



A Review Synthesis and Biological Evaluation of Plant-Based Metallic Gold Nanoparticles

Shama Parveen ^a, Garima Sharma ^a, Arun K. Khajuria ^b and Anuj Kandwal ^{c*}

^a *Department of Chemistry, Faculty of Science, Motherhood University, District- Haridwar, 247661, Uttarakhand, India.*

^b *Department of Botany, Cluster University of Jammu, Jammu- 180001, Jammu and Kashmir, India.*

^c *Department of Chemistry, Harsh Vidya Mandir (PG) College, Raisi, Haridwar, Uttarakhand, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JPRI/2022/v34i7B36262

Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://www.sdiarticle5.com/review-history/80194>

Review Article

Received 10 November 2021

Accepted 17 January 2022

Published 05 February 2022

ABSTRACT

Nanotechnology has become a trending area in the field of science and technology. It has made great advances with the development of functional, engineered nanoparticles. The better advancements made towards the synthesis of nanoparticles using plant materials have become a major focus of researchers because of their advantages including high stability and loading capacity. Recently, zinc oxide nanoparticles have drawn the attention of several researchers owing to their several biological applications including anticancer and antimicrobial activities. Different techniques have been employed for the production of gold nanoparticles due to their elaborated applications in different interdisciplinary fields. The synthetic procedure of plant-based nanoparticles has attracted a keen interest of various researchers as the synthesis is comparatively fast, safe and light and can be followed under basic room conditions without the requirement of any advanced synthesis requirements. Every part of the plants can be used for the synthesis of nanoparticles. Gold nanoparticles play a pivotal role as the most active, environment friendly and biocompatible towards a greener approach. In this review paper, we report highlighted about the various plants extract, which have been used for the synthesis of gold nanoparticles and their biological evaluation based on previous year's research and scientific papers and journal and articles.

*Corresponding author: E-mail: anujkandwal4@gmail.com;

Keywords: Synthesis; characterization; gold nanoparticles; anticancer activity; antimicrobial activity.

1. INTRODUCTION

These days there are many research activities on nanoparticles, which are going on all over the world. These particles that are intermediate between bulk materials and isolated atom sized materials in the range of 1 to 100 nm. The uses of these are not restricted but are involved in various agricultural and pharmaceutical applications [1]. NPs can be extensively divided into two groups, organic NPs which include carbon NPs (fullerenes, carbon nanotubes, etc.), and inorganic NPs consist of magnetic NPs, noble metal NPs (like silver and gold) and semi-channel NPs (like titanium oxide and zinc oxide). There is a developing enthusiasm for inorganic NPs i.e., metallic NPs (silver, gold and copper) as they give predominant material properties for functional versatility. Metallic NPs are most encouraging and wonderful biomedical operators. Among metallic NPs, Silver, Aluminum, Gold, Zinc, Platinum, Titanium, Palladium, Iron and Copper have been widely used. They exhibit unique properties that differ from those of the same material in bulk form NPs. Generally, show bio comp ability, strong adsorption ability and ease of surface modification. The application of these gold NPs is traced even in the 16th century for both therapeutic and re-coloring there is a further scope to grow ecologically cordial procedures through green amalgamation and other organic methodologies. Nowadays the nanoparticles are being synthesized from metal and from non-metallic materials. However, when it comes to the biological application of nanoparticles, silver and gold are the most preferred metals [2-3].

Synthesis of nanoparticles is an area of interest for many researchers and is synthesized through various physical and chemical methods. During the chemical production of nanoparticles the toxic and hazardous risks are involved and are a potential threat to the environment, as well as it is expensive [4]. The science of the synthesis of nanoparticles using biological means is a newly emerging area and gained significant attention from researchers. The green approach uses living organisms or the bi-products of them, which act as a reducing agent as well as stabilizers. It is being vastly utilized for the production of nanoparticles [5-6] especially for the synthesis of silver, gold, iron, zinc, palladium, etc.

Metallic nanoparticles have the most favorable antibacterial properties because of their huge surface area to volume ratio, and it is the foremost interest of researchers because of microbial resistance, which is growing against metal ion, resistant strains development and antibiotics. Amongst all noble metal nanoparticles, silver nanoparticles attained many interests because of its best conductivity, chemical stability, anti-viral, antifungal, anticancer and antibacterial activities that can be consolidated in the form of complex fibers [4,6].

2. MAIN APPROCHES

2.1 Brief History of Gold Nanoparticles

Nanoparticles and nanoparticulate materials exist from ancient times. Although some of these nanoparticles have been synthesized deliberately (or not) by humans, it is also likely to find some natural-synthesized nanoparticles. On the other hand, humans have also synthesized nanoparticles for a long time. Actually, it is possible to find some different nanostructures in old glasses, statues or pottery pieces. However, the first mention of nanoparticles may be awarded to Michael Faraday, who was probably the first person who synthesized deliberately gold nanoparticles by reducing Na[AuCl₄] with an aqueous solution of Na[AuCl₄] with phosphorous in carbon disulfide (Fig. 1). On February 5, 1857, Faraday delivered a Lecture of the Royal Society entitled "Experimental Relations of Gold (and other Metals) to "Light" in which he exposed his conclusions about extremely finely divided metal particles in suspension. Progressing towards later times in 1959, Richard Feynman, an American physicist from the Technological Institute of California (Caltech), presided a conference in the American Physical Society entitled "There's Plenty of Room at the Bottom", in which he pointed the possibility of manipulating the atoms directly one by one, with Nanometric precision. Subsequently, Feynman received the Physics Nobel Award in 1965. Both the scientific and technological worlds have become very interested in nanoparticles and other kind of nanostructures. In the recent times different governments are moving towards investing huge capitals for the better establishment of a new domain titled "Nano world". For instance, the EEUU budget during the 2005-2010 periods was about 2.500 million euros, and the current UE budged since 2007

has reached 3.300 million euros. Thus, the resulting nanoparticle properties are sometimes mostly due to the large material surface area, which overcomes the small bulk material contributions. For instance, nanoparticle suspensions are possible because of the particle surface interaction with the solvent, which is strong enough to exceed [7-9].

The difference in densities can result in a material either floating or forming precipitates inside the medium. Different other size-dependent parameters include different optical properties (i.e. gold nanoparticles are red and

turn to dark purple when aggregating) or superparamagnetic behavior at room temperature in magnetic materials, among others. As well as size, the shape is also a crucial parameter that becomes necessary to control when studying nanoparticle properties. Gold nanoparticles exhibit various sizes ranging from 1 nm to 8 μm and they also exhibit different shapes such as spherical, sub-octahedral, octahedral, decahedral, icosahedral multiple twined, multiple twined, irregular shape, tetrahedral, nano triangles, nano prisms, hexagonal platelets and nano rods (Fig. 2).



Fig. 1. Faraday's gold nanoparticle dispersion (left), TEM image from this nanoparticles (middle) and Faraday's portrait (right) [91]

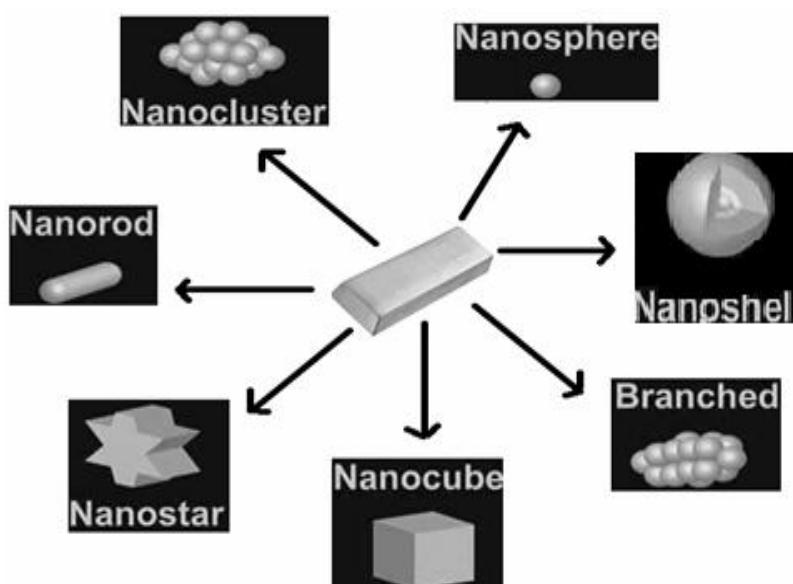


Fig. 2. Different shape of gold nanoparticles [152]

2.2 Recent Advances of Gold Nanoparticles

High surface/volume ratio and thus the huge number of surface gold atoms create much increased surface chemical reactivity and enhance chemisorption's of molecules such as CO and H₂ has been widely studied for applications in catalysis AuNPs [8-9]. Possess properties such as dielectric function, electrical conductivity, and inert properties to oxidation to allow them to be used in applications as sinter inks, selective coatings, data storage, single electron conductivity, and quantum devices Surface Plasmon Resonance (SPR) is one of the most remarkable properties of AuNPs [10-11]. SPR is a physical concept describing the collective oscillations of conduction band electrons in the electromagnetic field. SPR will occur when a particle is small enough that its size is comparable to the wavelength of light. This property provides a new platform for applications as sensors for detection of many targets including biological, environmental and military molecules [13-14].

2.3 Characterization of Gold Nanoparticles

Various analytical techniques have been developed, in recent years, to characterize noble metal nanoparticles, according to their unique thermal, electrical, chemical, and optical properties, and to confirm their size, shape, distribution, surface morphology, surface charge, and surface area [28-29].

The common techniques of characterizing nanoparticles are as follows: UV-visible spectrophotometry, dynamic light scattering (DLS), scanning electron microscopy (SEM), transmission electron microscopy (TEM), Fourier transform infrared spectroscopy (FTIR), powder X-ray diffraction (XRD) and energy dispersive spectroscopy (EDS) [30-32]. Spectrophotometric absorption measurements in the wavelength ranges of 400–450 nm and 500–550 nm are used in characterizing the silver and gold nanoparticles, respectively [32-33,123]. The morphology of AuNPs can now is better characterized, due to recent developments in advanced microscopic techniques. These include SEM, TEM, HRTEM, and atomic force microscopy (AFM), which are commonly employed to determine and characterize their size, shape, and surface morphology [29,34,124]. SEM provides Nanoscale information about particles and determines their

surface morphology and dispersion, while TEM is used to provide information about the number of material layers and broad evidence of uptake and localization, composition, polymer tethering, and physical properties [29]. Also, TEM is commonly used as a quantitative method to measure size, volume, and shape, and it produces mainly two-dimensional(2D) image of three-dimensional (3D) nanoparticles [35]. HR-TEM is used to determine the exact shape, size, and crystalline structure. AFM, which is similar to the scanning probe microscopy, provides information about surface topography of AuNPs. AFM has the advantage of obtaining 3D images in a liquid environment [29].

The dynamic light scattering (DLS) is used to characterize the surface charge and the size distribution of the particles suspended in a liquid. Electron microscopy is another commonly used method of characterization. Scanning electron microscopy and transmission electron microscopy are used for morphological characterization at the nanometer to micrometer scale. The elemental composition of metal nanoparticles is commonly established using energy dispersive spectroscopy [33-36].

3. SYNTHETIC ROUTE OF NANOPARTICLES

Nowadays, there is a huge interest in the development of synthetic protocols in order to control size, shape, morphology and crystallinity of metal nanoparticles. The methods for making nanoparticles can generally involve either a “top down” approach or a “bottom up” approach [33]. In top-down synthesis (Fig. 3), nanoparticles are produced by size reduction from a suitable starting material. Size reduction is achieved by various physical and chemical treatments (Fig. 1). Top down production methods introduce imperfections in the surface structure of the product and this is a major limitation because the surface chemistry and the other physical properties of nanoparticles are highly dependent on the surface structure [37].

In bottom up synthesis, the nanostructured building blocks of the nanoparticles are formed first and then assembled to produce the final particle [37]. The bottom up synthesis mostly relies on chemical and biological methods of production. The probable mechanism of nanoparticle synthesis by bottom up approach is shown in Fig. 2. Of the biological methods of synthesis, the methods based on

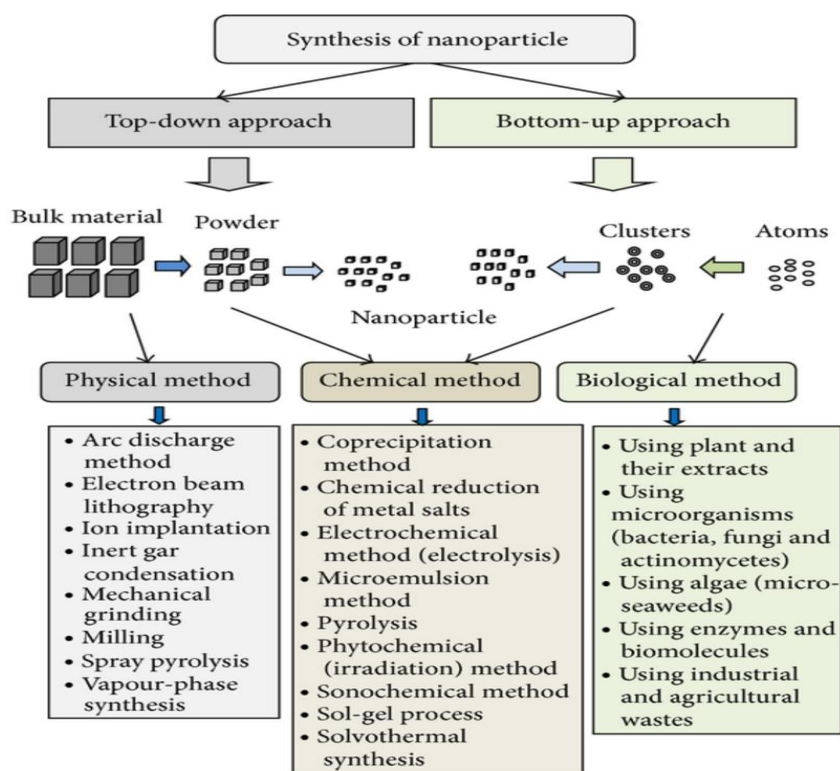


Fig. 3. Scheme of synthesis of nanoparticles

microorganisms have been widely reported [38-41]. Microbial synthesis is of course readily scalable, environmentally benign and compatible with the use of the product for medical applications, but the production of microorganisms is often more expensive than the production of plant extracts.

4. SIZE CONTROL

There are several factors contributing to the final size of the AuNPs. The first is their reductant used. Reductant plays the most important role in the nucleation process. Several synthetic methods with different reductants have been reported [15]. The Brust-Schiffrin method using NaBH_4 as reductant can prepare AuNPs of 2-10 nm [15-17], the Turkevich method using citrate can prepare AuNPs of 10-20 nm, the Murphy method using ascorbic acid can prepare AuNPs of 10-50 nm [20], the Perrault method using hydroquinone can prepare AuNPs of 50-200 nm [21] and the polyol method using diols can prepare AuNPs in 20-200 nm range. The surface stabilizer is another critical factor to control the size and shape of AuNPs [156] (Fig. 4). The higher the concentration of the surface stabilizer, the finer, faster, and more completely coated AuNPs are formed, resulting in smaller size of

the particles. A mole ratio between the reductant and gold ion also affects the particle size. Higher mole ratio between reductant and gold ion will produce more nuclei, leading to smaller sizes [18-23].

5. SYNTHESIS OF GOLD NANOPARTICLES USING PLANT EXTRACT

The properties of gold nanoparticles are very different from that of bulk, as the gold nanoparticles are wine red solution while the bulk gold is yellow solid. A tuber extract of *Dioscorea bulbifera* was used to produce gold and silver nanoparticles of various shapes Ghosh et al., [97]. Production of spherical and triangular-shaped gold nanoparticles using fruit extract of *Tanacetum vulgare* have been reported Dubey et al., [92]. Njagi et al., [42] used an aqueous extract of *Sorghum bran* to produce nanoparticles of iron and silver at room temperature. Kasthuri et al., [43] used a dilute phyllanthin containing extract derived from the plant *Phyllanthus amarus*, to produce hexagonal and triangular gold nanoparticles from HAuCl_4 . Increasing the concentration of the extract led to the formation of spherical nanoparticles. Narayanan and Sakthivel [56] produced gold

nanoparticles using a leaf extract of *Coriandrum sativum* (coriander). The particles ranged in size from about 7 to 58 nm and had diverse shapes (spherical, triangular, decahedral). Raghunandan et al., [44] produced irregularly shaped gold nanoparticles using an extract of dried clove (*Syzygium aromaticum*) buds. Reduction and stabilization of gold nanoparticles were ascribed to the flavonoids present in the extract. Parida et al., [51] reported the synthesis of gold nanoparticles mediated by an extract of *Allium cepa*. The particles had an average size of 100 nm and could be internalized by MCF-7 breast cancer cells via endocytosis. In another method Liu et al., [45] synthesized gold nanoparticle using extracts of Chrysanthemum and tea beverages. A nanoparticle-based assay was developed for quantifying the antioxidant properties of teas. Gold nanoparticles made using the extract were found to be superior to the extract as hypoglycemic agents in rats for the management of diabetes mellitus [45,46]. Daisy and Saipriya [111] synthesized gold nanoparticles (55–98 nm) using an aqueous extract of *Cassia fistula*. Extracts of *C. fistula* bark are known to be hypoglycemic. Kumar et al., (2012) used an aqueous extract of *Terminalia chebula* to produce gold nanoparticles with sizes ranging from 6 to 60 nm. These nanoparticles were active against both Gram-positive *S. aureus* and Gram-negative *E. coli*. In another Wu et al., [152] reported an approach for size and shape separation of NPs synthesized using *Cacumen platycladi* leaf extract. In the first step, size separation was performed via density gradient centrifugation method. Then, the size-purified GNPs were subjected to agarose gel electrophoresis (AGE) to separate gold

nanospheres from gold nanoplates. The authors observed that AGE cannot be effective in shape separation of nanoparticles without initial size separation by the density gradient centrifugation. This report is one of the most important papers on size and shape purification of nanoparticles. In 2014, the extract of *Garcinia combogia* fruit was used for the production of GNPs in spherical and anisotropic shapes Rajan et al., (2014). Huo et al., [47] used medicinal plants to synthesize AuNPs. Root extracts of *Glycyrrhiza uralensis* have been extensively used as a traditional medicine for anti-viral, antioxidant and anti-inflammatory purposes due to the presence of glycyrrhizinand flavonoids. The reaction of HAuCl₄ with Chineseliquorice extract occurred rapidly within 4 mins. Spherical AuNPs were obtained with a size of 12.25 nm. It was also found that that the red watermelon extract tended to produce sphere and hexagonal plates, while the green watermelon extract tended to generate triangular shaped nanoparticles. Both red and green watermelon extracts produced nanoparticles with similar antibacterial activity towards both *Eshcherichia coli* and *Staphylococcus epidermidis*. The gold nanoparticles were synthesized using the lichen *Parmelia sulcata* extract. The elemental composition and spherical shape of AuNPs were confirmed by energy dispersive spectroscopy and transmission electron microscopy. The average particles size is 54 nm. The potential effect of synthesized nanoparticles and lichen extract was evaluated for antioxidant bioassays like DPPH and H₂O₂ and tested for mosquitocidal activity against *Anopheles stephensi* [27].

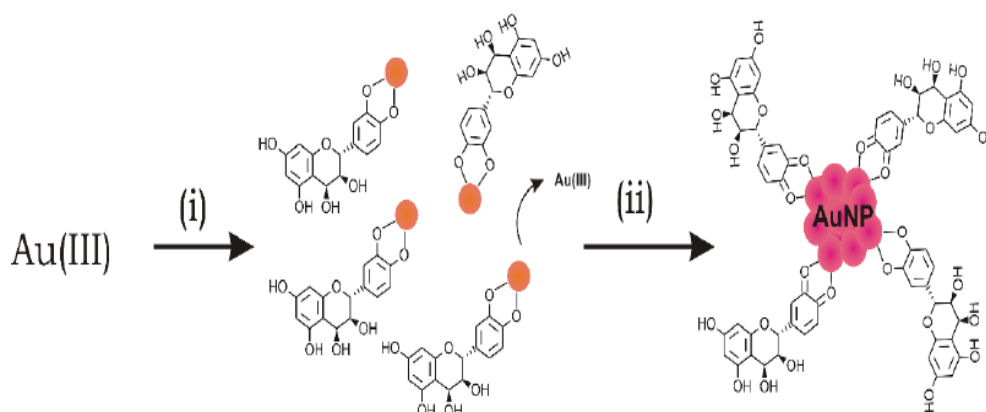


Fig. 4. Mechanism of the synthesis, autoreduction and stabilization of Au nanoparticles by polyphenolic compounds present in the bark extract of Terminalia arjuna: (i) bark extract of Terminalia arjuna containing polyphenolic compounds, (ii) autoreduction and stabilization by the polyphenolic compounds [156]

Table 1. Different plants species that have been used for the synthesis of gold nanoparticles

S. No.	Plant	Plant part	Shape	Size in nm	Reference
1.	<i>Azadirachta indica</i> A.Juss	Leaf	Spherical, triangle, hexagonal	50-35	[48]
2.	<i>Populous alba</i> L.	Leaf	Uniform	16.3 ± 0.7	[49]
3.	<i>Cicer arietinum</i> L.	Beans	Triangular prism	25	[50]
4.	<i>Alium cepa</i> L.	Leaf	Spherical and triangle	100	[51]
5.	<i>Macrotyloma uniflorum</i> (Lam)	Leaf	Flate and plate-like triangle	14-17	[52]
6.	<i>Justicia gendarussa</i> Bum.f.	Leaf	Spherical and triangle	20-42	[53]
7.	<i>Camellia sinensis</i> (L.) Kuntze	Leaf	Spherical	20-30	[54]
8.	<i>Pelargonium roseum</i> L.	Leaf	Hexagonal	2.5-27.5	[55]
9.	<i>Coriandrum sativum</i> L.	Leaf	Spherical triangle and a truncated triangle	5-70	[56]
10.	<i>Mentha piperita</i> L.	Leaf	Nanoprism and spherical	90-150	[57]
11.	<i>Mirabilis jalapa</i> L.	Plant	Spherical and triangles	100	[58]
12.	<i>Rosa hybrid</i> L.	Petal	Triangles, pentagons, hexagonal and spherical	10	[59]
13.	<i>Mangifera indica</i> L.	Peel	Spherical	6.03-18	[60]
14.	<i>Gymnocladus assamicus</i> P.C. Kanjilal	Leaf	Hexagonal, pentagonal, triangular	4-22	[61]
15.	<i>Garcinia mangostana</i> L.	Peel	Spherical and hexagonal	32.96	[62]
16.	<i>Pogestemon benghalensis</i> (Burm. F.) O. Kuntze	Leaf	Cubic	13.07	[63]
17.	<i>Vitis vinifera</i> L.	Fruit	Spherical	5-40	[64]
18.	<i>Nerium oleander</i> L.	Leaf	Spherical	2-10	[65]
19.	<i>Butea monosperma</i> (Lam.) Taub.	Leaf	Spherical	10-100	[66]
20.	<i>Arachis hypogaea</i> L.	Leaf	Spherical	110-130	[67]
21.	<i>Nyctanthes arbortristis</i> L.	Flower	Spherical, triangular	19.8	[68]
22.	<i>Hibiscus cannabinus</i> L.	Leaf	Spherical	10-13	[69]
23.	<i>Sesbania grandiflora</i> (L.) Poiert	Leaf	Spherical	7-34	[70]
24.	<i>Salix alba</i> L.	Leaf	.....	50-80	[71]
25.	<i>Eucommia ulmoides</i> Oliv.	Leaf	Spherical	.....	[72]
26.	<i>Galaxaura elongate</i> J. Agardh	Leaf	Spherical	3.85-77.13	[73]
27.	<i>Ocimum sanctum</i> L.	Leaf	Hexagonal	30	[74]
28.	<i>Torreya nucifera</i> (L.) Siebold and Zucc.	Leaf	Spherical	10-125	[75]

S. No.	Plant	Plant part	Shape	Size in nm	Reference
29.	<i>Olea europaea</i> L.	Leaf	Triangular, hexagonal, Spherical	50-100	[76]
30.	<i>Rosa indica</i> L.	Leaf	Spherical	23.52-60.83	[77]
31.	<i>Pistacia integerrima</i> J.L.Stewart ex Brandis	Leaf	.....	20-200	[78]
32.	<i>Terminalia arjuna</i> (Roxb.) Wight & Arn.	Leaf	Spherical	60	[79]
33.	<i>Euphorbia hirta</i> L.	Leaf	Spherical	6-71	[80]
34.	<i>Morinda citrifolia</i> L.	Leaf	Spherical	12.17-38.26	[81]
35.	<i>Ziziphus mauritana</i> Lam.	Leaf	Spherical	20-40	[82]
36.	<i>Aloe vera</i> (L.) Burm.f.	Leaf	Spherical	50-30	[83]
37.	<i>Anacardium occidentale</i> L.	Leaf	Spherical	6	[84]
38.	<i>Chenopodium album</i> L.	Leaf	.....	12-10	[85]
39.	<i>Dioscorea bulbifera</i> L.	Tuber	Spherical	13	[86]
40.	<i>Pelargonium graveolens</i> L'Hér.	Leaf; Stem	Spherical; Spherical	16-40; 8-24	[87], [109]
41.	<i>Mucuna pruriens</i> (L.) DC.	Leaf	Spherical	6.17-7	[88]
42.	<i>Parthenium hysterophorus</i> L.	Leaf	Face center cube	50	[89]
43.	<i>Psidium guajava</i> L.	Leaf	Spherical	20-30	[90]
44.	<i>Cacumen platycladi</i> L.	Leaf	-----	Variable	[91]
45.	<i>Rosa rugosa</i> Thunb.	Leaf	Hexagonal	12	[92]
46.	<i>Tanacetum vulgare</i> L.	Leaf	Spherical and triangular	16	[93]
47.	<i>Terminalia catappa</i> L.	Leaf	Spherical	10-30	[94]
48.	<i>Nigella arvensis</i> L.	Leaf	Spherical	3-37	[95]
49.	<i>Scutellaria barbata</i> D.Don	Leaf	Spherical	154	[96]
50.	<i>Gnidia glauca</i> L.	Flower	Spherical	10	[97]
51.	<i>Cinnamomum japonicum</i> Sieb.	Leaves	Spherical	10-50	[98]
52.	<i>Salicornia brachiata</i> L.	Leaf	Spherical	22-35	[99]
53.	<i>Cicer arietinum</i> L.	Beans	Triangular	191	[100]
54.	<i>Terminalia chebula</i> L.	Fruit	Spherical	60	[101]
55.	<i>Trichoderma koningii</i>	Leaves	Triangular	30-40	[102]
56.	<i>Tamarindus indica</i> L.	Flower	Triangular	2-40	[103]
57.	<i>Pyrus sp.L.</i> (Pear)	Fruit	Triangular, hexagonal	200-500	[104]
58.	<i>Magnolia kobus</i> DC. and <i>Diopyros kaki</i> Thunb.	Leaf	Triangle, pentagons and hexagons	5-300	[105]
59.	<i>Medicago sativa</i> L.	Plant extract	Irregular, tetrahedral, hexagonal platelet, decahedral, icosahedral	2-40	[106]
60.	<i>Emblicaofficinales</i> L.	Fruit	Triangular	15-25	[107]
61.	<i>Cymbopogon citrates</i> (DC.) Stap.	Leaf	Triangular and spherical	10-30	[108]
62.	<i>Pelargonium graveolens</i> L'Hér.	Stem	Spherical	8.3-23.8	[109]
63.	<i>Eucalyptus camaldulensis</i> Dehnh.	Leaf	Triangle and hexagonal	1.25-17.5	[110]

6. ADVANTAGE OF BIOSYNTHESIS

Biosynthesis method is simple and facile. It is easy to control the size and shape of the NPs by altering the reaction parameters and the reduction of NPs is relatively rapid and cost effective.

7. DISADVANTAGE OF BIOSYNTHESIS

It is difficult to determine the reactive components in plants because plant extracts contain many organic compounds.

8. BIOLOGICAL EVALUATION OF GOLD NANOPARTICLES

Presently, metal nanoparticles are of much importance because of their catalytic activity, optical properties, electronic properties, antimicrobial activity and magnetic activity [112-114]. In medicine, nanomaterials have been used in specific applications such as tissue-engineered scaffolds and devices, drug delivery systems, cancer therapy and bioanalytical diagnostics and therapeutics [115-117].

NPs contain small atoms or molecules that possess unique properties which vary from their bulk counterparts. Hence, they perform differently in terms of electronic, magnetic, optical, physical and chemical properties [89]. Spherical AuNPs play an important role in the future of bio-nanotechnology development. They have large surface-to-volume ratios, good optoelectronic properties, excellent biocompatibility and low toxicity. AuNPs tend to interact with biomolecules (such as lipid, nucleic acid and proteins) due to their multiple surface compatibility properties. The immediate adsorption of biomolecules to AuNPs is called the "nanoparticle-protein corona". This interaction provides greater promise for clinical use. The effect of such a corona reduced the release of paclitaxel from Nano carriers and this effect is dependent on protein concentrations [90].

AuNPs have been shown to be non-toxic to normal L-cells when used at different amounts (from 1 to 100 μ L) [91]. Another toxicity test was completed by Irama using radish. The root length and percent of seed germination were determined. Their research showed that AuNPs of sizes greater than 30 nm rarely entered the cell nucleus; hence, they may be more suitable for drug delivery [92]. The toxicity of AuNPs was

determined using *in vivo* animal models where it was found that toxicity was size dependent. Particles that were 10 nm in size were present in almost every tissue while larger particles were only detected in the liver, blood and spleen [93]. Based on the work from Sadauskas et al., (2009), it was found that AuNPs gradually decreased and were removed from the circulation system to one fifth of their original amount after 6 months mainly by Kupffer cells. It was a long-term process [94,102]. However, the damage caused by AuNPs was not permanent as cells were able to recover following AuNP removal. Near full recovery occurred for the cells after 14 days of AuNP removal (13nm and 45 nm in diameter). The number of vacuoles decreased which in turn allowed the cells to form normal actin fibers and increase their production as the cells divided and the concentration of AuNPs decreased [95]. Still, more work is needed before AuNPs can be widely used clinically as current studies, especially involving humans, remain fragmented.

Govindaraju et al., [138] reported antimicrobial and anticancer activity of synthesized nanoparticles using *Pongamia pinnata* leaf extract. Synthesized gold nanoparticles inhibited breast cancer cell line (MCF-7) proliferations with an efficiency of IC50 of 1.85 μ g/mL.

9. ANTIMICROBIAL ACTIVITY

AuNPs are also capable of fighting bacteria, fungi and other pathogens [96-97]. AuNPs exhibit antibacterial effects when they attach to the surface of a microbial cell wall because of their surface charge. The physicochemical surface modification between bacteria and NPs will release reactive oxygen species (ROS). This will cause protein denaturation, DNA destruction, mitochondrial dysfunction and finally cell death [98]. Antifungal activity of AuNPs may be due to binding of the NPs on the microbial surfaces through electrostatic interactions too. This reaction will inhibit the growth of fungi and generate ROS. The NPs will interrupt cell membrane permeability by attaching and collapsing intercellular communication. The synthesized Au NPs have shown enhanced antibacterial activity. It is very interesting that all these green synthesized Au NPs show efficient antibacterial activity against certain bacterial strains, especially compared to chemically synthesized Au NPs which showed nearly no antimicrobial activity against similar strains. The

antibacterial activity may be due to the synergistic effect of the combination of Au NPs and extracts. Antimicrobial potential of the NPs is affected by the size and surface chemistry [150-153].

An increase in size will decrease their activity and vice versa. This is also supported by study of Ahmad according to their study 7 nm Au NPs restrict the trans membrane H⁺ efflux of the *Candida* species more than the 15 nm Au NPs. Moreover, despite the size the antimicrobial activity was also different in the case of cell wall composition. Au NPs showed the highest activity against gram negative bacteria than gram-positive bacteria (Fig. 5). The Antimicrobial property of nanoparticles against *Staphylococcus aureus*, *Pseudomonas aeruginosa*, and *E.coli* has been investigated [99]. Nanoparticles were found to be cytotoxic to *E.coli*. The fluorescent bacteria were used to investigate the antimicrobial properties of nanoparticles. Recently studies had demonstrated that specially formulated metal oxide nanoparticles have good antimicrobial activity. Its compounds have strong inhibitory and bactericidal effects as well as a broad spectrum of antimicrobial activities of fungi, viruses, and bacteria since ancient times [100]. Due to the development of resistant strains resistance of bacteria to bactericides and antibiotics has increased [101]. Some antimicrobial agents are extremely toxic and there are vital need and much interest in finding ways to formulate a new type of safe and cost-effective biocidal material [102].

AuNPs show excellent antibacterial activity against *E. coli* by absorbing light and converting it into heat. The growing drug resistance of fungal strains also demands the development of new drugs for better treatment of fungal diseases [128-132]. Among the various nanoparticles AuNPs are sensitive to candida cells, which can inhibit the growth and kill the fungal pathogen *C. albicans*. They increase the ROS and damage the cell membrane by their unique properties, which include converting light to heat when irradiated and strong anionic binding with the fungal plasma membrane [143-144, 145].

The general consensus is that AuNP drug conjugates exhibit greater antibacterial activity than individual nanoparticles and drugs. Payne et al., [146] evaluated the antibacterial activities of kanamycin and AuNPs–kanamycin conjugates against the Gram- positive *Staphylococcus epidermidis* and the Gram- negative

Enterobacteria aerogenes, and concluded that the minimum inhibitory concentration of the conjugate was significantly lower than that of free kanamycin. Similar conclusions were drawn by Rattanata et al., (2016), who evaluated the activities of gallic acid and AuNP–gallic acid against the foodborne pathogenic bacterial species *Plesiomonas shigelloides* and *Shigella flexneri* B. Furthermore, analysis of the underlying mechanism by Fourier transform infrared spectroscopy revealed that AuNP–gallic acid altered lipids, proteins and nucleic acids of the bacterial cell membrane [154]. Bagga et al., [149] indicated that 27.2- nm AuNP–levofloxacin conjugates were more efficient than levofloxacin alone and improved the antibacterial efficacy against *Staphylococcus aureus*, *Escherichia coli* and *Pseudomonas aeruginosa* by 1.94, 2.89 and 1.46 times respectively. Peng et al., (2016) demonstrated that an AuNPs antimicrobial peptide system had greater antimicrobial efficacy than free antimicrobial peptides in rat mesenchymal stem cells, and they attributed the improvement to the high peptide density on the AuNP surface. It has been speculated that AuNPs interact with bacterial components, such as lysosomes, ribosomes and enzymes, and change the permeability of the cell membrane, leading to the disruption of the electrolyte balance, enzyme inhibition and protein deactivation [151].

Payne et al., [146] evaluated the antibacterial activities of kanamycin and AuNP–kanamycin conjugates against the Gram positive *Staphylococcus epidermidis* and the Gram negative *Enterobacter aerogenes* and concluded that the minimum inhibitory concentration of the conjugate was significantly lower than that of free kanamycin. Rattanata et al., [147] evaluated the activities of gallic acid and AgNPs gallic acid against the food borne pathogenic bacteria species *Plesiomonas shigelloides* and *Shigella flexneri*B. Furthermore, analysis of the underlying mechanism by Fourier transform infrared spectroscopy revealed that AuNPs gallic acid altered lipids, proteins and nucleic acids of the bacterial cell membrane. In depth, research has identified various mechanisms by which AuNPs drug conjugates enter and influence micro-organisms. Small angle X ray scattering analyses have indicated that AuNPs conjugates adhere to and penetrate the bacterial cell wall, resulting in the disruption of the cellular environment and leading to cell lysis due to the leakage of cellular components (Payne et al., 2016). A similar mechanism was observed for AuNPs gallic acid

conjugates, which disrupted the cell membrane structure and integrity [147] and [148] reported that the antibacterial tests were performed using the agar well diffusion with selected gram-positive (*S. aureus*, *P. aeruginosa*) and gram negative bacteria (*Bacillus* sp. and *E. coli*).

10. ANTICANCER ACTIVITY OF GOLD NANOPARTICLES

The International Agency for Research on Cancer estimates of the incidence of mortality and prevalence from major types of cancer, at national level, for 184 countries of the world revealed that there were 14.1 million new cancer cases, 8.2 million cancer deaths, and 32.6 million people living with cancer (within 5 years of diagnosis) in 2012 worldwide. By 2030, it is projected that there will be 26 million new cancer cases and 17 million cancer deaths per year. Today, despite considerable efforts, cancer still remains an aggressive killer worldwide. Moreover, during the last decade, novel synthetic chemotherapeutic agents currently in use clinically have not succeeded in fulfilling expectations despite the considerable cost of their development. Therefore there is a constant demand to develop new, effective, and affordable anticancer drugs. From the dawn of ancient medicine, chemical compounds derived from plants have been used to treat human diseases. Natural products have received increasing attention over the past 30 years for their potential as a novel cancer preventive and therapeutic

agents. Gold nanoparticles have been investigated in diverse areas such as *in vitro* assays, *in vitro* and *in vivo* imaging, cancer therapy, and drug delivery. In order to be useful for cancer treatment, the AuNPs must be noncytotoxic (i.e. nontoxic for cells) for normal cells. This biocompatibility of gold nanoparticles helps to high utilization in the biomedical field.

AuNPs can be employed as a drug for cancer treatment. The small size of NPs enables them to penetrate through cancer cells for targeted treatment. The presence of large vascular pores on the vessels that supply oxygen and nutrients to the tumor sites and inflamed tissues enables NPs to pass through easily and accumulate at these areas [103]. Many researchers have shown that AuNPs have the ability to combat cancer cells successfully (Fig. 6). AuNPs synthesized using *Gymnema sylvestre*, or commonly known as cowplant, exhibited cytotoxic effects towards Hep2 cells. Morphological changes were observed in Hep2 cells after treatment with AuNPs. Increases in the level of reactive oxygen species and nucleus changes were determined and suggested that the death of Hep2 cells was mediated by apoptosis [104]. Another cervical cancer cell, HeLa cell line, reacted towards AuNPs as well. Morphological changes such as rounding, shrinking and granulation were observed. The activity of AuNPs was due to easy penetration of the NPs through the cell membrane [105]. AuNPs have also reacted on other tumor cells,

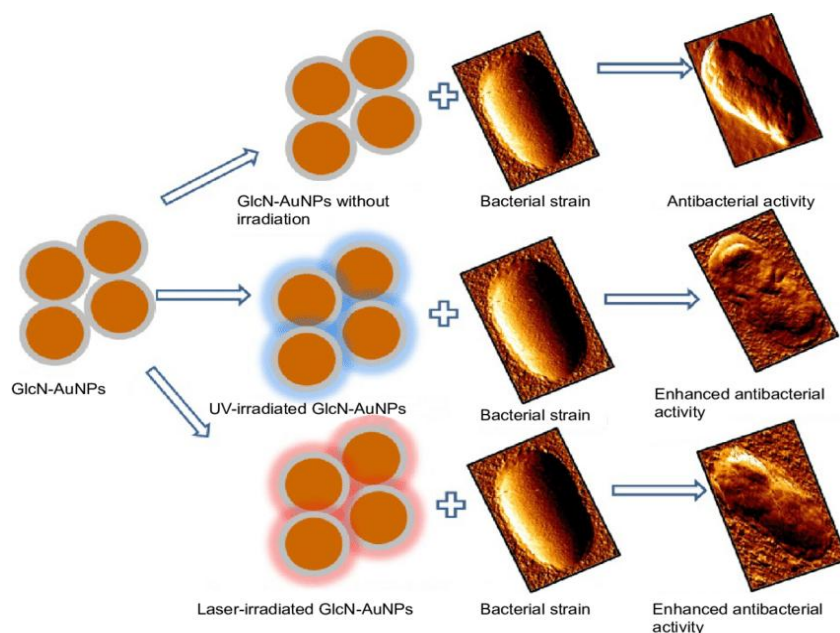


Fig. 5. Schematic diagram for antibacterial activity of Au nanoparticles [154]

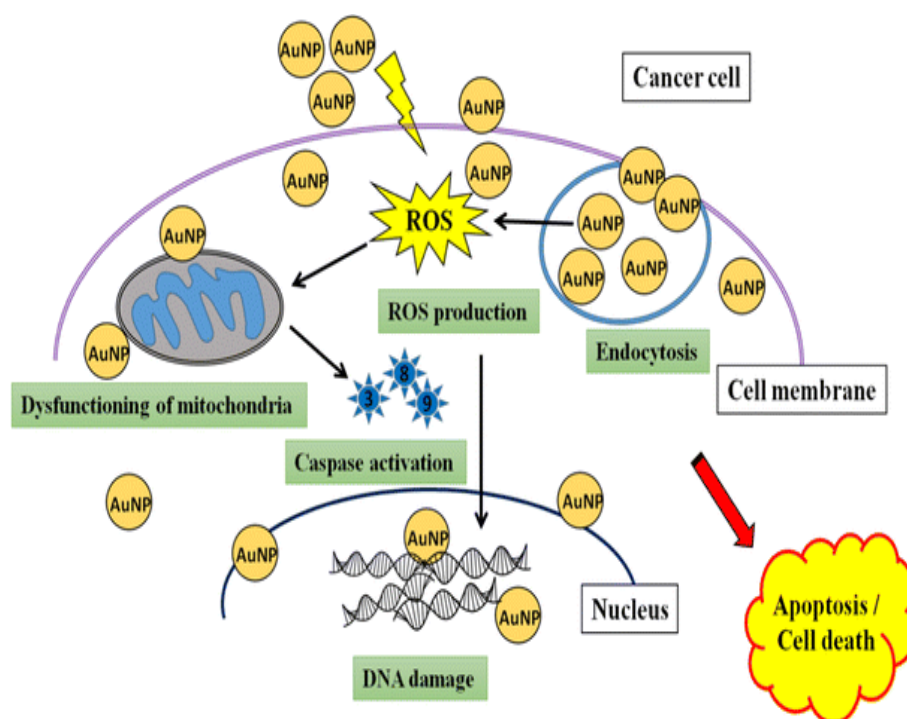


Fig. 6. Mechanisms of anticancer activity for AuNPs [155]

Ehrlich's Ascites Carcinoma, breast cancer cells and MCF-7 cells to name a few. Green tea polyphenols have been utilized to synthesize AuNPs. A comparison was made between green tea synthesized AuNPs and EGCG synthesized AuNPs. Both NPs were able to induce apoptosis in tumor cells while protecting normal hepatocytes from tumor cell damage. However, green synthesized AuNPs showed enhanced tumoricidal and hepatoprotective properties [106]. AuNPs that were synthesized by *Actinidia deliciosa* showed 71% viability at their highest concentration (350 μ g/mL) when tested on HCT-116 cells using an MTT assay. The NPs exhibited a cytotoxic effect in a concentration dependent manner [107].

Zharov et al., [143] showed that the absorbance wavelength (in the visible range) of small gold nanospheres is not optimal for *in vivo* applications, besides investigating the assembly of gold nanoclusters on the cell membrane. Chithrani et al., [142] research shows the effect of AuNPs size on HeLa cells due to internalization time. The internalization time of AuNPs measuring between 14 and 74 nm is independent of their size. However, this difference modifies the number of internalized particles. They also reveal that the accumulation of AuNPs near cancer cells is because of the Enhanced Permeability and Retention (EPR)

effect and the vectorization is called a "passive" one. Dhar et al., [141] has reported the cellular uptake studies and cytotoxic effect of biosynthesized gold nanoparticles human glioma cell line LN-229 and human glioma stem cell line HNGC-2. The gold nanoparticles showed greater cytotoxicity by killing the glioma cell lines and the glioma stem cell lines also. Lokina and narayanan [61] studies show that cytotoxicity on HeLa cancer cell of gold nanoparticles synthesized from grape fruit extract was very inevitable results in addition to antimicrobial activity.

Divakaran et al., [130] reported that AuNPs are more significant in the research field owing to their non-toxic effects; self-assembled natural and improved drug delivery [125-27,129]. *Scutellaria barbata* has a potent antitumor activity in breast cancer [130], colorectal cancer [131], hepatocarcinoma [132], skin cancer [133], lung cancer [134] and ovarian cancer [135]. Moreover, Lee et al., [137] reported that the active fractions of *Scutellaria barbata* have anti-inflammatory activity in BV-2 cells. [136]. The Main properties of nanoparticles to be an effective drug delivery agent include monodispersity lack of cytotoxicity and simple mechanism of interaction with desired ligands [155]. Based on these characteristics many nanoparticles have been synthesized and used

in cancer treatment, drug delivery systems and imaging such as dendrimers, quantum dots, polymer gels, gold nanoparticles [118-122].

Recent progress in inorganic material based nanoparticles for cancer therapy and imaging, multiple nano vehicle have been developed and evaluated. Zahra et al., [140] studied that nanocomposite of zinc oxide and gold nanoparticles was used as a platform for immobilizing thiolated TB DNA (Probe DNA) a simple and cost effective electrochemical DNA biosensor was developed. Abdel-Ghany et al., [73] effect of gold nanoparticles on induce G2/M cell cycle arrest and enhance the expression of E-cadherin in breast cancer cells MCF-7. Govindaraju et al., [138] reported antimicrobial and anticancer activity of synthesized nanoparticles using pongamia pinnata leaf extract. Synthesized gold nanoparticles inhibited breast cancer cell line (MCF-7) proliferation with an efficiency of IC₅₀ of (1.85 µg/mL). *In vitro* anticancer evaluation against HepG2 cell lines was conducted by MTT assay for craton spassiflorus extract derived AuNPs in different conc. 5 to 150 µg/mL studied.

11. CONCLUSION

Biological application of MNPs has increased the need to develop plant-based method in the synthesis of these NPs. Plants are inexpensive, available and renewable source. Also it is very simple to prepare an extract from plants. The great variety of plants in nature leads to great diversity in type and amount of capping and reducing agents from plant extract which make possible the synthesis of MNPs of different shape and morphologies. Further, there is evidence that nanoparticles exhibit an array of genotoxic effects in higher organism. This raises concern about possible impacts to higher organism including humans. Although significant progress has been made to the mechanisms of nanoparticles toxicity, further research is required to fully understand the processes involved and to safely exploit the tremendous antimicrobial properties of nanoparticles without jeopardizing human health, critical infrastructure and the environment. Future *in-vitro*, *in-vivo* and environmental studies should consider more systematically the various effects of aquatic chemistry on nanomaterial fate and toxicity. The products of nanoparticles have a large surface area to volume ratio, which is their most important feature responsible for the widespread use of nanomaterial's in mechanics, optics,

electronics, biotechnology, microbiology, environmental remediation, medicine, numerous engineering fields and material science.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Salata OV. Applications of nanoparticles in biology and medicine. *Journal of Nanobiotechnology*. 2004;2(1):1-6.
2. Abou El-Nour KM, Eftaiha AA, Al-Warthan A, Ammar RA. Synthesis and applications of silver nanoparticles. *Arabian Journal of Chemistry*. 2010;3(3):135-140.
3. Dykman LA, Khlebtsov NG. Gold nanoparticles in biology and medicine: recent advances and prospects. *Acta Naturae*. 2011;3(2):34-55.
4. Forough M, Fahadi K. Biological and green synthesis of silver nanoparticles. *Turkish Journal of Engineering and Environmental Sciences*. 2011;34(4):281-287.
5. Kalishwaralal K, Deepak V, Ramkumarpandian S, Nellaiah H, Sangiliyandi G. Extracellular biosynthesis of silver nanoparticles by the culture supernatant of *Bacillus licheniformis*. *Materials Letters*. 2008;62(29):4411-4413.
6. Kharissova OV, Dias HR, Kharisov BI, Pérez BO, Pérez VMJ. 3 The greener synthesis of nanoparticles. *Trends in Biotechnology*. 2013;1(4):240-248.
7. Shams S, Pourseyedi S, Raisi M. Green synthesis of Ag nanoparticles in the present of *Lens culinaris* seed exudates. *International Journal of Agriculture and Crop Sciences (IJACS)*. 2013;5(23):2812-2815.
8. Bond G. The early history of catalysis by gold. *Gold Bulletin*. 2008;1(3):235-241.
9. Bond G, Thompson D. Formulation of mechanisms for gold-catalysed reactions. *Gold Bulletin*. 2009;42(4):247-259.

10. Blaber MG, Arnold MD, Harris N, Ford MJ, Cortie MB. Plasmon absorption in nanospheres: A comparison of sodium, potassium, aluminium, silver and gold. *Physica B: Condensed Matter*. 2007;394(2):184-187.
11. Bakhishev T, Subramanian V. Investigation of gold nanoparticle inks for low-temperature lead-free packaging technology. *Journal of Electronic Materials*. 2009;38(12):2720-2725.
12. Kelly KL, Coronado E, Zhao LL, Schatz GC. The optical properties of metal nanoparticles: The influence of size, shape, and dielectric environment. *The Journal of Physical Chemistry B*. 2003;107(3):668-677.
13. Daniel MC, Astruc D. Gold nanoparticles: assembly, supramolecular chemistry, quantum-size-related properties, and applications toward biology, catalysis, and nanotechnology. *Chemical Reviews*. 2004;104(1):293-346.
14. Thanh NTK, Rosenzweig Z. Development of an aggregation-based immunoassay for anti-protein A using gold nanoparticles. *Analytical Chemistry*. 2002;74(7):1624-1628.
15. Brust M, Fink J, Bethell D, Schiffrin DJ, Kiely C. Synthesis and reactions of functionalised gold nanoparticles. *Journal of the Chemical Society, Chemical Communications*. 1995;16:1655-1656.
16. Goulet PJ, Lennox RB. New insights into Brust-Schiffrin metal nanoparticle synthesis. *Journal of the American Chemical Society*. 2010;132(28):9582-9584.
17. Pong BK, Elim HI, Chong JX, Ji W, Trout BL, Lee JY. New insights on the nanoparticle growth mechanism in the citrate reduction of gold (III) salt: Formation of the Au nanowire intermediate and its nonlinear optical properties. *The Journal of Physical Chemistry C*. 2007;111(17):6281-6287.
18. Turkevich J. Colloidal gold (Part II). *Gold Bulletin*. 1985;18(4):125-131.
19. Chow MK, Zukoski CF. Gold sol formation mechanisms: role of colloidal stability. *Journal of Colloid and Interface Science*. 1994;165(1):97-109.
20. Jana NR, Gearheart L, Murphy CJ. Seeding growth for size control of 5– 40 nm diameter gold nanoparticles. *Langmuir*. 2001;17(22):6782-6786.
21. Perrault SD, Chan WC. Synthesis and surface modification of highly monodispersed, spherical gold nanoparticles of 50– 200 nm. *Journal of the American Chemical Society*. 2009; 131(47):17042-17043.
22. Sharma V, Park K, Srinivasarao M. Colloidal dispersion of gold nanorods: Historical background, optical properties, seed-mediated synthesis, shape separation and self-assembly. *Materials Science and Engineering: R: Reports*. 2009;65(1-3):1-38.
23. Grabar KC, Freeman RG, Hommer MB, Natan MJ. Preparation and characterization of Au colloid monolayers. *Analytical Chemistry*. 1995;67(4):735-743.
24. Nallagouni CSR, Gangapuram BR, Karnati PR. Green synthesis of Gold Nanoparticles using leaf extract of *Caesalpinia bonducella* and its biological Applications. *Research Journal of Pharmacy and Technology*. 2021;14(2):1037-1040.
25. Mata R, Bhaskaran A, Sadras SR. Green-synthesized gold nanoparticles from *Plumeria alba* flower extract to augment catalytic degradation of organic dyes and inhibit bacterial growth. *Particuology*. 2016;24:p78-86.
26. Patra JK, Baek KH. Novel green synthesis of gold nanoparticles using *Citrullus lanatus* rind and investigation of proteasome inhibitory activity, antibacterial, and antioxidant potential. *International Journal of Nanomedicine*. 2015;10:7253.
27. Gandhi AD, Murugan K, Umamahesh K, Babujanathanam R, Kavitha P, Selvi A. Lichen *Parmelia sulcata* mediated synthesis of gold nanoparticles: An eco-friendly tool against *Anopheles stephensi* and *Aedes aegypti*. *Environmental Science and Pollution Research*. 2019;26(23):23886-23898.
28. Roduner E. Size matters: why nanomaterials are different. *Chemical Society Reviews*. 2006;35(7):583-592.
29. Khanna VK. *Nanosensors: Physical, chemical, and biological*. CRC Press; 2019.
30. Hu X, Zhang Y, Ding T, Liu J, Zhao H. Multifunctional Gold Nanoparticles: A novel nanomaterial for various medical applications and biological activities. *Frontiers in Bioengineering and Biotechnology*. 2020;8:1-17.
31. Talan A, Mishra A, Eremin SA, Narang J, Kumar A, Gandhi S. Ultrasensitive

- electrochemical immuno-sensing platform based on gold nanoparticles triggering chlorpyrifos detection in fruits and vegetables. *Biosensors and Bioelectronics*. 2018;105:14-21.
32. Fedlheim DL, Foss CA. Metal nanoparticles: synthesis, characterization, and applications. CRC Press; 2001.
 33. Sepeur S. Nanotechnology: Technical basics and applications. Vincentz Network GmbH & Co KG; 2008.
 34. Azharuddin M, Sahana S, Datta H, Dasgupta AK. Corneal Penetration of Gold Nanoparticles—Therapeutic Implications. *Journal of Nanoscience and Nanotechnology*. 2014;14(8):5669-5675.
 35. Quester K, Avalos-Borja M, Vilchis-Nestor AR, Camacho-López MA, Castro-Longoria E. SERS properties of different sized and shaped gold nanoparticles biosynthesized under different environmental conditions by *Neurospora crassa* extract. *PLoS One*. 2013;8(10):1-8.
 36. Schaffer B, Hohenester U, Trügler A, Hofer F. High-resolution surface plasmon imaging of gold nanoparticles by energy-filtered transmission electron microscopy. *Physical Review B*. 2009;79(4):041401.
 37. Thakkar KN, Mhatre SS, Parikh RY. Biological synthesis of metallic nanoparticles. *Nanomedicine: Nanotechnology, Biology and Medicine*. 2010;6(2):257-262.
 38. Korbekandi H, Iravani S, Abbasi S. Production of nanoparticles using organisms. *Critical Reviews in Biotechnology*. 2009;29(4):279-306.
 39. Dhillon GS, Brar SK, Kaur S, Verma M. Green approach for nanoparticle biosynthesis by fungi: Current trends and applications. *Critical Reviews in Biotechnology*. 2012;32(1):49-73.
 40. Gericke M, Pinches A. Microbial production of gold nanoparticles. *Gold Bulletin*. 2006;39(1):22-28.
 41. Sanghi R, Verma P. pH dependant fungal proteins in the 'green'synthesis of gold nanoparticles. *Adv. Mater. Lett*. 2010;1(3):193-199.
 42. Njagi EC, Huang H, Stafford L, Genuino H, Galindo HM, Collins JB, Hoag JE, Suib SL. Biosynthesis of iron and silver nanoparticles at room temperature using aqueous sorghum bran extracts. *Langmuir*. 2011;27(1):264-271.
 43. Kasthuri J, Veerapandian S, Rajendiran N. Biological synthesis of silver and gold nanoparticles using apiin as reducing agent. *Colloids and Surfaces B: Biointerfaces*. 2009;68(1):55-60.
 44. Raghunandan D, Bedre MD, Basavaraja S, Sawle B, Manjunath SY, Venkataraman A. Rapid biosynthesis of irregular shaped gold nanoparticles from macerated aqueous extracellular dried clove buds (*Syzygium aromaticum*) solution. *Colloids and Surfaces B: Biointerfaces*. 2010;79(1):235-240.
 45. Liu Q, Liu H, Yuan Z, Wei D, Ye Y. Evaluation of antioxidant activity of chrysanthemum extracts and tea beverages by gold nanoparticles-based assay. *Colloids and Surfaces B: Biointerfaces*. 2012;92:348-352.
 46. Nadagouda MN, Iyanna N, Lalley J, Han C, Dionysiou DD, Varma RS. Synthesis of silver and gold nanoparticles using antioxidants from blackberry, blueberry, pomegranate, and turmeric extracts. *ACS Sustainable Chemistry & Engineering*. 2014;2(7):1717-1723.
 47. Huo Y, Singh P, Kim YJ, Soshnikova V, Kang J, Markus J, et al. Biological synthesis of gold and silver chloride nanoparticles by *Glycyrrhiza uralensis* and *in vitro* applications. *Artificial cells, nanomedicine, and biotechnology*, 2018; 46(2):303-312.
 48. Shankar SS, Rai A, Ahmad A, Sastry M. Rapid synthesis of Au, Ag, and bimetallic Au core–Ag shell nanoparticles using Neem (*Azadirachta indica*) leaf broth. *Journal of Colloid and Interface Science*. 2004;275(2):496-502.
 49. Guliani A, Kumari A, Acharya A. Green synthesis of gold nanoparticles using aqueous leaf extract of *Populus alba*: Characterization, antibacterial and dye degradation activity. *International Journal of Environmental Science and Technology*. 2021;1-12.
 50. Ghule K, Ghule AV, Liu JY, Ling YC. Microscale size triangular gold prisms synthesized using Bengal Gram beans (*Cicer arietinum* L.) extract and H₂AuCl₄·3H₂O: A green biogenic approach. *Journal of Nanoscience and Nanotechnology*. 2006;6(12):3746-3751.
 51. Parida UK, Bindhani BK, Nayak P. Green synthesis and characterization of gold nanoparticles using onion (*Allium cepa*) extract. *World Journal of Nano Science and Engineering*. 2011;1(4):93-98.

52. Aromal SA, Vidhu VK, Philip D. Green synthesis of well-dispersed gold nanoparticles using *Macrotyloma uniflorum*. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*. 2012;85(1):99-104.
53. Fazaludeen MF, Manickam C, Ashankyti IM, Ahmed MQ, Beg QZ. Synthesis and characterizations of gold nanoparticles by *Justicia gendarussa* Burm F leaf extract. *Journal of Microbiology and Biotechnology Research*. 2012;2(1):23-34.
54. Dou L, Zhang X, Zangeneh MM, Zhang Y. Efficient biogenesis of Cu₂O nanoparticles using extract of *Camellia sinensis* leaf: Evaluation of catalytic, cytotoxicity, antioxidant, and anti-human ovarian cancer properties. *Bioorganic Chemistry*. 2021;106:104468.
55. Ramezani N, Ehsanfar Z, Shamsa F, Amin G, Shahverdi HR, Esfahani HRM, et al. Screening of medicinal plant methanol extracts for the synthesis of gold nanoparticles by their reducing potential. *Zeitschrift für Naturforschung B*. 2008;63(7):903-908.
56. Narayanan KB, Sakthivel N. Coriander leaf mediated biosynthesis of gold nanoparticles. *Materials Letters*. 2008; 62(30):4588-4590.
57. Mubarak Ali D, Thajuddin N, Jeganathan K, Gunasekaran M. Plant extract mediated synthesis of silver and gold nanoparticles and its antibacterial activity against clinically isolated pathogens. *Colloids and Surfaces B: Biointerfaces*. 2011;85(2):360-365.
58. Vankar PS, Bajpai D. Preparation of gold nanoparticles from *Mirabilis jalapa* flowers. *Indian Journal of Biochemistry & Biophysics*. 2010;47(3):157-160.
59. Noruzi M, Zare D, Khoshnevisan K, Davoodi D. Rapid green synthesis of gold nanoparticles using *Rosa hybrida* petal extract at room temperature. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*. 2011;79(5): 1461-1465.
60. Yang N, WeiHong L, Hao L. Biosynthesis of Au nanoparticles using agricultural waste mango peel extract and its *in vitro* cytotoxic effect on two normal cells. *Materials Letters*. 2014;134:67-70.
61. Tamuly C, Hazarika M, Bordoloi M. Biosynthesis of Au nanoparticles by *Gymnocladus assamicus* and its catalytic activity. *Materials Letters*. 2013;108:276-279.
62. Xin Lee K, Shameli K, Miyake M, Kuwano, N, Bt Ahmad Khairudin NB, Bt Mohamad, SE, Yew YP. Green synthesis of gold nanoparticles using aqueous extract of *Garcinia mangostana* fruit peels. *Journal of Nanomaterials*. 2016;2016: 1-8.
63. Paul B, Bhuyan B, Purkayastha DD, Dey M, Dhar SS. Green synthesis of gold nanoparticles using *Pogostemon benghalensis* (B) O. Ktz. leaf extract and studies of their photocatalytic activity in degradation of methylene blue. *Materials Letters*. 2015;148:37-40.
63. Lokina S, Narayanan V. Antimicrobial and anticancer activity of gold nanoparticles synthesized from grapes fruit extract. *Chemical Science Transactions*. 2013;2(S1):S105-S110.
64. Tahir K, Nazir S, Li B, Khan AU, Khan ZUH, Gong PY, Khan SU, Ahmad A. Nerium oleander leaves extract mediated synthesis of gold nanoparticles and its antioxidant activity. *Materials Letters*. 2015;156:198-201.
65. Patra S, Mukherjee S, Barui AK, Ganguly A, Sreedhar B, Patra CR. Green synthesis, characterization of gold and silver nanoparticles and their potential application for cancer therapeutics. *Materials Science and Engineering: C*. 2015;53:298-309.
66. Raju D, Vishwakarma RK, Khan BM, Mehta UJ, Ahmad A. Biological synthesis of cationic gold nanoparticles and binding of plasmid DNA. *Materials Letters*. 2014;129:159-161.
67. Das RK, Gogoi N, Bora U. Green synthesis of gold nanoparticles using *Nyctanthes arbortristis* flower extract. *Bioprocess and Bio Systems Engineering*. 2011;34(5):615-619.
68. Bindhu MR, Rekha PV, Umamaheswari T, Umadevi M. Antibacterial activities of *Hibiscus cannabinus* stem-assisted silver and gold nanoparticles. *Materials Letters*. 2014;131:194-197.
69. Das J, Velusamy P. Catalytic reduction of methylene blue using biogenic gold nanoparticles from *Sesbania grandiflora* L. *Journal of the Taiwan Institute of Chemical Engineers*. 2014;45(5):2280-2285.
70. Islam NU, Jalil K, Shahid M, Rauf A, Muhammad N, Khan A, et al. Green synthesis and biological activities of gold nanoparticles functionalized with *Salix*

- alba*. Arabian Journal of Chemistry. 2019;12(8):2914-2925.
71. Guo M, Li W, Yang F, Liu H. Controllable biosynthesis of gold nanoparticles from a *Eucommia ulmoides* bark aqueous extract. Spectrochimica acta part A: Molecular and Biomolecular Spectroscopy. 2015;142:73-79.
 72. Abdel-Raouf N, Al-Enazi NM, Ibraheem IB. Green biosynthesis of gold nanoparticles using *Galaxaura elongata* and characterization of their antibacterial activity. Arabian Journal of Chemistry. 2017;10:S3029-S3039.
 73. Philip D, Unni C. Extracellular biosynthesis of gold and silver nanoparticles using Krishna tulsi (*Ocimum sanctum*) leaf. Physica E: Low-dimensional Systems and Nanostructures. 2011;43(7):1318-1322.
 74. Kalpana D, Han JH, Park WS, Lee SM, Wahab R, Lee YS. Green biosynthesis of silver nanoparticles using *Torreya nucifera* and their antibacterial activity. Arabian Journal of Chemistry. 2019;12(7):1722-1732.
 75. Khalil MM, Ismail EH, El-Magdoub F. Biosynthesis of Au nanoparticles using olive leaf extract: 1st nano updates. Arabian Journal of Chemistry. 2012; 5(4):431-437.
 76. Manikandan R, Manikandan B, Raman T, Arunagirinathan K, Prabhu NM, Basu MJ, et al. Biosynthesis of silver nanoparticles using ethanolic petals extract of *Rosa indica* and characterization of its antibacterial, anticancer and anti-inflammatory activities. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy. 2015;138:120-129.
 77. Islam NU, Jalil K, Shahid M, Muhammad N, Rauf A. Pistacia integerrima gall extract mediated green synthesis of gold nanoparticles and their biological activities. Arabian Journal of Chemistry. 2019; 12(8):2310-2319.
 78. Kumar KM, Mandal BK, Kumar HAK, Maddinedi SB. Green synthesis of size controllable gold nanoparticles. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy. 2013;116:539-545.
 79. Annamalai A, Christina VLP, Sudha D, Kalpana M, Lakshmi PTV. Green synthesis, characterization and antimicrobial activity of Au NPs using *Euphorbia hirta* L. leaf extract. Colloids and Surfaces B: Biointerfaces. 2013;108:60-65.
 80. Suman TY, Rajasree SR, Ramkumar R, Rajthilak C, Perumal P. The Green synthesis of gold nanoparticles using an aqueous root extract of *Morinda citrifolia* L. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy. 2014;118:11-16.
 81. Sadeghi B. Zizyphus mauritiana extract-mediated green and rapid synthesis of gold nanoparticles and its antibacterial activity. Journal of Nanostructure in Chemistry. 2015;5(3):265-273.
 82. Chandran SP, Chaudhary M, Pasricha R, Ahmad A, Sastry M. Synthesis of gold nanotriangles and silver nanoparticles using Aloe vera plant extract. Biotechnology Progress. 2006;22(2):577-583.
 83. Sunderam V, Thiyagarajan D, Lawrence AV, Mohammed SSS, Selvaraj A. *In-vitro* antimicrobial and anticancer properties of green synthesized gold nanoparticles using Anacardium occidentale leaves extract. Saudi Journal of Biological Sciences. 2019;26(3):455-459.
 84. Dwivedi AD, Gopal K. Plant-mediated biosynthesis of silver and gold nanoparticles. Journal of Biomedical Nanotechnology. 2011;7(1):163-164.
 85. Ghosh S, Patil S, Ahire M, Kitture R, Jabgunde A, Kale S, Pardesi K, Bellare J, Dhavale DD, Chopade BA. Synthesis of gold nanoanisotropes using *Dioscorea bulbifera* tuber extract. Journal of Nanomaterials. 2011;2011:1-8.
 86. Shankar SS, Ahmad A, Pasricha R, Sastry M. Bioreduction of chloroaurate ions by geranium leaves and its endophytic fungus yields gold nanoparticles of different shapes. Journal of Materials Chemistry. 2003;13(7):1822-1826.
 87. Arulkumar S, Sabesan M. The behavioral performance tests of *Mucuna pruriens* gold nanoparticles in the 1-methyl 4-phenyl-1, 2, 3, 6-tetrahydropyridine treated mouse model of Parkinsonism. Asian Pacific Journal of Tropical Disease. 2012;2:S499-S502.
 88. Parashar V, Parashar R, Sharma B, Pandey AC. Parthenium leaf extract mediated synthesis of silver nanoparticles: A novel approach towards weed utilization. Digest Journal of Nanomaterials & Biostructures (DJNB). 2009;4(1):45-50.
 89. Raghunandan D, Basavaraja S, Mahesh B, Balaji S, Manjunath SY, Venkataraman A.

- Biosynthesis of stable polyshaped gold nanoparticles from microwave-exposed aqueous extracellular anti-malignant guava (*Psidium guajava*) leaf extract. *Nanobiotechnology*. 2009;5(1):34-41.
90. Zhan G, Huang J, Lin L, Lin W, Emmanuel K, Li Q. Synthesis of gold nanoparticles by *Cacumen Platycladi* leaf extract and its simulated solution: Toward the plant-mediated biosynthetic mechanism. *Journal of Nanoparticle Research*. 2011;13(10): 4957-4968.
 91. Dubey SP, Lahtinen M, Sillanpää M. Green synthesis and characterizations of silver and gold nanoparticles using leaf extract of *Rosa rugosa*. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. 2010;364(1-3):34-41.
 92. Dubey SP, Lahtinen M, Sillanpää M. Tansy fruit mediated greener synthesis of silver and gold nanoparticles. *Process Biochemistry*. 2010;45(7):1065-1071.
 93. Ankamwar B. Biosynthesis of gold nanoparticles (green-gold) using leaf extract of *Terminalia catappa*. *E-Journal of Chemistry*. 2010;7(4):1334-1339.
 94. Chahardoli A, Karimi N, Sadeghi F, Fattahi A. Green approach for synthesis of gold nanoparticles from *Nigella arvensis* leaf extract and evaluation of their antibacterial, antioxidant, cytotoxicity and catalytic activities. *Artificial Cells, Nanomedicine, and Biotechnology*. 2018;46(3):579-588.
 95. Wang L, Xu J, Yan Y, Liu H, Karunakaran T, Li F. Green synthesis of gold nanoparticles from *Scutellaria barbata* and its anticancer activity in pancreatic cancer cell (PANC- 1). *Artificial Cells, Nanomedicine, and Biotechnology*. 2019; 47(1):1617-1627.
 96. Ghosh S, Patil S, Ahire M, Kitture R, Gurav DD, Jabgunde AM, et al. *Gnidia glauca* flower extract mediated synthesis of gold nanoparticles and evaluation of its chemocatalytic potential. *Journal of Nanobiotechnology*. 2012;10(1):1-9.
 97. Kalpana D, Pichiah PT, Sankarganesh A, Park WS, Lee SM, Wahab R, Cha WS, Lee YS. Biogenesis of gold nanoparticles using plant powders and assessment of *in vitro* cytotoxicity in 3T3-L1 cell line. *Journal of Pharmaceutical Innovation*. 2013;8(4): 265-275.
 98. Ahmed KBA, Subramanian S, Sivasubramanian A, Veerappan G, Veerappan A. Preparation of gold nanoparticles using *Salicornia brachiata* plant extract and evaluation of catalytic and antibacterial activity. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*. 2014;130:54-58.
 99. Kalyani G, Vithal A, Liu JY. Microscale size triangular gold prisms synthesized using bengal gram beans (*Cicer arietinum*) extract and H_2O : A green biogenic approach. *Journal of Nanoscience and Nanotechnology*. 2006;6: 3746-3751.
 100. Kumar KM, Mandal BK, Sinha M, Krishnakumar V. *Terminalia chebula* mediated green and rapid synthesis of gold nanoparticles. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*. 2012;86:490-494.
 101. Maliszewska I, Aniszkievicz L, Sadowski Z. Biological synthesis of gold nanostructures using the extract of *trichoderma koningii*. *Acta Physica Polonica A*. 2009;116.
 102. Ankamwar B, Chaudhary M, Sastry M. Gold nanotriangles biologically synthesized using tamarind leaf extract and potential application in vapor sensing. *Synthesis and Reactivity in Inorganic, Metal-Organic and Nano-Metal Chemistry*. 2005;35(1):19-26.
 103. Ghodake GS, Deshpande NG, Lee YP, Jin E. Pear fruit extract-assisted room-temperature biosynthesis of gold nanoplates. *Colloids and Surfaces B: Biointerfaces*. 2010;75(2):584-589.
 104. Song JY, Jang HK, Kim BS. Biological synthesis of gold nanoparticles using *Magnolia kobus* and *Diopyros kaki* leaf extracts. *Process Biochemistry*. 2009; 44(10):1133-1138.
 105. Keshavarzi M, Davoodi D, Pourseyedi S, Taghizadeh S. The effects of three types of alfalfa plants (*Medicago sativa*) on the biosynthesis of gold nanoparticles: An insight into phytomining. *Gold Bulletin*. 2018;51(3):99-110.
 106. Ankamwar B, Damle C, Ahmad A, Sastry M. Biosynthesis of gold and silver nanoparticles using *Emblica officinalis* fruit extract, their phase transfer and transmetallation in an organic solution. *Journal of Nanoscience and Nanotechnology*. 2005;5(10):1665-1671.
 107. Murugan K, Benelli G, Panneerselvam C, Subramaniam J, Jeyalalitha T, Dinesh D, et al. *Cymbopogon citratus*-synthesized

- gold nanoparticles boost the predation efficiency of copepod *Mesocyclops aspericornis* against malaria and dengue mosquitoes. *Experimental Parasitology*. 2015;153:129-138.
108. Elia P, Zach R, Hazan S, Kolusheva S, Porat ZE, Zeiri Y. Green synthesis of gold nanoparticles using plant extracts as reducing agents. *International Journal of Nanomedicine*. 2014;9:4007.
 109. Golmoraj VE, Reza Khoshayand M, Amini M, Mollazadeh Moghadam K, Amin G, Reza Shahverdi A. The surface chemistry and stability of gold nanoparticles prepared using methanol extract of *Eucalyptus camaldulensis*. *Journal of Experimental Nanoscience*. 2011;6(2):200-208.
 110. Daisy P, Saipriya K. Biochemical analysis of *Cassia fistula* aqueous extract and phytochemically synthesized gold nanoparticles as hypoglycemic treatment for diabetes mellitus. *International journal of nanomedicine*. 2012;7:1189.
 111. Rajan A, Meena Kumari M, Philip D. Shape tailored green synthesis and catalytic properties of gold nanocrystals. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*. 2014;118:793-799.
 112. Rad AG, Abbasi H, Afzali MH. Gold nanoparticles: Synthesising, characterizing and reviewing novel application in recent years. *Physics Procedia*. 2011;22:203-208.
 113. Edwards PP, Thomas JM. Gold in a metallic divided state—from faraday to present-day nanoscience. *Angewandte Chemie International Edition*. 2007; 46(29):5480-5486.
 114. Liu J, Peng Q. Protein-gold nanoparticle interactions and their possible impact on biomedical applications. *Acta Biomaterialia*. 2017;55:13-27.
 115. Elia P, Zach R, Hazan S, Kolusheva S, Porat ZE, Zeiri Y. Green synthesis of gold nanoparticles using plant extracts as reducing agents. *International Journal of Nanomedicine*. 2014;9:4007.
 116. Iram F, Iqbal MS, Athar MM, Saeed MZ, Yasmeen A, Ahmad R. Glucoxylation-mediated green synthesis of gold and silver nanoparticles and their phyto-toxicity study. *Carbohydrate Polymers*. 2014; 104:29-33.
 117. De Jong WH, Hagens WI, Krystek P, Burger MC. ANJAM sips and RE geertsma. *Biomaterials*. 2008;29(12):1912-1919.
 118. Sadauskas E, Danscher G, Stoltenberg M, Vogel U, Larsen A, Wallin H. *Nanomedicine: Nanotechnology Biology Medicine*. 2009;5:162-169.
 119. Mironava T, Hadjiargyrou M, Simon M, Jurukovski V, Rafailovich MH. Gold nanoparticles cellular toxicity and recovery: Effect of size, concentration and exposure time. *Nanotoxicology*. 2010;4(1):120-137.
 120. Saha S, Chattopadhyay D, Acharya K. Preparation of silver nanoparticles by bio-reduction using *nigrospora oryzae* culture filtrate and its antimicrobial activity. *Digest Journal of Nanomaterials & Biostructures (DJNB)*. 2011;6(4):1519-1528.
 121. Dhrutika P, Miral P, Krishnamurthy R. Silver nanoparticles biosynthesis and its antimicrobial activity. *Cibtech Journal of Bio-Protocol*. 2013;2(1):50-7.
 122. Nithya R, Ragunathan R. Synthesis of silver nanoparticle using *Pleurotus sajor caju* and its antimicrobial study. *Digest Journal of Nanomaterials and Biostructures*. 2009;4(4):623-629.
 123. Nasrollahi A, Pourshamsian KH, Mansourkiaee P. Antifungal activity of silver nanoparticles on some of fungi. *International Journal of Nano Dimension*. 2011;1(3):233-239.
 124. Dreaden EC, Austin LA, Mackey MA, El-Sayed MA. Size matters: gold nanoparticles in targeted cancer drug delivery. *Therapeutic Delivery*. 2012; 3(4):457-478.
 125. Nakkala JR, Mata R, Bhagat E, Sadras SR. Green synthesis of silver and gold nanoparticles from *Gymnema sylvestre* leaf extract: Study of antioxidant and anticancer activities. *Journal of Nanoparticle Research*. 2015;17(3):1-15.
 126. Rajan A, Rajan AR, Philip D. *Elettaria cardamomum* seed mediated rapid synthesis of gold nanoparticles and its biological activities. *Open Nano*. 2017;2:1-8.
 127. Mukherjee S, Ghosh S, Das DK, Chakraborty P, Choudhury S, Gupta P, et al. Gold-conjugated green tea nanoparticles for enhanced anti-tumor activities and hepatoprotection—Synthesis, characterization and *in vitro* evaluation. *The Journal of Nutritional Biochemistry*. 2015;26(11):1283-1297.

128. Naraginti S, Li Y. Preliminary investigation of catalytic, antioxidant, anticancer and bactericidal activity of green synthesized silver and gold nanoparticles using *Actinidia deliciosa*. Journal of Photochemistry and Photobiology B: Biology. 2017;170:225-234.
129. Divakaran D, Lakkakula JR, Thakur M, Kumawat MK, Srivastava R. Dragon fruit extract capped gold nanoparticles: Synthesis and their differential cytotoxicity effect on breast cancer cells. Materials Letters. 2019;236:498-502.
130. Marconett CN, Morgenstern TJ, San Roman AK, Sundar SN, Singhal AK, Firestone GL. BZL101, a phytochemical extract from the *Scutellaria barbata* plant, disrupts proliferation of human breast and prostate cancer cells through distinct mechanisms dependent on the cancer cell phenotype. Cancer Biology & Therapy. 2010;10(4):397-405.
131. Yang N, Zhao Y, Wang Z, Liu Y, Zhang Y. Scutellarin suppresses growth and causes apoptosis of human colorectal cancer cells by regulating the p53 pathway. Molecular Medicine Reports. 2017;15(2):929-935.
132. Kan X, Zhang W, You R, Niu Y, Guo J, Xue J. Scutellaria barbata D. Don extract inhibits the tumor growth through down-regulating of Treg cells and manipulating Th1/Th17 immune response in hepatoma H22-bearing mice. BMC Complementary and Alternative Medicine. 2017;17(1):1-10.
133. Suh SJ, Yoon JW, Lee TK, Jin UH, Kim SL, Kim MS, et al. Chemoprevention of *Scutellaria barbata* on human cancer cells and tumorigenesis in skin cancer. Phytotherapy Research: An International Journal Devoted to Pharmacological and Toxicological Evaluation of Natural Product Derivatives. 2007;21(2):135-141.
134. Chen CC, Kao CP, Chiu MM, Wang SH. The anti-cancer effects and mechanisms of *Scutellaria barbata* D. Don on CL1-5 lung cancer cells. Oncotarget. 2017;8(65):109340-109357.
135. Zhang L, Ren B, Zhang J, Liu L, Liu J, Jiang G, et al. Anti-tumor effect of *Scutellaria barbata* D. Don extracts on ovarian cancer and its phytochemicals characterisation. Journal of Ethnopharmacology. 2017;206:184-192.
136. Lee SR, Kim MS, Kim S, Hwang KW, Park SY. Constituents from *Scutellaria barbata* inhibiting nitric oxide production in LPS- stimulated microglial cells. Chemistry & Biodiversity. 2017;14(11):e1700231.
137. Govindaraju K, Vasantharaja R, Suganya KU, Anbarasu S, Revathy K, Pugazhendhi A, et al. Unveiling the anticancer and antimycobacterial potentials of bioengineered gold nanoparticles. Process Biochemistry. 2020;96:213-219.
138. Abdel-Ghany S, Mahfouz M, Ashraf N, Sabit H, Cevik E, El-Zawahri M. Gold nanoparticles induce G2/M cell cycle arrest and enhance the expression of E-cadherin in breast cancer cells. Inorganic and Nano-Metal Chemistry. 2020;50(10):926-932.
139. Zahra R, Jacob J, Bano N, Ali A, Mahmood K, Ikram S, et al. Effect of secondary phases on the thermoelectric properties of Zn₂GeO₄ nano-crystals grown by thermal evaporation on Au coated Si substrate. Physica B: Condensed Matter. 2019;564:143-146.
140. Dhar S, Mali V, Bodhankar S, Shiras A, Prasad BLV, Pokharkar V. Biocompatible gellan gum- reduced gold nanoparticles: Cellular uptake and subacute oral toxicity studies. Journal of Applied Toxicology. 201;131(5):411-420.
141. Chithrani BD, Chan WC. Elucidating the mechanism of cellular uptake and removal of protein-coated gold nanoparticles of different sizes and shapes. Nano Letters. 2007;7(6):1542-1550.
142. Zharov VP, Galitovskaya EN, Johnson C, Kelly T. Synergistic enhancement of selective nanophotothermolysis with gold nanoclusters: Potential for cancer therapy. Lasers in Surgery and Medicine: The Official Journal of the American Society for Laser Medicine and Surgery. 2005;37(3):219-226.
143. Wani IA, Ahmad T. Size and shape dependant antifungal activity of gold nanoparticles: A case study of Candida. Colloids and surfaces B: Biointerfaces. 2013;101:162-170.
144. Yu Q, Li J, Zhang Y, Wang Y, Liu L, Li M. Inhibition of gold nanoparticles (AuNPs) on pathogenic biofilm formation and invasion to host cells. Scientific Reports. 2016;6(1):1-14.
145. Payne JN, Waghwani HK, Connor MG, Hamilton W, Tockstein S, Moolani H, et al. Novel synthesis of kanamycin conjugated gold nanoparticles with potent antibacterial activity. Frontiers in Microbiology. 2016; 7:1-10.

146. Rattanata N, Klaynongsruang S, Leelayuwat C, Limpaboon T, Lulitanond A, Boonsiri P, et al. Gallic acid conjugated with gold nanoparticles: Antibacterial activity and mechanism of action on foodborne pathogens. *International Journal of Nanomedicine*. 2016;11:3347-56.
147. Rajan A, Rajan AR, Philip D. Elettaria cardamomum seed mediated rapid synthesis of gold nanoparticles and its biological activities. *Open Nano*. 2017;2:1-8.
148. Bagga P, Hussain Siddiqui H, Akhtar J, Mahmood T, Zahera M, Sajid Khan M. Gold nanoparticles conjugated levofloxacin: For improved antibacterial activity over levofloxacin alone. *Current Drug Delivery*. 2017;14(8):1114-1119.
149. Peng LH, Huang YF, Zhang CZ, Niu J, Chen Y, Chu Y, et al. Integration of antimicrobial peptides with gold nanoparticles as unique non-viral vectors for gene delivery to mesenchymal stem cells with antibacterial activity. *Biomaterials*. 2016;103:137-149.
150. Yang XY, Guo YS, Bi S, Zhang SS. Ultrasensitive enhanced chemiluminescence enzyme immunoassay for the determination of α -fetoprotein amplified by double-codified gold nanoparticles labels. *Biosensors and Bioelectronics*. 2009;24(8):2707-2711.
151. Wu W, Huang J, Wu L, Sun D, Lin L, Zhou Y, Wang H, Li Q. Two-step size-and shape-separation of biosynthesized gold nanoparticles. *Separation and Purification Technology*. 2013;106:117-122.
152. Khan AK, Rashid R, Murtaza G, Zahra AJTR. Gold nanoparticles: Synthesis and applications in drug delivery. *Tropical Journal of Pharmaceutical Research*. 2014;13(7):1169-1177.
153. Govindaraju S, Ramasamy M, Baskaran R, Ahn SJ, Yun K. Ultraviolet light and laser irradiation enhances the antibacterial activity of glucosamine-functionalized gold nanoparticles. *International Journal of Nanomedicine*. 2015;10:67-78.
154. Patil MP, Kim GD. Eco-friendly approach for nanoparticles synthesis and mechanism behind antibacterial activity of silver and anticancer activity of gold nanoparticles. *Applied Microbiology and Biotechnology*. 2017;101(1):79-92.
155. Rakhi M, Gopal BB. Terminalia arjunabark extract mediated size controlled synthesis of polyshaped gold nanoparticles and its application in catalysis. *Int. J. Res. Chem. Environ*. 2012;2(4):338-344.

© 2022 Parveen et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:

The peer review history for this paper can be accessed here:
<https://www.sdiarticle5.com/review-history/80194>