 69.09	Antifungal	Al-Qassim, Saudi Arabia	47
12	*Catha edulis*	leaves	Spherical 27-32	Antibacterial Antifungal	Sana'a, Yemen	48
13	*Catha edulis*	leaves	Spherical 18.11	N/R	Taiz, Yemen	49
14	*Ocimum basilicum*	leaves	Spherical 8-52	Antibacterial	Riyadh-Saudi Arabia	50
15	*Rhazya stricta*	leaves	21-90 nm and 7.2-25.3 nm	Fungicidal properties	Riyadh-Saudi Arabia	51
16	*Aloe vera*	Leaves	Spherical 50-100	Antibacterial, Antifungal, Anticancer	Riyadh-Saudi Arabia	52
17	*Phoenix dactylifera* L	Leaves	Spherical 40-50	Antibacterial, Antifungal	Al-Medina, Saudi Arabia	53
18	*Myrtus communis*	Leaves	Spherical 15	Antibacterial	Al-Qassim, Saudi Arabia	54
19	*Senna alexandrina*	Leaves	Spherical 4-7	Antibacterial, Anticancer	Al-Medina, Saudi Arabia	55
20	*Ochradenus arabicus*	Leaves	Spherical 6-27	Antibacterial	Riyadh-Saudi Arabia	56
21	*Mentha longifolia*	Leaves, stems	Spherical 17.77	Antimicrobial, Antioxidant	Al-Medina and Hail, Saudi Arabia	57
22	*Salvadora persica*, *Allium sativum*, *Allium cepa*, *Zingiber officinale*, *Mentha spicata,*	Leaves roots	N/R	Antibacterial,	Najran, Saudi Arabia	58

	Ziziphus spina-Christi					
23	*Caralluma subulata*	stems	Spherical 8-26 nm	Antibacterial	Jizan, Southwestern Saudi Arabia	59
24	*Phoenix dactylifera*	Roots	Spherical 15-40	Antibacterial, Antifungal, Anticancer	Jeddah-Saudi Arabia	60
25	*Phoenix dactylifera* L	Seeds	Spherical7-37	Antibacterial	Riyadh-Saudi Arabia	61
26	*Hibiscus sabdariffa* L	Flowers	Spherical 58.682	Antibacterial	Riyadh-Saudi Arabia	62
27	*Abelmoschus esculentus*	Flowers	Spherical 5.52-31.96	Cytotoxicity, Antimicrobial	Al-Kharj, Saudi Arabia.	63
28	*Conocarpus lancifolius*	Fruits	21-173	Antimicrobial, Anticancer	Jeddah-Saudi Arabia	64
29	*Phoenix dactylifera*	Fruits	Spherical 20-100	Antimicrobial and Cytotoxic effects	Jazan, Saudi Arabia	65
30	*Palm date*	Fruit	Spherical3-30	Antibacterial, Antifungal, Catalytic degradation	Jeddah-Saudi Arabia	66
31	*Pomegranate peel*	Peel of fruits	Spherical 21.7-43.7	Antibacterial Cytotoxicity	Addakhliya-Oman	67
32	*Citrus limon*	Peels	Spherical 59.74	Antimicrobial, Cytotoxic effect	Riyadh-Saudi Arabia	68
33	*Anthemis pseudocotula*	Aerial Parts	Spherical 20	Antibacterial, Antifungal, Antibiofilm	Northern Riyadh, Saudi Arabia	69

N/R = Not Reported

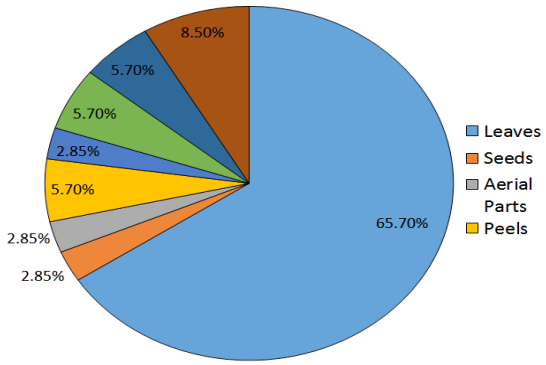

Fig. 1. Percentage of AgNPs synthesized from medicinal plant parts

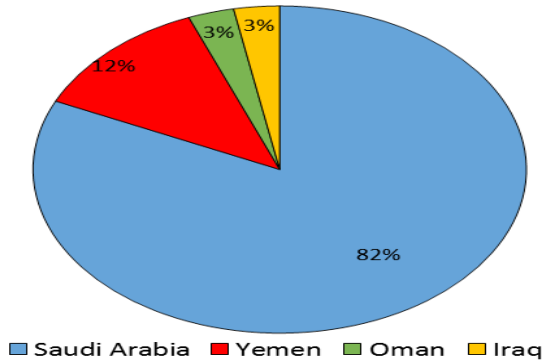

Fig. 2. Percentage distribution of plants used to synthesis AgNPs in countries on the Arabian Peninsula

CONCLUSION

Nanotechnology, particularly bio-nanotechnology, is becoming increasingly important due to the unique properties of nanoparticles that can be utilized in medicine, biosensors, agriculture, food technology, etc. Green synthesis of AgNPs using some medicinal plants in the Arabian Peninsula has been a particular promising area of research during the last decade. Extracts of all plant parts can synthesize AgNPs that contain bioactive compounds which enable the formation nanoparticles of varying sizes. Thers is no doubt that green AgNPs have biological properties such as antibacterial, antifungal, biofilm effecting and anticancer activities, all of which warrant further study.

ACKNOWLEDGMENT

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of Interest

The author declares no conflict of interest.

REFERENCES

1. Vadlapudi, V.; Kaladhar, D., *Middle East J Sci Res.*, **2014**, *19*, 834–842.
2. Xu, Z. P.; Zeng, Q.H.; Lu, G.Q.; Yu, A.B., *Chem Eng Sci.*, **2006**, *61*, 1027–1040.
3. Mirkin, C.A.; Letsinger, R.L.; Mucic, RC.; Storhoff, J., *J. Nature.*, **1996**, *382*, 607–609.

4. Han, M.; Gao, X.; Su. J.Z.; Nie, S., *Nat Biotechnol.*, **2001**, *19*, 631–635.
5. Maier, S.A.; Brongersma. M.L.; Kik, P.G.; Meltzer, S.; Requicha, A.A.; Atwater, H.A., *Adv Mater.*, **2001**, *13*, 1501–1505.
6. Cao, Y.; Jin, R.; Mirkin, C.A., *J Am Chem Soc.*, **2001**, *123*, 7961–7962.
7. Boncheva, M.; Gracias, D.H; Jacobs, H.O.; Whitesides, G.M., *Proc Natl Acad Sci.*, **2002**, *99*, 4937–4940.
8. Matejka, P.; Vlckova, B.; Vohlidal, J.; Pancoska, P.; Baumruk, V., *J Phys Chem.*, **1992**, *96*, 1361–1366.
9. Zach, M.; Hägglund, C.; Chakarov, D.; Kasemo, B., *Curr Opin Solid State Mater Sci.*, **2006**, *10*, 132–143.
10. Savage, N.; Diallo, M.S., *J Nanopart Res.*, **2005**, *7*, 331–342.
11. Hullmann, A., *Scientometrics.*, **2007**, *70*, 739–758.
12. Caruthers, S.D.; Wickline, S.A.; Lanza, G.M., *Curr Opin Biotechnol.*, **2007**, *18*, 26–30.
13. Samberg, M.E.; Oldenburg. S.J.; Monteiro-Riviere, N.A., *Environ Health Perspect.*, **2010**, *118*, 407–413.
14. Pal, A.; Shah S.; Devi, S., *Mater. Chem. Phys.*, **2009**, *114*, 530–532.
15. Wu, T.; Shen, H.; Sun, L.; Cheng, B.; Liu B.; Shen, J., *ACS Appl. Mater. Interfaces.*, **2012**, *4*, 2041–2047.
16. Zhang, X.; Sun, H.; Tan, S.; Gao, J.; Fu Y.; Liu, Z., *Inorg. Chem. Commun.*, **2019**, *100*, 44–50.
17. Remya, V.R.; Abitha, V.K.; Rajput, P. S.; Rane, A. V.; Dutta, A., *Chem. Int.*, **2019**, *3*, 165–171.
18. Rafique, M.; Sadaf, I.; Rafique, M.S.; Tahir, M.B. Artif. Cells, Nanomed., *Biotechnol.,* **2017**, *45*, 1272–1291.
19. Ahmad, A.; Mukherjee, P.; Senapati, S.; Mandal, D.; Khan, M.I.; Kumar, R.; Sastry, M., *Colloids and Surfaces B: Biointerfaces.*, **2003**, *28*, 313–318.
20. Li, L. S.; Shen, Y.; Xie, A.; Xuerong, Y.; Lingguang, Q.; Li, Z.; Qingfeng, Z., *Green Chem.*, **2007**, *9*, 852-858.
21. Potbhare, A.K.; Chouke, P.B.; Mondal, A.; Thakare, R.U.; Mondal, S.; Chaudhary, R.G.; Rai, A.R., *Mater. Today Proc.*, **2020**, *29*, 939–945.
22. Yin, I. X.; Zhang, J.; Zhao, I.S.; Mei, M. L.; Li, Q.; Chu, C.H., *Inter. J. Nanomedi.*, **2020**, *15*, 2555–2562.
23. Bapat, R. A.; Chaubal, T. V.; Joshi, C. P.; Bapat, P. R.; Choudhury, H.; Pandey, M.; Gorain, B.; Kesharwani, P., *Mater Sci Eng C.*, **2018**, *91*, 881–898.
24. Khorrami, S.; Zarrabi, A.; Khaleghi, M.; Danaei, M.; Mozafari, M., *Int J Nanomedicine.*, **2018**, *13*, 8013–8024.
25. Ramkumar, V. S.; Pugazhendhi, A.; Gopalakrishnan, K.; Sivagurunathan, P.; Saratale, G. D.; Dung, T.N.B.; Kannapiran, E., *Biotechnol Rep.*, **2017**, *14*, 1–7.
26. Durán, N.; Nakazato, G.; Seabra. A., *Appl Microbiol Biotechnol.*, **2016**, *100*(15), 6555–6570.
27. Liao, C.; Li, Y.; Tjong, S.C., *Int J Mol Sci.*, **2019**, *20*(2), 449.
28. Meikle, T.; Dyett, B.P.; Strachan, J.B.; White, J.; Drummond. C.J.; Conn, C.E., *ACS Appl Mater Interfaces.*, **2020**, *12*(6), 6944–6954.
29. Noronha, V.T.; Paula A.J.; Durán, G.; Galembeck, A.; Cogo-Müller, K.; Franz-Montan, M.; Durán, N., *Dent Mater.*, **2017**, *33*(10), 1110–1126.
30. Cavassin, E. D., Figueiredo, L. F. P.; Otoch, J. P.; Seckler, M.M.; Oliveira, R.A. Franco, F. F. Marangoni, V. S.; Zucolotto, V..; Levin, A. S.S.; Costa, S. F., *J. Nanobiotechnology.*, **2015**, *13*. 64.
31. Jebril, S. R.; Khan, R.; Ben Jenana Dridi, C., *Mater. Chem. Phys.*, **2020**, *248*, 122898.
32. Martínez-Fern´andez, D.; Barroso, D.; Kom´arek, M., *Environ. Sci. Pollut. Res.*, **2018**, *23*, 1732–1741.
33. Amarasinghe, L.D.; Wickramarachchi, P.A.; Aberathna, A.A.; Sithara, W.S.; De Silva, C., *R. Heli.*, **2020**, *6*, e04322.
34. Yaqoob, A.A.; Umar, K.; Ibrahim, M.N.M., *Appl. Nanosci.*, **2020**, *10*(5), 1369–1378.
35. Daniel, M.C., *Astruc, D. Chem. Rev.*, **2004**, *104*(1), 293–346.
36. Shanmuganathan, R; Karuppusamy I.; Saravanan, M.; Muthukumar, H.; Ponnuchamye, K.; Ramkumar, V. S.; Pugazhendh, A., *Curr. Pharm. Des.*, **2019**, *25* (24), 2650–2660.
37. Abalkhil, T.A.; Sulaiman, A.A.; Salmen, S.H.; Wainwright. M., *Biotechnol Biotec Eq.*, **2017**, *31*, 411-417.
38. Salmen, S.H.; Alwhibi, M.S.; Alharbi, S.A., *Appl. Ecol. Environ. Res.*, **2019**, *17*(6), 12869.

39. Mickymaray, S., *Biomolecules.*, **2019**, *9*, 662.
40. Salmen, S.; Alharbi, S.A., *Green Chem. Lett. Rev.*, **2020**, *13*, 1-5.
41. Salmen, S. H.; Alkammash, N. M.; Alahmadi, T. A.; Alharbi, S. A., *Rev. Chim.*, **2021**, *72*(2), 76-82
42. Salmen, S.H.; Damra, E.; Alahmadi, T.A.; Alharbi, S.A., *Rev. Chim.*, **2021**, *72*(1), 145-152.
43. Hawar, S. N.; Al-Shmgani, H. S.; Al-Kubaisi, ZA; Sulaiman, G. M.; Dewir, Y. H.; Rikisahedew, J. J., *J. Nanomater.*, **2022**, *1058119*, 8.
44. Rizwana, H.; Alwhibi, M. S.; Aldarsone, H. A.; Awad, M. A.; Soliman, D. A.; Bhat, R. S., *Green Process. Synth.*, **2021**, *10*, 421–429.
45. Al-Ghamdi, A.Y., *Adv. Microbiol.*, **2018**, *8*, 938-949.
46. Ansar, S.; Tabassum, H.; Aladwan, N.S.M.; Ali, M. N.; Almaarik, B.; AlMahrouqi, S.; Abudawood, M.; Banu, N.; Alsubki, R., *Scientifc Reports.*, **2020,** *10*, 18564.
47. Al-Otibi, F.; Alfuzan, S. A.; Alharbi, R. I.; Al-Askar, A. A.; AL-Otaibi, R. M.; Al Subaie, H.F.; Moubayed, N. M. S., *Saudi J. Biol. Sci.*, **2022**, *29*, 2772–2781.
48. Numan A. A.; Ahmed M.; Galil M. S. A.; Al-Qubati M.; Raweh, A. A. Helmi, E.A., *Advances in Nanoparticles.,* **2022**, *11*, 2.
49. Amrani, M. A.; Bagash, M.; Yehya, F., *Al-Baydha Univ. J. Res.*, **2019**, *1*(2), 214-223.
50. Qaeed, M. A.; Hendi, A.; Obaid, A.S.; Thahe, A.A.; Osman, A.M.; Ismail A.; Mindil, A.; Eid, A.A.; Aqlan, F.; Osman, N.M.A.; AL-Farga, A.; Al-Maaqar, S. M.; Saif, A. A., *Scientifc Reports.*, **2023**, *13*, 5866.
51. Al-Sahli, S. A.; Al-Otibi, F.; Alharbi, R. I.; Amina M.; Al Musayeib, N.M., *Scientifc Reports.*, **2024**, *14*, 1297.
52. Alwhibi, M. S.; Soliman, D. A.; Awad, M. A.; Alangery, A. B.; Al Dehaish, H.; Alwasel, Y.A., *Green Process. Synth.*, **2021**, *10*, 412–420.
53. Al Mutairi, J. F.; Al-Otibi, F. H.; Alhajri, M.; Alharbi, R. I.; Alarifi, S.; Alterary, S. S., *Molecules.*, **2022**, *27*, 3113.
54. Alyousef, A. A.; Arshad, M.; AlAkeel, R.; Alqasim, A., *Biotechnol. Biotechnol. Equip.*, **2019**, *33*, 931–936.
55. Alharbi, N. S.; Khaled, J. M.; Alanazi, K.; Kadaikunnan, S.; Alobaidi, A.S., *Saudi Pharm. J.*, **2023**, *31*, 911–920.
56. Al-Qurainy, F.; Nadeem, M.; Khan, S.; Siddiqui, M.R.; Husain, F.M.; Gaafar, A.R.Z.; Alansi, S.; Alshameri, A.; Tarroum, M.; Alenezi, N.A.; Salih, A.M.; Shaikhaldein, H.O., *Biotechnol. Biotechnol. Equip.*, **2021**, *35*, 1238–1246.
57. Qanash, H.; Bazaid, A.S.; Binsaleh, N.K.; Alharbi, B.; Alshammari, N.; Qahl, S.H.; Alhuthali, H.M.; Bagher, A. A., *Plants.*, **2023**, *12*, 2177.
58. Masoud, E. A.; Al-Hajry, A.; Harraz, F.A.; Ahsan, M.F., *Braz Arch Biol Technol.*, **2019**, *62*, e19180266.
59. Alamier, W. M.; Hasan, N.; Syed, I. S.; Bakry, A.M.; Ismail, K.S.; Gedda, G.; Girma, W. M., *Catalysts.,* **2023**, *13*, 1290.
60. Oves, M.; Aslam, M.; Rauf, M.A.; Qayyum, S.; Qari, H.A.; Khan, M.S.; Alam, M.Z.; Tabrez, S.; Pugazhendhi, A.; Ismail, I.M.I., *Mater. Sci. Eng. C.*, **2018**, *89*, 429–44.
61. Salmen, S. H., *Orient. J. Chem.*, **2020**, *36*(6), 1-5.
62. Aljeldah, M. M.; Yassin, M. T.; Mostafa, A. A. F.; Aboul-Soud, M. A. M., *Infect. Drug Resistance.*, **2023**, *16*, 125–142.
63. Devanesan, S.; AlSalhi, M.S., *Int. J. Nanomed.,* **2021**, *16*, 3343–3356.
64. Oves, M.; Rauf, M.A.; Aslam, M.; Qari, H.A.; Sonbol, H.; Ahmad, I.; Zaman, G.S.; Saeed, M., *Saudi J. Biol. Sci.*, **2022**, *29*,460–471.
65. Zafar, S.; Zafar, A., *Open Biotechnol. J.*, **2019**, *13*, 37-45.
66. Zaheer, Z., *J. Photochem. Photobiol. B, Biol.*, **2018**, *178*, 2018, 584.
67. Saad, P. G.; Castelino, R. D.; Ravi, V.; Al-Amri, I. S.; Khan, S.A., *Beni-Suef Univ. J. Basic Appl. Sci.*, **2021,** *10*, 29.
68. Alkhulaifi, M. M.; Alshehri, J. H.; Alwehaibi, M. A.; Awad, M. A.; Al-Enazi, N. M.; Aldosari, N. S.; Hatamleh, A.A.; Abdel-Raouf, N., *Saudi J. Biol. Sci.*, **2020**, *27*, 3434–3441.
69. Ajlouni, A. W.; Hamdan, E. H.; Alshalawi, R. A. E.; Shaik, M. R.; Khan, M.; Kuniyil, M.; Alwarthan, A.; Ansari, M. A.; Khan, M.; Alkhathlan, H.Z.; Shaik, J.P.; Adil, S.F., *Molecules.*, **2023**, *28*, 246.