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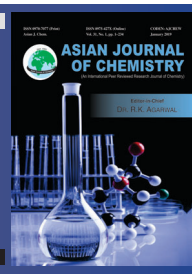

REVIEW

Biogenic Synthesis of Gold Nanoparticles and their Applications: A Review

AMANDEEP KAUR and SANGEETA SHARMA*

Department of Applied Sciences & Humanities, Shaheed Bhagat Singh State Technical Campus, Ferozpur-152001, India

*Corresponding author: E-mail: sangeetassharma70@gmail.com

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The purpose of the present study is to explore the merits and demerits of various biogenic synthesis route of gold nanoparticles using plant materials and microbes. Literature survey indicated that microbe mediated synthesis route is found to be quite effective buttheavailability and feasibility of microbes, enzyme control conditions is of great challenge for the researchers. Among all the available bio-reductants for the synthesis of gold nanoparticles rhizome of *Zinger officinale* (ginger) has been found more advantageous in accordance with availability, stability, applicability, reaction time, *etc*. for the fabrication of gold nanoparticles.

Keywords: Microbes, Fungi, Bacteria, Yeast, Gold nanoparticles.

INTRODUCTION

Last decades have witnessed enormous growth in fabrication and applications of nano-scale materials that possess unique properties. Among nano-materials, nanoparticles (NP's) have attained much attention because of their excellent features in field of health care, food and biology, cellular transportation and many more [1]. Nano-scale materials in form of gold nanoparticles have attained more attraction in the scientific area all over the world. It has been related with some of it's promising features such as small size, high surface to volume ratio, target binding properties, unique physico-chemical properties that can be changed according to size, shape and composition [2]. In addition, gold nanoparticles have widely accepted as drug delivery carriers for the treatment of cancer, diabetes, cardiovascular diseases and many other biomedical applications [3]. Various methods such as electrochemical reduction [4], solvothermal [5], photochemical reduction [6], microwave and ultrasonic waves [7-9], citrate mediated reduction [10], $NaBH_4$ mediated reduction [10] have been reported for the synthesis of gold nanoparticles. But, biological strategy provide advancement over these available techniques as it has been found to be cost effective and eco-friendly thereby avoiding involvement of toxic chemicals, high temperature and pressure conditions [11]. Here, it seems interesting to know about various green route synthesis of gold nanoparticles involving fruit, flower, plant extract, different microbes, *etc*. The present article targets the biological synthesis of gold nanoparticles using agro based waste material and various microbes. The utilization of waste material not only minimizes the use of toxic chemicals buts stimulates the green synthesis routes also.

Plant mediated synthesis of nanoparticles is one of the simple processes that involves following steps: (a) collection of plant extract of interest followed by washing them thoroughly with distilled water 2/3 times to remove undesired associated chaff if any. (b) The cleaned plant extracts are crushed into powder form after drying them for few days in dark conditions [12]. (c) Then, 10 g (approximately) of dried powder is boiled with deionized distilled water (100 mL). This resulting solution is then filtered so that no insoluble biomass left. After that filterate is collected following the addition of $HAuCl_4$ with continous shaking. Colour change of the mixture indicates the reduction of $Au^+ \rightarrow Au^0$ and thereafter resultant sample is monitored on UV-VIS , spectrophotometer at regular intervals to indentify characteristics absorption properties of nanoparticles. The Au^+ ions are primarily requirement for gold nanoparticle synthesis that can be obtained from water soluble salts of gold. The aqueous $HAuCl_4$ solution with Au^+ ion concentration ranges

between 0.1-10 mm has been used by the researchers. A metal salt solution is prepared by mixing metal salt with plant extract, completion of reaction occurs at room temperature in few min to few hours. The metal salt solution involves reduction of Au^{+} ions to Au^{0} nanoparticles [13]. At last they need to be separate out and purified further to carry out its applicability [12].

Characterization techniques: After the synthesis of nanoparticles, the other important step of characterization need to be carried out to identify their shape, size, surface area [14]. These characterization techniques have been discussed briefly as follows:

UV-visible spectroscopy: Generally, 200-800 nm wavelength light has been used for characterization of particle size ranging between 2-100 nm [15].

Dynamic light scattering: This technique has been used to know the surface charge, size distribution and quality of the nanoparticles. It has also been used to find out poly-dispersity index of the nanoparticles [16].

Zeta potential: This has been used to check the stability of synthesized nanoparticles. More the value of zeta potential, more would be stability [17].

Scanning electron microscopy (SEM) and transmission electron microscopy (TEM): Both techniques have been implied for the morphological characterization at submicron scale to micron scale [18]. But, TEM provides results at more resolution as compared to SEM. Hence, to know exact shape and size of nanoparticles, TEM has been used.

Fourier transforms infrared spectroscopy (FTIR): This technique was found to be useful in determination of organic functional groups that have been attached on the surface of nanoparticles [19].

X-Ray diffraction (XRD): XRD analysis provides phase identification and crystal structure characterization of the nanoparticles [20].

Energy dispersive spectroscopy (EDS): This technique has been used to know the elemental composition of the metal nanoparticles [21].

Biological synthesis of gold nanoparticles: Biosynthesis of gold nanoparticles has been found to be clean, safe, non-toxic, eco-friendly and acceptable green route procedure [22]. The biosynthesis of gold nanoparticles has been carried out with plant extract, various microbes including bacteria, fungi, yeast, *etc*. But, plant mediated synthesis of nanoparticles has been found more beneficial over microbe mediated biosynthesis due to ease of improvement and less bio-hazards. Also, plant mediated biosynthesis has been found to have reducing agents such as citric acid, flavonoids, ascorbic acid, reductases and dehydrogenases that play important role in the biosynthesis of attractive nanoparticles with diverse morphology [23]. This biogenic route for the synthesis of gold nanoparticles has been discussed as follows:

Plant/phytoplankton mediated biosynthesis: Plant mediated biosynthesis has been proved to be clean, safer, ease of availability and eco-friendly approach [24]. The different plant extracts *i.e*. leaf, bud, stem, peels, fruits, seeds, *etc*. have been involved in the synthesis methodology of gold nanoparticles.

Leaf mediated biosynthesis: Leaf is one of the flattened green outgrown from the stem of plants. Leaves of different plants species have been examined to carry out synthesis process. These synthesized gold nanoparticles have been observed with different size and shapes like spherical, triangular, hexagon, pentagon, *etc*. Leaf mediated biosynthesis of gold nanoparticles using leaves of different plants have been examined by many researchers. These plant species are *Bougainvillea glabra* [25], *Bacopa monnieri* BLE [26], *Costus igneus* [27], tamarind [28], *Anacardium occidentale* [29], *Zingiber officinals* [30], *Gymnema sylvestre* [31], *Stevia rebaudiana* [32], *Cinnamomum zeylanicum* [33], *Azadirachta indica* [34], *Cacumen platycladi* [35], hibiscus [36], coriander [37], *Chenopodium album* [38], *Vitis vinifera* [39], *Erythrina variegate* [40], *Cicier arietinum* L. [41], *Amaranthus spinosus* [42], alfalfa [43], *Hygrophila spinose* [44], *Pelargonium graveoleus* [45], *Dendropanax morbifera* [46], *terminalia catappa* [47], *Dracocephalum kotschyl* [48], *Cinnamomum camphora* [49], *Abutilon indicum* [50], *Olea europaea* [51], *Butea monosperma* [52], *Cacumen platycladi* [53], *Nepenthes khasiana* [54], *Suaeda monoica* [55], *Ipomoea carnea* [56], *Geranium* sp. [57], *Aloe perfoliata* L. [58], *Costusigneus* [59], *Rosa rugosa* [60], *Phoenix dactylifera* [61], *Zataria multiflora* [62], *Diospyros ferrea* [63], *Silybum marianum* [64], *Opuntia ficus-indica* [65], *Nerium oleander* [66], *Argemone mexicana* [67], *Olea europaea* [68], *Azadirachta indica* [69], *Aloe vera* [70], *Solanum nigrum* [71], *Hibiscus rosa-sinensis* [72], *Magnolia kobus* and *Diospyros kaki* [73], *Camellia sinensis* [74], *Bacopa monnieri* [75], *Sesbania grandiflora* [76], *Ficus benghalensis* [77], *Memecylon umbellaium* [78], *Thuja orientalis* [79], *Gloriosa superb* [80], *Sargassum myriocystum* [81], *Sargassum muticum* [82], *Putranjiva roxburghi* [83], *Murraya koenigii* [84], *Euphorbia hirta* [85], *Hibiscus sabdariffa* [86] and *Phoenix dactylifera* [87]. Almost all the synthesized gold nanoparticles from above mentioned species have been screened for different activities like antibacterial, antifungal, antidiabetic, anticancer, dyes removal, *etc*.

Merits: The merits of nanoparticles synthesized with the use of leaf extract of *Cassia auriculata* have been examined and non-toxic even to human at the concentration of 10 µg/mL. These synthesized gold nanoparticles have been reported with stability of 2 months. Neem leaves synthesized nanoparticles have attained the merit because of their easy availability and easy cultivation all over the nation. Moreover, it adapts all climatic conditions so, offers pharmaceutical and cosmetic applications easily. Synthesis route reaction for gold nanoparticles with *Acalypha indica* L. has the merit as the reaction gets completed in 0.5 h only. Synthesized nanoparticles acts as anticancer agent to cure human breast cancer. Leaves of *Amaranthus spinosus* have been highly associated with property of antioxidant because of presence of hydroxyl or imino groups, that readily loses hydrogen atoms thereby facilitating reduction of $Au^{3+} \rightarrow Au^{0}$. Synthesized gold nanoparticles have been widely accepted as anticancer agents as cytotoxicity studies revealed the non-toxicity nature of synthesized gold nanoparticles. The *Bauhinia tomentosa* Linn. plant sp. possess various medicinal applications associated with different plant parts as dried leaf buds and flowers have been applied in dysentery, leaves exhibits antioxidant activity and flowers exhibit antilipidemic and antihyper glycemic activities. Synthesized gold nanoparticles

have also been reported with anticancer activity. Synthetic reaction of gold nanoparticles using leaf extract of *Acacia nilotica* (babool) completes within few minutes at room temperature. The appearance of pink-reddish color during synthesis reaction confirmed the synthesis of stabilized gold nanoparticles as intensity of colour remains constant for few months. No additional capping/stabilizing agent has been required for the synthesis process. Leaf extract of *Terminalia catappa* (almond) has also been implied as stabilizing and reducing agent along with the synthesis of gold nanoparticles, Synthesized gold nanoparticles have been examined with good stability for about 4 months with no precipitation.The merit of the synthesized gold nanoparticles from leaf extracts of *Punica granatum* is that they could be used for sensing of toxic arsenate. During the synthesis route of gold nanoparticles with leaves of *Mangifera indica* (mango) no extra capping and reducing agent has been required rather leaf extract of mango has been implied for the same purpose.

Demerits: The disadvantage of gold nanoparticles synthesized with leaf extract of *Amaranthus spinosus* is that more than 1 % of plant extract has been required. Bioroute synthesis reaction for the synthesis of gold nanoparticles using leaves of *Erythrina variegate* has been carried out at 600 ºC, which has been little bit found difficult. During the synthesis route of gold nanoparticles with leaf extract of *Cacumen platycladi*, the demerit found to be is that pH of the reaction has been proved to be most critical factor as high pH value leads to reduces the reduction rate of chloroaurate ions rapidly. The synthesis reaction carried out at pH 4 has resulted in the formation of silver nanoparticles of different morphology. It has been examined that with increasing pH, the size of gold nanoparticles goes on decreasing.

Applications of leaf synthesized gold nanoparticles: Antibacterial/antimicrobial agent is basically antibiotic that destroy or inhibit the growth of bacteria and prevents the bacterial infection. Synthesized gold nanoparticles from leaf extract of different species have been examined with their antibacterial/antimicrobial activity. The leaf extracts of plant species namely *Coleus ambainicus* [88], *Salix alba* [89], *Zizyphus mauritiana* [90], *Solanum nigrum* [91], *Trianthema decandra* [92] and *Catharanthus roseus* [93] have been examined to carry out biogenic synthesis process for gold nanoparticles by many researchers. Gold nanoparticles extracted from the leaf extracts of *Mentha piperita* [94], *Salicornia brachiata* [95], *Cucurbita pepo* and *Malva crispa* [96] have also been screened for antibacterial activity.

Antifungal: Antifungal is fungicide medication that is used to cure fungal diseases, gold nanoparticles synthesized by using leaf extract of different plant species have been examined with antifungal activity. Leaves of *Salix alba* commonly called white willow have been used to synthesize non-spherical gold nanoparticles of 50-80 nm having antifungal activity [89].

Antidiabetic: These are the drugs that used to cure diabetes thereby lowering the level of glucose in the blood stream. Leaf mediated synthesized gold nanoparticles have been found with the applicability as antidiabetic. Biosynthesis of 15-25 nm sized gold nanoparticles using leaf extract of *Cassia auriculata* involving reduction reaction of auric chloride at room temperature within 10 min has been examined [97]. Synthesized gold nanoparticles from *Psidium guajava* also show antidiabetic activity [98].

Antimalarial: Antimalarial medications have been designed to treat malaria. Synthesis of gold nanoparticles has been carried out with leaf extract of *Cymbopagon citratus*, that acts as reducing agent as well as capping agent to carry out synthesis. The synthesized nanoparticles have been tested against malaria vector *Anopheles stephensi* and Dengue vector *Aedes aegypti* [99]. Leaves of *Suaeda monoica*, is shrubby sea blite, have been used to synthesize gold nanoparticles showing antiviral activity [99].

Anticancer: The medication for cure of cancer has been designed. In order to avoid chemotherapies researchers have tried to design biogenic nanoparticles having anticancer activity. Leaf extract of *Acalypha indica* has been used to synthesize gold nanoparticles of 20-30 nm, showing cytotoxic effect against human breast cancerian cells and MDA-MB-231 [100]. Guava (*Psidium guajava*) leaves have been used for the preparation of gold nanoparticles of 27 nm showing antimalignant activity [101]. Leaf extract of *Vitex negundo* has been used for the preparation of spherical shaped gold nanoparticles showing anticancer drug delivery activity [102]. Papaya (*Carica papaya*) leaves have been used for the synthesis of spherical, triangular shaped gold nanoparticles showing antitumour activity [93]. Anticancer activity has also been screened out by gold nanoparticles synthesized from leaf extract of *Bauhinia tomentosa* [103] and *Dracocephalum kotschyi* [48].

Dyes removal: Presence of dyes is major contaminant found in textile effluent, contributing to environmental pollution. Researchers have tried to develop nanoparticles for the degradation of dyes from waste water stream. Leaves of *Pogostemon benghalensis* have been used for the preparation of cubical gold nanoparticles of 13.07 nm size and have been applied for the degradation of methylene blue dye [104].

Peels mediated biosynthesis: Peels, also called rind, is outer protective layer of vegetable and fruit. Mostly, they have been discarded as waste material. Researchers investigated this discarded material for the synthesis of gold nanoparticles. Banana peels mostly discarded as waste material has been utilized for the gold nanoparticles synthesis.The obtained nanoparticles has been found of 300 nm size, possessing antimicrobial activity against microbes [105]. *Punica granum* fruit peels have been used for the synthesis of gold nanoparticles. These synthesized nanoparticles have been studied for anticancer drug delivery [106]. Spherical shaped gold nanoparticles have been synthesized by using mango peels and these synthesized nanoparticles possess cytotoxicity property [107]. Gold nanoparticles has been found to be the size of 300 nm size with diverse morphology have been synthesized by using peels of banana and synthesized nanoparticles have been screened out with antibiotic activity against human living cancerous cells [108].

Merits: The synthesis route for the production of gold nanoparticles involving peels of vegetables and fruits reduces household waste that has been discovered as advantageous step.

Fruit mediated biosynthesis: Seed bearing structure formed from ovary of the angiosperm is known as fruit. Inspite of its eating, researchers have tried out edible part of angiosperm to synthesize gold nanoparticles. Fruit mediated synthesis route

using grape waste has been explored for the synthesis of gold nanoparticles of size 20-25 nm [109]. This has been found one of the attractive approach of using grape waste in context of reuse, reduce and recycling. Gold nanoparticles synthesis from *Hovenia dulcis* [110], *Solanum lycopersicum* [111], *Punica granatum* [112], *Ananas comosus* [113] shows antimicrobial activity against numerous microbes. Gold nanoparticles with diverse morphology have also been synthesized by using some other fruits such as *Emblica officinalis* [114], *Couroupita guianensis* Aubl [115], *Averrhoa bilimbi* [116], *Terminalia arjuna* [117], *Tanacetum vulgare* [118], *Citrus maxima* [119], *Citrus limon* [120], *Dimocarpus longan* [121], *Genipa Americana* [122], *Citrus sinensis* [120], *Lansium domesticum* [123], *Nitraria schoberi* [124], *Garcinia combogia* [125] and *Citrus reticulata* [120] as reported in the literature.

Merits: The merit associated with the synthesis process of gold nanoparticles with *Tamarindus indica* fruit is that active constitutes of fruit have also been used as reducing and capping agent for the synthesis of gold nanoparticles. No additional reagent has been required throughout the process.

Demerits: However, tedious and longer reaction time *i.e.* 48 h has been found a demerit during synthesis reaction that involves reduction of auric chloride solution at 300 ºC and thereafter leads to formation of gold nanoparticles with flower extract of *Plumeria alba* Linn. Need of additional capping agent has been found a demerit during synthesis reaction with leaf extract of *Azadirachta indica*. Plant sp. *Morinda citrifolia* has been used as capping agent because of presence of chemical compound in fruit of *Morinda citrifolia* that can intercats with synthesized gold nanoparticles adhering to its surface.

Flower mediated biosynthesis: Some flowers have been examined by the researchers for the synthesis of gold nanoparticles of diverse morphology. Flower mediated biosynthesis for the gold nanoparticles synthesis has been carried out by using different flowers such as *Gnidia glauca* [126], *Nyctanthes arbortristis* [127], *Prunus serotina* [128], *Ixora coccinea* [129], *Cassia auriculata* [130], *Couroupita guianensis* [131], *Mimosa pudica* [132], *Moringa oleifera* [133], *Plumeria alba* Linn. [134], *Mirabilis jalapa* [135], *Tagetes arecia* [136], *Bauhinia purpurea* [137] and *Tagetes erecta* [138]. Gold nanoparticles that have been prepared by using flower extract of *Caesalpinia pulcherrima* shows antifungal and antibacterial activities [139]. Gold nanoparticle prepared from flower *Plumeria alba* have been associated with antibacterial activity and degradation of dyes [140].

Merits: Synthesis route of gold nanoparticles involving flower of *Mimosa pudica* offers many advantages like less reaction time, requiring less cleaning steps during synthesis and room temperature conditions. Also, synthesis route involves no pH change and even no stirring and heating during the formation of gold nanoparticles. Biosynthesis route involving flower extract of *Gnidia glauca* gets completed in 20 min only operating at temperature conditions of 500 ºC. Stabilized gold nanoparticles have been demonstrated with flower extract of *Ixora coccinea*. Quite stabilized (without precipitation) synthesized gold nanoparticles have been reported of 24 nm sized using flower extract of *Cassia auriculata*. Oil extracted from *Plumeria alba* Linn. have been used for aroma-therapy purposes. Inspite of this, *Plumeria alba* Linn has been associated with other numerous applications such as to cure asthma, constipation, reducing fever, controlling diabetes, curing ulcers, leprosy and promoting menstruation in womens. Rapid synthesis of gold nanoparticles in 1-2 h has been reported with flower extract of *Mirabilis jalapa*.

Demerits: The synthesis reaction involving reduction of auric chloride solution required 48 h at 300 ºC and thereafter leads to formation of gold nanoparticles with flower extract of *Plumeria alba* Linn. that offers a disadvantage with the synthesis process. One other disadvantage of requirement of additional capping agent for coating of synthesized gold nanoparticles during synthesis process has been studied by using leaf extract of *Azadirachta indica*. Plant sp. *Morinda citrifolia* has been used as capping agent because of presence of chemical compound in fruit of *Morinda citrifolia* that can interacts with synthesized gold nanoparticles adhering to its surface.

Seed mediated biosynthesis: Application of seed has been studied for the biosynthesis of gold nanoparticles. Seeds of *Vitis vinifera* [141], *Cajjanus cajau* [142], *Cucurbita pepo* [143], *Ocimum sanctum* [144] have been studied to carry out biosynthesis process. Gold nanoparticles prepared by using seed extract of plant *Elettaria cardamomum* has been studied for its antifungal and antibacterial activities [145]. Biosynthesis of gold nanopartilces has been carried out with seed extract of *Abelmoschus esculentus* [146]. Synthesized nanoparticles carrying antifungal activity has been used to prepare drugs to cure fungal diseases and they have been tested on *Aspergillus niger*, *Puccinia graminis* tritci, *Aspergillus flavus* and *Candida albicans* [146]. Anticancer activity has also been noticed by gold nanoparticles prepared from seed extract of *Elettaria cardamomum* [145]. Seeds of *Ocimum sanctum* has also been used to synthesize gold nanoparticles of hexagonal shape [147].

Demerits: The drawback associated with synthetic routes involving seeds of *Ocimum sanctum* for gold nanoparticles synthesis is longer reaction time *i.e.* one day instead of few hours.

Stem mediated biosynthesis: Stem is the stalk/main body of the plant. It is basically arising above the ground level and has been widely accepted to carry out synthesis process of gold nanopartlcles. Stem part of *Hibiscus cannabinus* has been used for the preparation of spherical shaped gold nanoparticles of 13 nm size [148].

Merits: No extra reducing agent has been required during synthesis step of gold nanoparticles because of presence of carboxylic acid in the stem of *Hibiscus cannabinus* [148]. The produced nanoparticles have been used as water purifiers.

Root mediated biosynthesis: Roots of some plants have been examined for the preparation of gold nanoparticles. Such plants are *Marinda citrifolia* [149], *Panicum maximum* [150] and *Ipomoea carnea* [56] have been used for the preparation of gold nanoparticles. Triangular shaped gold nanoparticles prepared by using root extract of plant *Coleus forskohlii* has been studied for the antibacterial and anti-cancer activity [151]. Square shaped gold nanoparticles haves also been prepared with roots of *Mammea suriga* [152].

Merits: The produced gold nanoparticles using root extract of *Marinda citrifolia* have been screened out for anticancer

and antidiabetic activities. During synthesis reaction, no additional reducing/capping agents have been required because proteins present in root extract have been used for the same.

Demerits: The weed *Ipomoea carnea* is harmful weed, root extract of this plant sp. has been used for the synthesis of gold nanoparticles, which has been reported as its disadvantage [59].

Bark mediated biosynthesis: Biosynthesis of gold nanoparticles has been carried out with bark of some plant species namely *Hypericum hookerianum* [153], *Cassia fistula* [154], *Acacia nilotica* [155], *Pistia stratiotes* L. [156] and *Ficus religiosa* [157]. These synthesized gold nanoparticles have been found of different shapes and sizes. Bark of *Rucommia ulmoides* plant has also been taken for the synthesis of gold nanoparticles of 16.4 nm size which have been screened out for the removal of dyes [158].

Merits: Easily availability of *Cassia fistula* from local markets has been reported as its merit for the synthesis process of gold nanoparticles. Also, the synthesis reaction occurs in about 2 h only. *Ficus religiosa* acts as trigger *i.e.* reducing and capping agent carrying reaction in single step only for the synthesis of gold nanoparticles with clearly uniformity which has been marked as its big advantage. The produced gold nanoparticles with this plant sp. also offers excellent stability.

Rhizome mediated biosynthesis: Rhizome is one of the stem part of the plant that sends out roots and shoots from the nodes. This root stalk part of the plant has also been studied for the synthesis process. Gold nanoparticles prepared from rhizome extract of *Acorus calamus* [113], *Dioscorea batatas* [159] plants have been studied for their antibacterial activity. Rhizome of ginger (*Zingiber officinale*) has been used for the preparation of gold nanoparticles of 5-15 nm size [160]. These prepared gold nanoparticles have been used as anticancer drug carriers.

Merits: Bark of *Zingiber officinale* has been used for the synthesis process of gold nanoparticles where, it's easy availability and low cost have been marked as a merit.

Algae mediated biosynthesis: Algae is one of the non-flowering aquatic plant that contains chlorophyll but it lacks true stem, leaf, root, *etc*. so its whole plant part has been used by the researchers to carry out synthesis process. Some of the algae species namely *Stoechospermum marginatum* (brown algae) [161], *Stylidium tenerrimum* (marine algae) [162], *Turbinaria conoides* (marine algae) [162], *Chlorella pyrenoidusa* (algae) [163] have been used for the preparation of gold nanoparticles of variable size and shapes. Antibacterial activity has been screened out for the gold nanoparticles that have been synthesized from red algae *Galaxaura elongate* [164].

Merits: No extra stabilizing and reducing agent has been required for the synthesis of gold nanoparticles with *Stachys lavandulifolia* vahl, which has been marked as its advantage. Another synthesized gold nanoparticle possess merit of greater stability for about months with the application of *Turbinaria conoides* algae.

Demerits: The synthesized gold nanoparticles from *Turbinaria conoides* algae have been found quite stable but synthetic reaction required 48 h for completion, the more reaction time offers a lillte bit drawback.

Juice mediated biosynthesis: Researchers have tried to synthesize nanoparticles from the juice of several fruits. Spherical shaped gold nanoparticles have been prepared with juice of pomegranate [165]. The water extract of pomegranate peels have explored for the synthesis of gold nanoparticles that can act as reducing and capping agent to synthesize gold nanoparticles [166]. The peels contain portion of polyphenols and proanthocyanidins that are well known for antioxidant activity. The water extract yield of polyphenols and proanthocyanidins have been reported 15-20 % and 1.2-9 %, respectivey with pomegranate peels. The synthesized gold nanoparticles have been tried out for the removal of heavy metal ions and methylene blue dye from effulents [166].

Merits: Zero requirement of additional capping/stabilizing agent is one of the merit associated with juice mediated route of gold nanoparticle synthesis with *Punica granatum*. Some other plant parts have also been used for the synthesis of gold nanoparticles. Nuts of palm tree has been used to synthesize 13.7 nm sized nanoparticles that has also been reported with antioxidant, antibacterial and anticancer activity [167]. Oil extract of cashew tree helps to synthesize hexagonal shaped gold nanoparticles [29]. Planar shaped gold nanoparticles have also been prepared from *Gymnocladus assamicus* [168]. Gold nanoparticles have also been synthesized with the use of galls of *Pistacia integerrima* [169]. Synthesized nanoparticles shows antifungal and antibacterial activities. Whole plant parts of species namely *Diospyros ferrea* [150], *Avena sativa* [170], *Stachys lavandulifolia* vahl [171], *Rivea hypocrateria* formis (aerial part) [172], *Prasiola crispa* [173] have been used to synthesize gold nanoparticles of different morphology. Buds of *Syzygium aromaticum* has been studied for the synthesis of gold nanoparticles, that ensures milk safety [174]. Gold nanoparticles have also been investigated with other species like *Euphorbia hirta* [85], *Torreya nucifera* [175], *Madhuca longifolia* [176], *Rosa indica* [177], *Arachis hypogaea* [178], *Terminalia arjuna* [179] and *Morinda citrifolia* [180]. Plant mediated biosynthesis route using different parts of several plant species has given in Table-1.

Microbe mediated synthetic route: Chemical synthesis of gold nanoparticles produces many toxic residue that give arise to environmental issues while, synthesis of gold nanoparticles with biological route involving diversity of microbes have been found to be cost effective and environmental friendly. Microorganisms have been used for the nanoparticles synthesis because of their easy handling, low cost growth medium like wastelands/cellulosic waste, great potential for adsorption of metal ions and reducing them into nanoparticles by the enzymes produced by metabolic process.

Synthesis of nanoparticles by microorganisms can be extra/intra cellular depending upon their location. The mechanism with intracellular location involves the transportation of specific ions into cell wall, which is negatively charged and if with positively charged metal they get diffused through the cell wall by electrostatic attraction. After that the enzyme present in cell wall of microbe converts the toxic metal into non-toxic metal nanoparticles [181].

While, the mechanism with extra-cellular route involves the enzyme mediated synthesis such as nitrate reductase or

TABLE-1
DIFFERENT PARTS OF VARIOUS PLANT SPECIES MEDIATED BIOSYNTHESIS OF GOLD NANOPARTICLES

S. No.	Scientific name	Common name	Plant part	Activity	Size (nm)	Characterization	Shape	Ref.
1	*Bougainvillea glabra*	Paper flower	Leaf	–	–	UV-VIS, FTIR	–	[25]
2	*Bacopa monnieri* BLE	Valaarai, waterhyssop	Leaf	–	3-45	TEM, UV-VIS, X-ray diffraction	Spherical	[26]
3	*Costus igneus*	Spiral flag	Leaf	Antidiabetic	54-62	SEM, UV-VIS	Spherical	[27]
4	*Tamarind*	Imli	Leaf	–	20-40	–	–	[28]
5	*Anacardium occidentale*	Cashew tree	Leaf	–	6-17	TEM, FTIR, UV-VIS	Spherical	[29]
6	*Zingiber officinals*	Ginger	Leaf	Antiplatenet agent	10	TEM, UV-VIS, DLS	–	[30]
7	*Gymnema sylvestre*	Gymnema	Leaf	Anticancer	72.8	FTIR, XRD, EDAX, UV-VIS, SEM	Spherical	[31]
8	*Stevia rebaudiana*	Sweet leaf	Leaf		5-20	SEM, UV-VIS, FTIR, TEM, XRDS	Spherical	[32]
9	*Magnolia* and *Diopyros kaki*	Kobus	Leaf		5-300		Triangular, pentagonal, hexagonal	[32]
10	*Stevia rebaudiana*	Sunflower	Leaf	–	5-20	XRD, TEM, SEM, UV-VIS	Spherical	[32]
11	*Cinnamomum zeylanicum*	Cinnamon	Leaf		25	TEM, XRD, UV-VIS, FTIR	Spherical	[33]
12	*Azadirachta indica*	Neem	Leaf		15.1	SEM, TEM, DLS	Hexagonal, spherical, triangles	[34]
13	*Cacumen platycladi*	Chinese arborvitae	Leaf		2.2-42.8	SAED, TEM, EDX, UV-VIS, FTIR	Spherical	[35]
14	*Cacumen platycladi*	–	Leaf	–	Variable		FCC	[35]
15	*Hibiscus*	–	Leaf	–	13		–	[36]
16	*Coriander*	Dhania	Leaf		6.75-57.91	XRD, TEM, FTIR, EDAX, UV-VIS	Decahedron, spherical, triangular	[37]
17	*Chenopodium album*	Goosefoot	Leaf		10-30	TEM, XRD, EDX, FT-IR	Quasi-spherical	[38]
18	*Vitis vinifera*	Grapes	Leaf		10-17	TEM, FTIR, XRD, UV-VIS	Spherical	[39]
19	*Erythrina Variegate*	Indian coral tree	Leaf		20-50	SEM, TEM, XRD, EDX, FTIR, UV-VIS	Cubic	[40]
20	*Cicer arietinum L.*	Chick pea	Leaf		30-80	TEM, SEM, UV-VIS	Pentagonal, spherical, traingulars	[41]
21	*Amaranthus spinosus*	Spiny pigweed	Leaf	Anticancer	10.74	FTIR, EDX, TEM, UV-VIS, XRD	Triangular, spherical	[42]
22	*Alfalfa*	Lucera(pea)	Herb		30, 15		Decahedron, icosahedron	[43]
23	*Hygrophila spinose*	Lasia spinosa	Leaf	Hematopoietic antioxidant activity	50-80	DLS, XRD, FTIR, SEM-EDAX, UV-VIS	Spherical, triangle shaped	[44]
24	*Pelargonium graveoleus*	Rose geranium	Leaf			FTIR, EDS, TEM, SPR, EDS, UV-VIS		[45]
25	*Dendropanax morbifera*		Leaf		5-10	Anticancer	Polygon	[46]
26	*Terminalia catappa*	Country almond	Leaf	Anticancer, antioxidant, antibacterial	10-35	XRD, TEM, FTIR, UV-VIS	Spherical	[47]
27	*Dracocephalum kotschyi*	Lamiaceae (flowering plant)	Leaf	Anticancer, antibacterial	11	DLS, XRD, TEM-SEAD, Zeta potential, SEM-EDAX, FTIR	Spherical	[48]
28	*Cinnamomum camphora*	Camphor tree	Leaf	–	55-80	SPR, FTIR, XRD, EDX	Triangular and spherical	[49]
29	*Abutilon indicum*	Thuthi	Leaf	Anticancer	1-20	TEM, FTIR, UV-VIS, ZETA, GC-MS	Spherical	[50]
30	*Olea europaea*	Sweet oil	Leaf		50-100	TEM, FTIR, XRD, UV-VIS, photoluminescences	Hexagonal, spherical, triangle	[51]

31	*Butea monosperma*	Parasu	Leaf		20-80	DLS, XRD, UV-VIS, TEM, FTIR	Large spherical	[52]
32	*Butea monosperma*	Bastard teak, flame of forest	–	–	10-100	DLS, EDAX, XRD, TEM, UV-VIS, FTIR	Spherical, triangular	[52]
33	*Cacumen platycladi*	Biota	Leaf		2-70	TEM, DGC, AGE	Triangle, spherical	[53]
34	*Nepenthe khasiana*	Pitcher plant	Leaf	Antimicrobial	50 and 100	UV-VIS, XRD, TEM, SEM, FTIR	Triangular and spherical	[54]
35	*Olea europaea*	Olive	Leaf	Antibacterial	50-100		Spherical, Hexagonal, spherical	[54]
36	*Suaeda monoica*	Seepweed	Leaf	Antioxidant	14.5	TEM, EDAX, XRD, SEM, DLS, FTIR	Commonly spherical, triangular	[55]
37	*Ipomoea carnea*	Pink morning glory	Leaf		25-100	XRD, TEM, SEM, UV-VIS, EDAX, FTIR	Rod, Hexagonal, triangular, pentagon	[56]
38	*Geranium* sp.	Cranesbills	Leaf		12	STEM, UV-VIS, FTIR, TEM, EDAX, XRD	–	[57]
39	*Aloe perfoliata* L	Barbados aloe	Leaf		50-350	EDAX, TEM, AFM, FTIR, UV-VIS-NIR	Spherical	[58]
40	*Costus igneus*	Spiral flag	Leaf	Antibacterial	54-62	SEM, UV-VIS	Spherical	[59]
41	*Rosa rugosa*	Rosa rugosa	Leaf		11	ZETA POTENTIAL, XRD, TEM, EDX, FTIR, UV-VIS	Triangular, hexagonal	[60]
42	*Phoenix dactylifera*	datepalm	Leaf		32, 45	UV-VIS, FTIR, TEM	Spherical	[61]
43	*Zataria multiflora*	Avishan-E-Shirazi	Leaf	Anticancer	10-42		Diverse	[62]
44	*Diospyros ferrea*	Diospyros	Leaf		70-90	FTIR, SEM, UV-VIS	–	[63]
45	*Silybum marianum*	Milk thistle	Leaf		–	–	–	[64]
46	*Sesbania grandiflora*	Humming bird tree	–	–	7-34	SEM, TEM, DLS	Spherical	[64]
47	*Opuntia ficus-indica*	Barbary fig	Leaf		10-20	TEM	Diverse	[65]
48	*Nerium oleander*	Oleander	Leaf	Antioxidant	2-10	XRD, FTIR, HR-TEM, UV-VIS, SEM	Spherical	[66]
49	*Nerium oleander*	Vernacular	Shrub	Anticancer against MCF-breast cancer cells	2-10	TEM, SEM, XRD, DLS, FTIR, UV-VIS	Spherical	[66]
50	*Argemone mexicana*	Mexican poppy	Leaf		22-26	XRD, SEM, UV-VIS	Spherical	[67]
51	*Olea europaea*	Olive	Leaf		50-100	FTIR, XRD, TEM, UV-VIS, PHOTO LUMINESCENCE	Triangular, Hexagonal, spherical	[68]
52	*Azadirachta indica*	Neem	Leaf		50-100		Hexagonal, triangle, spherical	[69]
53	*Aloe vera*	Indian alces	Leaf		15.2	SPR, XRD, UV-VIS	Spherical	[70]
54	*Solanum nigrum*	Poison berry	Leaf	Antioxidant, corrosion inhibitor	50		Spherical	[71]
55	*Hibiscus rosa-sinensis*	Shoeblack plant	Leaf		13	TEM, XRD, UV-VIS, FTIR	Variable	[72]
56	*Magnolia kobus*	Mango	Leaf		5-300	EDS, TEM, XPS, SEM	Diverse	[73]
57	*Diospyros kaki*	Persimmon kaki	Leaf		5-300	EDS, TEM, XPS, SEM	Diverse	[73]
58	*Camellia sinensis (Huangdan)*	Green tea	Leaf		40	UV-VIS, X-ray, TEM, FTIR	Irregular	[74]
59	*Bacopa monnieri*	Waterhyssop	Leaf		3-45		Spherical	[75]
60	*Sesbania grandiflora*	Agati	Leaf		34.11	EDX, SEM, TEM, AFM, SPR, FTIR	Spherical	[76]

61	*Sesbania grandiflora L*	Vegetable humming bird			7-34	TEM, SEM, XRD, DLS, FTIR, UV-VIS	Triangular	[76]
62	*Ficus benghalensis*	Banyan	Leaf		1-100	FTIR, SPR, UV, XRD, TEM	Spherical	[77]
63	*Memecylon umbellaium*	Iron wood, Alli, Anjani	Leaf		20		Spherical	[78]
64	*Thuja orientalis*	Biota	Leaf	Antibacterial	–		Spherical	[79]
65	*Gloriosa superba*	Flame lily, creeping lily, climbing lily	Leaf	Antibacterial	20		Triangle, spherical	[80]
66	*Sargassum myriocystum*	Algae	Leaf		15		Triangular, spherical	[81]
67	*Sargassum muticum*	Japanese wire weed	Leaf		5.42±1.18	UV-VIS, TEM, XRD, ZETA POTENTIAL	Spherical	[82]
68	*Putranjiva roxburghi*	Sutajva	Leaf	Antimicrobial	38		Spherical	[83]
69	*Murraya koenigii*	Curry tree	Leaf		20	TEM, UV-VIS, XRD, FTIR	Diverse	[84]
70	*Euphorbia hirta*	Pill bearing spurge	Leaf		50	AFM, XRD, EDAX, TEM	Spherical	[85]
71	*Euphorbia hirta*	Asthma plant (hairy herb)	–	Antimicrobial	6-71	DLS, EDAX, XRD, TEM, UV-VIS, FTIR	Spherical	[85]
72	*Hibiscus sabdariffa*	Hibiscus	Leaf		10-60	XRD, XPS, FTIR, TEM, UV-VIS	Spherical	[86]
73	*Phoenix dactylifera*	Date	Leaf	Catalytic activity	32-45		Spherical	[87]
74	*Coleus ambainicus*	–	Leaf	Antibacterial	4.6-55.1	TEM, EDAX, XRD, FTIR, UV-VIS	Spherical, Hexagonal, triangular, decahedral	[88]
75	*Salix alba*	White willow	Leaf	Antifungal, antibacterial	50-80	AFM, FTIR, UV-VIS, SEM	Non-spherical	[89]
76	*Zizyphus mauritiana*	Indian jujube	Leaf	Antibacterial	20-40	XRD, FTIR, UV-VIS, SEM	Spherical	[90]
77	*Zizyphus mauritiana*	Chine apple		Antibacterial	20-40	UV-VIS, TEM, XRD, SEM, FTIR	Spherical	[90]
78	*Solanum nigrum*	Black nightshade	Leaf	Antibacterial	50	FTIR, XRD, TEM, UV-VIS, ZETA POTENTIAL, DLS	Spherical	[91]
79	*Trianthema decandra*	Black pigweed	Leaf	Antimicrobial	37.7-79.9		Spherical, Hexagonal, cubic	[92]
80	*Carica papaya*	Papaya	Leaf	Antitumour activity	2-20	ZETA POTENTIAL, XRD, UV-VIS, FTIR, TEM	Spherical, triangular	[93]
81	*Catharanthus roseus*	Madagascar	Leaf	Antitumour, antibacterial	3.5-9	UV-VIS, X-ray, SEM	Spherical, triangular	[93]
82	*Mentha piperita*	Mint	–	Antimicrobial	150	UV VIS, XRD, SEM, EDAX, TEM, FTIR	Spherical	[94]
83	*Salicornia brachiata*	Pickleweed, glasswort, pickle grass		Antibacterial	22-35		Spherical	[95]
84	*Cucurbita pepo, Malva crispa*	Pumpkin	–	Antibacterial	–	UV-VIS, FE-SEM, EDS, HR-TEM	–	[96]
85	*Cassia auriculata*	Matura tea tree	Leaf	Antidiabetic	15-25	X-ray, TEM, SEM-EDAX, FT-IR	Spherical & triangular	[97]
86	*Psidium guajava*	Lemon guava	–	Antidiabetic, antibacterial	11.65	TEM, SEM, XRD, DLS, FTIR, UV-VIS		[98]
87	*Cymbopagon citratus*	Lemon grass	Leaf	Antimalaria and dengue vector	–	–	–	[99]
88	*Acalypha indica*	Indian neetle	Leaf	Cytotoxic effect towards breast cancerian cell	20-30		–	[100]
89	*Psidium guajava*	Guava	Leaf	Antimalignant	27	EDAX, XRD, TEM, UV-VIS	–	[101]

90	*Vitex negundo*	Sambhalu, Nirgundi	Leaf	Tumor target drug delivery	98.65-71.86		Spherical	[102]
91	*Bauhinia tomentosa*	Yellow bauhinia	Leaf	Anti cancer	31.32	XRD, UV-VIS, HR-TEM, FESEM, FTIR, HR-TEM, EDAX	Crystalline, spherical	[103]
92	*Pogostemon benghalensis*	Pangala, mint	Leaf	Methylene blue dye degradation	13.07		Cubical	[104]
93	*Musa*	Banana	Peels	Antimicrobial	300	UV-VIS, TEM, XRD, SEM, FTIR	–	[105]
94	*Punica granutum*		Fruit peel	Anticancer drug delivery				[106]
95	*Punica granatum*	Pomengranate	Fruit	Antimicrobial, cytotoxicity	5-17	SEM, TEM, DLS	Spherical & triangular	[106, 112]
96	*Magnolia kobus*	Mango	Peel	Cytotoxicity	6.03-18		Spherical	[107]
97	*Mangifera indica*	Mango	–	–	6.03-18	TEM, SEM, XRD, DLS, FTIR, UV-VIS	Spherical	[107]
98	*Musa paradisiaca*	Banana	Peel	Antibiotic resistant against human lung cancerous cells	300	UV VIS, XRD, SEM, EDAX, TEM, FTIR	Diverse	[108]
99	*Vitis vinifera*	Grape waste	Fruit	–	20-25		–	[109]
100	*Hovenia dulcis*	Japanese Rassin	Fruit	Antioxidant, antibacterial	20	XRD, TEM, FTIR, UV-VIS, EDX	Hexagonal, spherical	[110]
101	*Solanum lycopersicum*	Tomato	Fruit	Antibacterial	14		Diverse	[111]
102	*Ananas comosus*	Pine apple	Fruit	Antimicrobial	16	SEM, FTIR, EDX	Tetrahedral	[113]
103	*Emblica officinalis*	Gooseberry, amla	Fruit		25	DLS, EDAX, XRD, TEM, UV-VIS, FTIR	Spherical	[114]
104	*Couroupita guianensis Aubl.*	Kanuunankuulapuu	Fruit		25±6	UV VIS, XRD, SEM, EDAX, TEM, FTIR	Spherical, triangle and hexagon	[115]
105	*Averrhoa bilimbi*	Bilimbi	Fruit		75-150	SEM, TEM, DLS	Rhomboidal	[116]
106	*Terminalia arjuna*	Arjuna	Fruit		60	UV-VIS, TEM, XRD, SEM, FTIR	Pentagonal	[117]
107	*Tanacetum vulgare*	Tansy	Fruit		10-40		Triangle, Hexagonal, spherical	[118]
108	*Citrus maxima*	Pomelo	Fruit		25.7±10	UV VIS, XRD, SEM, EDAX, TEM, FTIR	Sphericaland rod shaped	[119]
109	*Citrus limon*	Lemon	Fruit		32.2	DLS, EDAX, XRD, TEM, UV-VIS, FTIR	Spherical	[120]
110	*Citrus reticulata*	Mandarin orange	Fruit		43.4		Spherical	[120]
111	*Citrus sinensis*	Sweet orange	Fruit		56.7	UV VIS, XRD, SEM, EDAX, TEM, FTIR	Spherical	[120]
112	*Dimocarpus longan*	Longon	Fruit		25	UV-VIS, TEM, XRD, SEM, FTIR		[121]
113	*Genipa americana*	Genipapo	Fruit		15-40		Spherical	[122]
114	*Lansium domesticum*	Duku	Fruit		20-40	DLS, EDAX, XRD, TEM, UV-VIS, FTIR	Triangular and hexagon	[123]
115	*Nitraria schoberi*	–	Fruit		30, 40	SEM, TEM, DLS	Circular	[124]
116	*Garcinia combogia*	Brindall Berry	Fruit		17		Spherical and hexagon	[125]
117	*Gnidia glauca*	Datpadi	Flower		5-20	TEM, SEM, UV-VIS, XRD	Spherical	[126]
118	*Nyctanthes arbortristis*	Night jasmine	Flower		19.8		Spherical	[127]
119	*Prunus serotina*	Wild black cherry	Flower		10-20	UV-VIS, TEM, XRD, SEM, FTIR	Spherical	[128]
120	*Anacardium occidentale*	Cashew tree	Oil		36	TEM, SEM, XRD, DLS, FTIR, UV-VIS	Hexagon	[129]
121	*Ixora coccinea*	Jungle geranium	Flower		$5^{-1}0$		Spherical	[129]
122	*Cassia auriculata*	Avaram	Flower		12-41		Spherical	[130]

123	*Cassia auriculata*	Matura tea	Flower		12-41	UV VIS, XRD, SEM, EDAX, TEM, FTIR	Spherical	[130]
124	*Couroupita guianensis*	Cannon ball tree	Flower		25-45	DLS, EDAX, XRD, TEM, UV-VIS, FTIR	Spherical	[131]
125	*Mimosa pudica*	Touch me not	Flower	–	24		Spherical	[132]
126	*Moringa oleifera*	Moringa	Flower		3-5	TEM, UV-VIS, XRD, FTIR	Spherical	[133]
127	*Plumeria alba Linn*	Rubra	Flower		20-30	AFM, XRD, EDAX, TEM	Spherical	[134]
128	*Mirabilis jalapa*	Marvel of Peru	Flower		60-70	ZETA POTENTIAL, XRD, UV-VIS, FTIR, TEM		[135]
129	*Tagetes arecia*	–	Flower		10		Spherical	[136]
130	*Bauhinia purpurea*	Butterfly tree	Flower		20-50		Cubical	[137]
131	*Tagetes erecta*	Marigold	Flower		30-50	TEM, SEM, XRD, DLS, FTIR, UV-VIS	Spherical	[138]
132	*Caesalpiniapulcherrima*	Peacock flower	Flower	Antifungal, antibacterial	10-50	SEM, TEM, DLS	Spherical	[139]
133	*Plumeria alba*	Champa, whitefrangipani	Flower	Antibacterial, degradation of dyes	28±5.6–15.6±3.4	TEM, SEM, FTIR, UV-VIS, XRD	Spherical	[140]
134	*Vitis vinifera*	Grape	Seed		10-17	UV-VIS, TEM, XRD, SEM, FTIR	Spherical	[141]
135	*Cajanus cajan*	Pigeon pea	Seed		9-41		Spherical	[142]
136	*Cucurbita pepo*	Pumpkin	Seed		600-800	DLS, EDAX, XRD, TEM, UV-VIS, FTIR	Triangle	[143]
137	*Ocimum sanctum*	Tulsi, basil	Seed		30	SEM, TEM, DLS	Hexagonal	[144]
138	*Elettaria cardamomum*	Kardemumma	Seed	Antibacterial, antioxidant, anticancer	432.3	UV-VIS, TEM, XRD, FTIR	Spherical	[145]
139	*Abelmoschus esculentus*	Lady finger	Seed	Antifungal	45-75	UV VIS, XRD, SEM, EDAX, TEM, FTIR	Narrow and sphere shaped	[146]
140	*Ocimum sanctum*	Tulsi, holy basil	Seed	–	30		Hexagon	[147]
141	*Hibiscus cannabinus*	Kenaf	Stem		13	UV-VIS, TEM, XRD, SEM, FTIR	Spherical	[148]
142	*Marinda citrifolia*	Morinda	Root		12.17-38.26		Spherical, triangular, hexagon	[149]
143	*Panicum maximum*	Zaina	Root		14.28		Spherical	[150]
144	*Coleus forskohlii*	Indian Coleus, Forskolin	Root	Bactericidal activity, anticancer	25-40	UV-VIS, PSA, XRD, FTIR, HR-TEM	Triangular	[151]
145	*Mammea suriga*	Indian rose chestnut	Root		22-50	TEM, SEM, XRD, DLS, FTIR, UV-VIS	Square	[152]
146	*Hypericum hookerianum*	St. John's wort	Bark		$S1^{-1}$0-70	TEM, SEM, XRD, DLS, FTIR, UV-VIS	Spherical	[153]
147	*Cassia fistula*	Golden rain tree	Bark		55.2- 98.4		–	[154]
148	*Acacia nilotica*	Prickly acacia	Bark		10-50	UV-VIS, TEM, XRD, SEM, FTIR	Quasi-spherical	[155]
149	*Ipomoea carnea*	Pink morning	Root		25-100		Triangular, pentagonal, rod, truncated, hexagon	[156]
150	*Pistia stratiotes L*	Arum	Bark		2-40		Spherical	[156]
151	*Ficus religiosa*	Peepal tree	Bark		20-30	UV VIS, XRD, SEM, EDAX, TEM, FTIR	Triangular, hexagonal, pentagonal	[157]
152	*Eucommia ulmoides*	Gutta percha tree	Bark	Dye removal	16.4	XRD, DLS, EDX, HR-TEM	Spherical	[158]
153	*Dioscorea batatas*	Chinese yam	Rhizome	Antimicrobial	18.48–56.18		Diverse	[159]

154	*Diospyros ferrea*	Black ebony or sea ebony	Whole plant	Antimicrobial	70-90	DLS, EDAX, XRD, TEM, UV-VIS, FTIR	–	[159]
155	*Zingiber officinale*	Ginger	Rhizome	Drug delivery, gene deliver	5-15	DLS, TEM UV-VIS	–	[160]
156	*Zingiber officinale*	Ginger	Rhizome	Drug deliveryy, genedelivery	5-15	TEM, SEM, XRD, DLS, FTIR, UV-VIS	–	[160]
157	*Stoechospermum marginatum*	Brown algae	Whole plant part	Antibacterial	18.7-93.7	SEM, TEM, DLS	Hexagonal, triangular	[161]
158	*Turbinaria conoides*	Agar-Agar lesong (marine algae)	Whole plant part		6-10	XRD, TEM	Diverse	[162]
159	*Stylidium tenerrimum*	Marine algae	Whole plant part		5-45		Anisotropic	[162]
160	*Chlorella pyrenoidusa*	Algae	Whole plant part		25-30	UV-VIS, TEM, XRD, SEM, FTIR	Spherical	[163]
161	*Galaxaura elongata*	Red algaes	Red algae	Antibacterial	3.85-77.13		Rod, Hexagonal, Spherical, triangular	[164]
162	*Pomegranate*	Pomengranate	Juice		5-15	SEM, TEM, DLS	Spherical	[165]
163	*Punica granatum*	Pomengranate	Juice	Removal of Heavy metal ion & methylene blue dye	23-36		Variable small size	[166]
164	*Areca catechu*	Palm	Nuts	Antioxidant, antibacterial, anticancer	13.7	TEM, SEM, XRD, DLS, FTIR, UV-VIS	Spherical	[167]
165	*Gymnocladus assamicus*	Minangmose	Pod		4-22	SEM, TEM, DLS	Planar	[168]
166	*Gymnocladus assamicus*	Minangmose	–	–	4-22	UV VIS, XRD, SEM, EDAX, TEM, FTIR	Hexagonal, pentagonal, triangular	[168]
167	*Pistacia integerrima*	Zebra wood	Galls	Antifungal, antibacterial, antinociceptive	20-200	UV-VIS, TEM, XRD, SEM, FTIR	–	[169]
168	*Avena sativa*	Oat	Whole plant part		5-20	DLS, EDAX, XRD, TEM, UV-VIS, FTIR	Irregular, rod, tetrahedral	[170]
169	*Stachys lavandulifolia Vahl*	Betony	Aerial part		56.3	UV VIS, XRD, SEM, EDAX, TEM, FTIR	Spherical, triangular	[171]
170	*Prasiola crispa*	Algae	Whole plant part		9.8		Spherical	[173]
171	*Syzygium aromaticum*	Lavang	Buds	Ensures milk safety	4-150	DLS, EDAX, XRD, TEM, UV-VIS, FTIR	Polygonal, triangular	[174]
172	*Torreya nucifera*	Conifer		Antimicrobial	10-125	SEM, TEM, DLS	Spherical	[175]
173	*Madhuca longifolia*	Mahua	–	–	–		Triangular	[176]
174	*Rosa indica*	–	–	Anti-inflammatory, antibacterial	23.52-60.83	TEM, SEM, XRD, DLS, FTIR, UV-VIS	Spherical	[177]
175	*Arachis hypogaea*	Pea nut	–	–	110-130		Variable	[178]
176	*Terminalia arjuna*	Arjun tree	–	Antioxidant, antiamylo-idogenic	20-50		Spherical	[179]
177	*Morinda citrifolia*	Mulberry	–	–	12.17-38.26	UV-VIS, TEM, XRD, SEM, FTIR	Spherical	[180]
178	*Acorus calamus*	Sweet flag	Rhizome	Antibacterial	>100		Spherical	[189]

hydroquinone synthesized by fungi/prokaryotic organism that converts the metallic ions into metallic nanoparticles. For the survival during metal stress situations microbes perform various mechanism in order to eliminate heavy toxic metals [182].

Keeping in view the concerns of chemical method, researchers have tried microorganisms for the synthesis of gold nanoparticles that have been discussed as follows:

Fungi: Fungal species tolerate high metal concentration as compared to bacteria and they secrete extracellular redox proteins abundantly to reduce soluble metal ions to insoluble form and then to nanocrystals. Synthesis of gold nanoparticles using fungal species has reduced the time of biosynthesis and would have scale up the production process. Some researchers have demonstrated few fungal species for the synthesis of gold nanoparticles with different morphology. Fungal sp. namely *Alternaria alternate* [183], *Aspergillus clavatus* [184], *Aspergillus niger* [185], *Aspergillus oryzae* var. viridis [186], *Aspergillus sydowii* [187], *Aureobasidium pullulans* [188], *Candida albicans* [189], *Colletotrichum* sp. [45], *Coriolis versicolor* [190], *Cylin-drocladium floridanum* [191], *Epicoccum nigrum* [192], *Fusarium oxysporum* [193], *Fusarium semitectum* [194], *Helminthosporum solani* [195], *Hormoconis resinae* [196], *Pichia jadinii* and *Verticillium luteoalbum* [197], *Neurospora crassa* [198], *Penicillium brevicompactum* [199], *Rhodococcus* sp. [200], *Penicillium rugulosum* [201], *Phanerochaete chrysosporium* [202], *Penicillium* sp. 1-208 [203], *Rhizopus orzyae* [204], *Rhizopus stolonifer* [205], *Saccharomyces cerevisiae* [206], *Sclerotium rolfsii* [207], *Verticillium* sp. [208], *Volvariella volvacea* [209], *Yarrowia lipolyticas* [210], *Pencillium chrysogenum* [211] have been used for the synthesis process operating at different reaction conditions.

Merits: Synthesized gold nanoparticles have been screened out as vector controlling agents against mosquito species, which has been marked as first potential strategy as 100 % mortality rate has been termed for *C. quinquefasciatus* larvae. Fungi Hormoconis resinae employed in the synthesis reaction has been widely found in soil near refinery, that providing opportunity for green route synthesis of valuable gold based nanomaterials.

Bacteria: Among microbes, prokaryotes have attained more attention in the era of nanoparticle synthesis. Firstly, microbial synthesis of gold nanoparticles have been carried out with *Bacillus subtilis* 168 that revealed the presence of 5-25 nm octahedral sized nanoparticles inside the cell wall. Spherical shaped gold nanoparticles have been synthesized with the application of few bacterial species namely *Bacillus megatherium* D01 [212], *Plectonema boryanum* [213], *E. coli* [214], *Magnetospirillum gryphiswaldense* [215], *Marinobacter pelagius* [216], *Pseudomonas aeruginosa* [217], *Rhodobacter capsulatus* [218], *Rhodopseudomonas capsulate* [219], *Plectonema boryanum* UTEX 485 [220], *Anabaena* sp. [221], *Spirulina platensis* [222], *Lyhghya majuscule* [223], *Escherichia coli* [224], *Escherichia coli* DH5α [225], *Pseudomonas denitrificans* [226], *Shewanella algae* [227], *Shewanella oneidensis* [228], *Stenotrophomonas maltophilia* [229], *Stenotrophomonas* sp., [230], *Desulfovibrio desulfuricans* [231], *Bacillus subtilis* 168 [232], *Bacillus subtilis* [233], *Bacillus licheniformis* [234], *Lactobacillus* sp. [235], *Geobacillus stearothermophilus* [236], *Jeotgalibacillus* sp. [237], *Brevibacterium casei* and *Thermonospora* sp. [238], *Arthrobacter* sp. 61B [239] at different reaction conditions.

Merits: The synthesized gold nanoparticles of crystalline nature with the application of *Arthrobacter* sp. 61B bacterial strain do not create large agglomerates, offering an advantageous parameter. Rapid synthesis reaction rate has been noticed with *Shewanella bacterial* sp., when the reaction has been carried out in light conditions rather than in dark conditions within 4 h. Easy availability in microbio laboratories and easily isolatable has been considered as one othet advantageous parameter during gold nanoparticle synthesis with *Bacillus subtilis*. Rapid synthesis of gold nanoparticles have been observed in 4-6 h only. The rapid synthesis has been taken as one of the merits. Good stability of about 3 months has been termed for gold nanoparticle solution with *Rhodopseudomonas capsulata* bacterial strain, offering a merit for synthesis process.

Demerits: Long reaction time during the synthesis of gold nanoparticles using bacteria strain *Arthrobacter* sp. 61B *i.e.* synthesis reaction gets completed in about 12 days [239]. The pH parameter has to be maintained properly as at neutral pH value, *Shewanella* sp. fails to produce gold nanoparticles. The reaction has been completed after 2 days that indicates slow process synthesis of gold nanoparticles using *Rhodopseudomonas capsulata*.

Yeasts: Yeast strains have been utilized for the synthesis of gold nanopartilces. Ease of controlling yeast species in the laboratory circumstances, synthesis of numerous enzymes and rapidly growth with use of simple nutrients, the yeasts strains offers more benefits over bacterial strains. Numerous sized gold nanopartilces have been synthesized from *Pichia jadinii* [240] and *Yarrowia lipolytica* NCIM 3589 yeast species [241].

Merits: The biosynthesis route occurring within a day has been found a merit associated with use of yeast *Pichia jadinii* when tried out for the synthesis of gold nanoparticles while, with the application of one another yeast namely *Yarrowia lipolytica*, the gold nanoparticles have been obtained with different morphology when subjected at different pH values.

Demerits: During the synthesis of gold nanoparticles using yeast, appropriate pH has to be made assure, this offers a little bit challenging for the researchers.

Table-2 listed the various microbe species which have been used for the biosynthesis of gold nanoparticles.

Conclusion

The green route for nanoparticle synthesis has rapidly replaced the chemical traditional route because of its inexpensiveness, eco-friendliness and zero production of toxic chemicals. The present article summarizes the gathered literature that would help to understand fabrication methodology of gold nanoparticles using plant extract and various microbes. Microbe mediated synthesis route has also been found to be effective but availability of micro organisms, appropriate temperature conditions, feasibility of microorganisms is a little bit problem whereas, plant mediated synthesis route only uses plant parts like leaves, seeds, flowers, peels, juices, fruits, *etc*. that are quite easily approachable to one. Among all available bioreductants, rhizome mediated synthesis route with rhizome of

TABLE-2
VARIOUS MICROBE SPECIES USED FOR THE BIOSYNTHESIS OF GOLD NANOPARTICLES

S. No.	Microbe	Class	Shape	Size	Other parameter	Applications	Route	Ref.
1	*Colletotrichum sp*	Fungi	Spherical	8-40	25–27°C, 96 h	Cancer detection in liver	–	[45]
2	*Alternaria alternate*	Fungi	Spherical	15	–		Extra cellular	[183]
3	*Aspergillus clavatus*	Fungi	Triangular, spherical and hexagonal	24.4±11	48-72 h	Antibacterial, antifungal	Extra-cellular	[184]
4	*Aspergillus niger*	Fungi	Spherical, elliptical	12.8±5.6	Room temp., 96 h		–	[185]
5	*Aspergillus oryzae var. viridis*	Fungi	Various shapes mostly spherical	10-60	72-120 h, 25°C		–	[186]
6	*Aspergillus sydowii*	Fungi	Spherical	8.7–15.6	–		Extra-cellular	[187]
7	*Aureobasidium pullulans*	Fungi	Spherical	29			Intra-cellular	[188]
8	*Fusarium oxysporum*	Fungi	Spherical, mono-dispersible	2-50			–	[188]
9	*Candida albicans*	Fungi	Non-spherical	60–80	24 h		–	[189]
10	*Coriolis versicolor*	Funfi	Spherical and ellipsoidal	100-300, 20-100			Intra-cellular and extra-cellular	[190]
11	*Cylindrocladium floridanum*	Fungi	Spherical	5-35	168, 30°C		–	[191]
12	*Epicoccum nigrum*	Fungi	–	5-50	72 h, 27–29°C		Intra- and extra-cellular	[192]
13	*Fusarium oxysporum*	Fungi	Spherical, triangular	8-40	72 h	Antibacterial	Extra-cellular	[193]
14	*Fusarium semitectum*	Fungi	Spherical	10-80	Room temp, 24 h	Anticancer	Extra-cellular	[194]
15	*Helminthosporum solani*	Fungi	Sphere, rod, trianglular, pentagonal, pyramid, star shaped	2-70	37±1°C, 72 h		Extra-cellulars	[195]
16	*Hormoconis resinae*	Fungi	Spherical	3-20	24 h, 30 °C		Extra-cellular	[196]
17	*Pichia jadinii*	Fungi	Spherical	<100	–		Extra cellular	[197]
18								
19	*Verticillium luteoalbum*	Fungi	Spherical and rod shaped	<10	Intra-cellular		Intra-cellular	[197]
20	*Neurospora crassa*	Fungi	Spherical	32 (3–100)	24 h, 28°C		Intra-cellular	[198]
21	*Penicillium brevicompactum*	Fungi	Spherical, triangular and hexagonal	10-60	12–72 h, 30°C	Targeting cancer cells	Extra-cellular	[199]
22	*Rhodococcus sp.*	Fungi	–	5- 15	–		Intra cellular	[200]
23	*Penicillium rugulosum*	Fungi	Spherical, triangular and hexagonal	20-80	8-24 h, 30°C		–	[201]
24	*Phanerochaete chrysosporium*	Fungi	Spherical	10-100			Extra-cellular	[202]
25	*Penicillium sp. 1-208*	Fungi	Spherical	40-60	0.08 h		Intra-cellular	[203]
26	*Rhizopus orzyae*	Fungi	Spherical	16-25	24 h, 30°C	Pesticides	–	[204]
27	*Rhizopus stolonifer*		Irregular	1-5			–	[205]
28	*Saccharomyces cerevisiae*	Fungi	Spherical	15-20	<24, 30°C		–	[206]
29	*Sclerotium rolfsii*	Fungi	Spherical, Hexagonal, triangular	25.2±6.8	Room temp,		–	[207]
30	*Verticillium sp.*	Fungi	Spherical	20±8	28°C, 72 h		–	[208]
31	*Volvariella volvacea*	Fungi	Triangular, spherical, hexagonal	20-150	–	Therapeutic	–	[209]
32	*Yarrowia lipolytica*	Fungi	Various shapes	–	120 h, 30°C		Intra-cellular	[210]

33	*Pencillium chrysogenum*	Fungi	Spherical, rod, triangular	5- 100	–		Intra cellular	[211]
34	*Bacillus megatherium D01*	Bacteria	Spherical	1.9±0.8	9 h, 26°C		Extra-cellular	[212]
35	*Plectonema boryanum*	Bacteria	Spherical, Octahedral	~60	24 h, 25°C		Intra-cellular & extra-cellular	[213]
36	*Escherichia coli*	Bacteria	Spherical	25±8	Room temp, 120 h	Antibacterial	–	[214]
37	*Magnetospirillum gryphiswaldense*	Bacteria	Spherical	10-40	1 hour		Intra-cellular	[215]
38	*Marinobacter pelagius*	Bacteria	Spherical, triangular	2-10	22 h		Extra-cellular	[216]
39	*Pseudomonas aeruginosa*	Bacteria	Spherical	40±10	24 h, 37°C		Extra-cellular	[217]
40	*Rhodobacter capsulatus*	Bacteria	Spherical	–	24 h, 30°C		–	[218]
41	*Rhodopseudomonas capsulata*	Bacteria	Spherical, planar	50–400, 10-20	48 h, room temp		Extra-cellular	[219]
42	*Plectonema boryanum* UTEX 485	Bacteria	Cubic	–			–	[220]
43	*Anabaena sp.*	Bacteria	–	–	–		Intra-cellular	[221]
44	*Spirulina platensis*	Bacteria		6-10			Extra-cellular	[222]
45	*Lyngbya majuscula*	Bacteria	Spherical	b20			Intra-cellular & extra-cellular	[223]
46	*Escherichia coli*	Bacteria	–	20			–	[224]
47	*Escherichia coli* DH5α	Bacteria	Spherical	–	–		–	[225]
48	*Pseudomonas denitrificans*	Bacteria	Face-centered	25-30			–	[226]
49	*Shewanella algae*	Bacteria		10-20				[227]
50	*Shewanella oneidensis*	Bacteria	Spherical	12 ± 5		Antibacterial		[228]
51	*Stenotrophomonas maltophilia*	Bacteria		40			Intra-cellular	[229]
52	*Stenotrophomonas sp.*	Bacteria	Multi shaped	10-50			Extra-cellular	[230]
53	*Desulfovibrio desulfuricans*	Bacteria	–	20-50			--	[231]
54	*Bacillus subtilis 168*	Bacteria	Octahedral	5-25				[232]
55	*Bacillus subtilis*	Bacteria		20				[233]
56	*Bacillus licheniformis*	Bacteria	Cubic	10-100				[234]
57	*Lactobacillus sp.*	Bacteria	Hexagonal	20-50			Intra-cellular	[235]
58	*Geobacillus stearothermophilus*	Bacteria	Circular	12			Extra-cellular	[236]
59	*Jeotgalibacillus sp.*	Bacteria		5-35			Intra-cellular	[237]
60	*Brevibacterium casei*	Bacteria		10-50				[238]
61	*Thermonospora sp.*	Bacteria	Spherical	7-12, 8			Extra-cellular	[238]
62	*Arthrobacter sp. 61B*	Bacteria	Spherical	8-40				[239]
63	*Pichia jadinii*	Yeast		100			Intra-cellular	[240]
64	*Yarrowia lipolytica* NCIM 3589	Yeast	Particles and plates	Variable			–	[241]

Zingiber officinale (ginger) has been found more advantageous in accordance with availability, stability, applicability and reaction time, *etc*. for the synthesis of gold nanoparticles that have been tried out as drug delivery carriers.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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