Asian Journal of Chemistry; Vol. 34, No. 4 (2022), 793-806

ASIAN JOURNAL OF CHEMISTRY

https://doi.org/10.14233/ajchem.2022.23523

REVIEW

A Compendious Prospective about Biogenesis of Nanoparticles and their Persuasions

Kiran Singh[1], Olusola B. Sokefun[2] and Shweta Yadav[1,*]

[1]Department of Zoology, School of Biological Sciences, Dr. Harisingh Gour, Vishwavidyalaya (A Central University), Sagar -470003, India
[2]Department of Zoology and Environmental Biology, Faculty of Science, Lagos State University, Ojo, 102101 Lagos, Nigeria

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

Received: 8 September 2021; *Accepted*: 8 December 2021; *Published online*: 10 March 2022; AJC-20719

Nanotechnology cogitates manufacturing and exploitation of materials, in which all components are present at the nanoscale and their size ranges up to 100 nm. Nanoparticles can be synthesized chemically or biologically; nevertheless, biologically synthesized nanoparticles are less toxic to the environment and human health. Biogenesis of nanoparticles is acquiring momentum due to the use of biocompatible precursors' *viz*., fungi, algae and various plant extracts. Nanoparticles are being useful in various branches of industrial products including energy storage and daily applications namely cosmetics, garments, optical stuff, catalytic, bactericidal, electronics, biological labeling as well as treatment of certain cancerous diseases. Due to their mounting applications, it is essential to develop a toxic-free approach for the synthesis of nanoparticles and their assemblage to eradicate the use of hazardous substances. The broad spectrum of naturally occurring cost effective precursors are available, which can be used in biomedicine, biosensors development, organic dyes and in the fabrication of nanodevices, *etc*. The study has reviewed the prospective of biocompatible organically synthesized nanoparticles and their cogency in various fields.

Keywords: Nanoparticles, biological synthesis, synthetic approach, Plant extracts, Medical scopes.

INTRODUCTION

Particles in nanosized range (1-100 nm) have been present on earth since perhaps as long as the earth has existed and have been utilized by human being long ago. In recent times, nanoparticles have bedazzled because of their expanding potentiality to synthesize and handling in various commercial applications. Extensively physical, chemical and biological methods are being used to synthesize these nanoparticles. The application of nanoparticles has transformed medical diagnostics through intensifying images of diseased tissue in the body. On the other hand, nanocomposites are being used in the industrial production of solar and oxide fuel batteries, cosmetic products, garments, food packaging, flame-retardants, *etc*. [1]. Organic syntheses of nanoparticles have been constantly challenged in designing of nanoparticles of targeted morphologies and sizes. However, it could be effectively possible because of obtainable materials and reagents for the target molecule. The chemical industries play a major role to accomplish human needs and development. The increased requirement of chemicals would intercept the chemist's progress. Further, chemists are striving to settle related issues *viz*. adverse effect of chemicals on the environment and living beings, reduction to these resources and requirements to ecological development. Nevertheless, the chemical synthesis of nanoparticles may consist serious hazardous reactions. Keeping this fact in view researchers have developed a strategy to synthesize nanoparticles from naturally occurring biomolecules under an umbrella of Green chemistry [2]. The nanoparticles show unique properties due to their dimensions, surface and shape which assist them to interconnect precisely with living creature [3,4]. The nanoparticles are also used indirectly in multiple ways in our circadian requirement. Massive literature is available on chemical synthesis of nanoparticles and their characterization while, insubstantial studies are available on green synthesis of nanoparticles and their mechanism of action [5]. With reference to various hazardous issues to chemically synthesized nanoparticles, the present study is an attempt to reckon biogenesis of nanoparticles and their application. The study reviewed the biologically synthesized nanoparticle by diverse biological sources and their applications which may figure out the possibilities of new biological sources for nanoparticles synthesis.

Nanoparticle conglomeration: Recently nanoparticles have been purposefully engineered by specific technologies with new available resources. It is not clearly evident how humans are exposed to these nanoparticles at the working place or by the use of nanotechnology-based yields.

Top-down and bottom-up are two common procedures of synthesis of nanoparticles (Fig. 1). The top-down approach appertains to a non-operational method to escort the synthesis of nanoparticles; which instigate from the bulk portion of the material following progressive development of nanometer-sized organizations. Photon and electron beam lithographic procedures (electron, UV, scanning probe, laser beam processing, *etc.*) and mechanical procedures (machining, crushing and refining) follow top-down methods. The bottom-up method is based on chemical reaction; it synthesizes the material from atomic or molecular species, permitting the precursor particles to develop in nano-size. The bottom-up procedure includes a series of chemical strategy including sublimation, tapping of stream of light, autogenous association, nanocrystalline accumulation, film dethronement, *etc.* This method generates much reduced sized particles with ascendancy like absolute exactitude, complete control throughout the procedure and least energy damage compared to top-down approach [6]. Both methods can be cast-off in gas, liquid, solid or in a vacuum and supercritical fluid.

Future prospective of biologically synthesized nanoparticles: Nanotechnology has been evolved as a modern research field in nanoparticle designing, synthesis and manipulation in the structure of particles. Several methods (chemical, physical and biological) are available to fabricate various types of nanoparticle including hybrid methods [7,8]. The chemically synthesized nanoparticles are precarious due to the use of different chemical reagents; which curtails their application in biomedical and clinical fields. Having promulgated this, concerns a nontoxic, consistent and ecofriendly procedure for nanoparticle synthesis, is being developed to expand their exceptional application in medical science. To achieve the goal of the biogenesis of nanoparticles several microorganisms *viz.*, (bacteria, fungi, yeasts) are being used by and large. The green synthesis of ecofriendly methods has extensive applications in the biological systems than chemically synthesized nanoparticles. Some of the greatest potential users of biologically

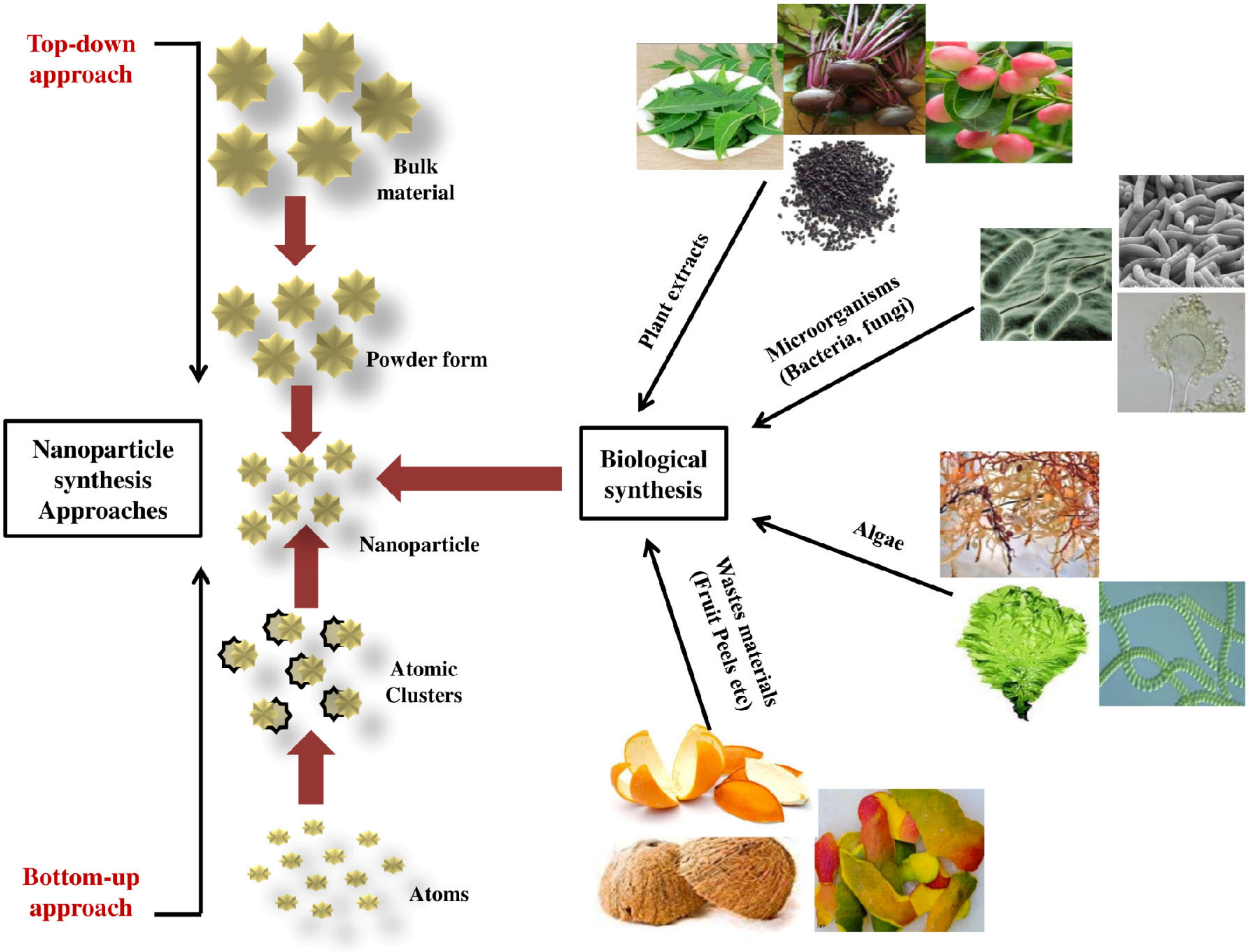

Fig. 1. Biological synthesis of nanoparticles by top-down and bottom-up approaches [6]

synthesized nanoparticles are sensing element device trace detector, solid waste management, water treatment and water purification plants. These prospective can be categorically divided into nanoparticles participating readily towards prevailing environmental issues and other prescient apprehension and prevention of upcoming problems. Furthermore, remediation and treatment are important readily participating prospective which have been made possible through application of nanoparticles while, prescient apprehension especially taking place in green energy production. Solar fuel cells are forthcoming source which may be produced effectively by nanoparticles at commercial scale and may be an alternate unpolluted energy source. Green nanotechnology has dual facets; (i) synthesis of nanoparticles to eradicate pollutants at their source and (ii) production of efficient nanomaterials for manufacturing of devices at commercial scale. Biologically synthesized nanoparticles are significantly valuable in application for public health and environment protection however it also has marginal effects to protect environment inside human body and inside the natural ecosystem. Studies suggest the future prospects of nanoparticles synthesis may involve simple synthesis techniques with use of boiled, crushed, crushed-boiled extract at various pressure, pH and with use of different salt which can show imperative role in bringing significant features of nanoparticles. It may be helpful for achieving novel characteristics features. Overall, green technology may facilitate green synthesized nanoparticles tender as industrial level instead of chemically manufactured nanoparticle which is noxious for environment and living being in comparison to biologically synthesized nanoparticles.

Impediments of green synthesis of nanoparticles: Even though the green chemistry practise has numerous advantages in comparison to chemical synthetic approach, nevertheless few concerns are there to be resolved before to practise at large industrial scale specifically: (i) the realizable ecological discrepancy of the natural bioresources of microbes and plants by reason of maximal use; (ii) the changes in concentrations of the active biomolecules or phytochemicals because of periodic or climatic alterations; (iii) unavailability of strong reducing agents; (iv) isolation and recognition of bioactive compounds for medical diagnostics and curatives available in plant bioresources; (v) recycling, reprocess, regeneration, bioaccumulation, toxicity features as well as stability of bioresources are needed to be investigated; and (vi) lack of understanding in essential mechanism like modeling factors, difficulty in assemblage and structures. However, these limitations are exploring an innovative opportunity to work in this promising research area.

Ordeal factors coherent with biosynthesis of nanoparticles: The type of adsorbate and action of catalysts may influence green synthesis of nanoparticles as reported by Somorjai *et al*. [9]. Pennycook *et al.* [10] found the incubation time and environmental factors diversely effect the synthesis of nanoparticles. Therefore, following factors involved in biosynthesis procedure of nanoparticles could not be ignored during synthesis, characterizations and application of those nanoparticles:

pH: The size and texture of nanoparticles have been found affected by pH [11].

Temperature: Temperature of the reaction medium affects the synthesis of nanoparticle [12]. By and large it desires less than 100 ºC.

Pressure: The size and shape of synthesized nanoparticles may alter because of an applied pressure [13]. The reduction level of metal ions of nanoparticles has been found faster at ambient pressure [14].

Duration of time: The timing of incubation reaction affects size and structure of biosynthesized nanoparticle [15]. The length of time, synthesis procedure, light and state of storage also swap the characteristics of synthesized nanoparticles [16]. Long-time storage may agglomerate the nanoparticles which may be resulted into increase in a size of nanoparticles or may shrink into a small size [17].

Environment: The environment of reaction medium also takes important role in nanoparticles synthesis. The formation of aggregates and concentration of free nanoparticles depend on trapped or eliminated particles through sedimentation. A single nanoparticle may convert into core-shell nanoparticles by absorbing surrounding material or by chemical reactions amid a flurry of substances [18].

Other factors: Secondary metabolites plants [19], different intracellular and extracellular enzymes of microorganisms [20], methods of purification of nanoparticles affect various components of nanoparticles.

Nanoparticles synthesis using various plants extracts: Plant-mediated nanoparticles synthesis has gaining worldwide attention because of its cost effective and ecofriendly approach. The technique comprises blending of the plant extract in a precursor solution containing metal ion at ambient temperature for a few minutes. Gold and silver nanoparticles are commonly manufactured by this procedure [21]. Various characteristics of plant extracts like their concentration, pH and concentration of metal salt solution have implications on nanoparticle production [22]. The succeeding uses of plant products for metallic nanoparticle syntheses have particularized attention towards the mechanism of uptake and reduction process of metal during the synthesis of the nanoparticle. In recent times, synthesizing metal nanoparticle with plant products such as leaves, stems, flowers, fruits and others have been widely considered as a well known green and proficient approach for developing appropriate nano-sized materials.

Synthesis of silver nanoparticle using plant extracts: In current existence, green chemistry and biosynthetic approaches have developed a new attractive technique to attain AgNPs. *Clitoria ternatea* (butterfly pea), an herb used as medicine in Ayurveda, has several neurological welfares. Krithiga *et al.* [23] manufactured 20 nm silver nanoparticles from the leaves of *C. ternatea*, by manipulating pH, temperature and reaction period. Bunghez and his group [24] extracted 458 and 415 nm AgNPs from aqueous petal extracts of ornamental flowers *Dianthus caryophyllus* and *Hyacinthus orientalis*, respectively. The ability and stability of those particles were checked by UV-Vis absorption, FTIR, DLS and chemiluminescence method. Shankar *et al.* [25] extracted AgNPs extracellularly from the leaves of Geranium (*Pelargonium graveolens*) with aqueous solution of silver nitrate and procured highly stable, crystalline16-40 nm nanoparticles. Iravani & Zolfaghari [26] synthesized spherical 10-40 nm silver nanoparticles using bark extract *Pinus brutia* (formerly known as *P. eldarica*), the plant is found in the tropical and subtropical regions and often used as a medicinal plant. Pratap *et al.* [27] prepared 106 nm particles AgNPs from leaves of medicinal plants *Abutilon indicum* plant. Shankar *et al.* [28] prepared 16-40 nm silver nanoparticles from leaf extract of rose geranium (*Pelargonium graveolens*). Safaepour *et al.* [29] used geraniol (a monoterpenoid) to produce 1-10 nm AgNPs and their cytotoxicity using Fibro-sarcoma-Wehi 164 cancer cell line. Highly stable silver nanoparticles of 16-40 nm size was synthesized from leaf extract of plant Datura (*Datura stramonium)* [30]. The plant *Dioscorea bulbifera* was consumed to produce different forms of gold and silver nanoparticles [31]. These nanoparticles combined with antibiotics and found that, they exhibit antibacterial activity as a synergistic effect, in contrast to testing microorganisms, against some bacteria *viz. Escherichia coli, Pseudomonas aeruginosa* and *Acinetobacter baumannii* [32]. Jebril *et al.* [33] used a leaf extracts of *Melia azedarach* to produce18-30 nm AgNPs and measured the yield by DLS, zeta potential, scanning electron microscopy, X-ray diffraction and FTIR. Similarly, the leaf extract of *Eclipta prostrate* has been used to synthesize 35-60 nm AgNPs and found to conceded a larvicidal activity in contrast to vectors of malaria and lariasis. The particles were characterized using UV-visible spectroscopy, (SEM), TEM, FTIR and XRD [34]. The leaves of *Eucalyptus globulus* were used for the synthesis of 1.9-4.3 nm silver nanoparticles by rapid microwave assisted method and their antibacterial and antibiofilm activity were also recorded [35]. The leaves and barks of *Syzygium cumini* were used to produce 400 nm silver nanoparticles [36]. Nanoparticles were examined using UV-Vis, AFM and SEM techniques. *Aloe vera* was also used to synthesized AgNPs (70.70 ± 22–192.02 ± 53 nm) and examined under XRD and SEM. The synthesized particles inhibited the growth of pathogenic bacteria *S. epidermidis* and *P. aeruginosa* [37].

The leaf extract of holy basil *Oscimum sanctum* was used to synthesize 18 nm AgNPs and stabilized AgNPs have shown antimicrobial activity against *Staphylococcus aureus* and *E. coli* [38]. They were observed under UV-vis spectrophotometer and FTIR spectroscopy, XRD and SEM [39]. AgNPs were synthesized using leaf extracts of neem (*Azadirachta indica*) and their antimicrobial activities against Gram-negative and Gram-positive bacteria have been observed. Particles were examined by DLS and UV-visible spectrophotometer techniques [40]. Haytham & Ibrahim [41] synthesized 23.7 nm silver nanoparticles using banana peel and found their effective antibacterial activity against representative pathogens. Sun dried leaf of *Cinnamomum camphora* was used to produce triangular, spherical 55 to 80 nm Au and AgNPs. The water-soluble heterocyclic constituents have been found primarily responsible for silver ions or chloroaurate ions reduction and stabilization of the nanoparticles which in turn responsible for change in shape of gold and silver nanoparticles. The reasonable advantages of these protective and reductive biomolecules, besides polyol components have been endorsed [42]. The synthesis of 5-35 nm AgNPs was attempted using leaf extract of *Ficus benghalensis* and their crystal structure was confirmed by XRD studies. Zeta potential of synthesized particles was recorded −39.1, which indicated their good stability [43]. Eventually, the synthesis of nanoparticles from different parts of plants including flower, fruit, leaf, seed, *etc.* have been turned into a prominent eco-friendly approach and is contemporary to chemical and physical synthesis. Nevertheless, synthesis of AgNPs using the aqueous solution of leaf extracts is overriding other parts of plants.

Synthesis of gold nanoparticle (AuNPs) using plant extracts: Gold nanoparticles are being reflected more biocompatible than other metallic nanoparticles. Consequently, investigations with respect to the green synthesis of gold nanoparticles with use of plant extract have been blooming around the world. Shankar *et al*. [44] have initiated biosynthesis of metal nanoparticles with use of geranium leaf extract, which has the ability to reduce and acts as a capping agent for synthesis of AuNPs. The same researcher group [45] also synthesized AuNPs using the leaf extracts of neem plant. The reaction time was ended in merely 2.5 h. The extract of neem containing flavonoids and terpenoids were absorbed by the surface of the nanoparticles and made them stable for 4 weeks. This study got contemplation because of the first time simultaneous reduction of both silver and gold ions to synthesize nanoparticles with spherical, triangular and in few cases hexagonal in shapes [45]. The extract of the dried bud of *Syzygium aromaticum* was used for the production of 4-150 nm polygonal and triangular shape gold nanoparticles in which the main eugenol acted as reducing agent [46]. Parida *et al*. [47] demonstrated rapid green synthesis technique for AuNPs using *Allium cepa.* They found reduction in size of nanoparticles because of presence of vitamin C in onion extract. *Phyllanthus amarus* has also been found suitable for biosynthesis of stable AuNPs with range of 65-99 nm [48]. Narayanan & Sakthivel [49] synthesized used leaf extract of *Coriandrum sativum* to synthesize 6.75-57.91 nm, spherical, decahedral and triangular AuNPs. *In situ* biogenic synthesis of 6-80 nm, anisotropic AuNPs was done by using of *Terminalia chebula* [50].

Liu *et al*. [51] used the extracts of beverages like *Chrysanthemum* and tea for the synthesis of AuNPs and established an assay for quantification of antioxidant property [51]. Daisy & Saipriya [52] fabricated 55-98 nm gold nanoparticles using stem bark of *Cassia stula* to evaluate hypoglycemic effects of the plant. Castro and his coworkers [53] used the sugar beet pulp for the synthesis of gold nanowires. They reported the formation of nanowires was induced owing to aptitude to biomolecules, hydroxide ions and high concentrations of gold ions solution. It occurred due to the limited application of capping agent which stacked nanoparticles into nanowires instead of nanospheres. The geranium leaves (*Pelargonium graveolens*) was used by Shankar *et al.* [44] in extracellular synthesis of 16-40 nm decahedral, isohedral, triangular and rod-shaped AuNPs after 48 h exposure of aqueous Au ions. Anuradha *et al.* [54] synthesized fairly uniform shape AuNPs using aqueous extract of *Azadirachta indica* in 24 h after exposure of Au(III) solution. The triangular and spherical silver nanoparticles have been made by *Aloe vera* leaf extract [55]. The leaves and buds of *Camellia sinensis* have also been used to synthesize 2.94-

45.8 nm AuNPs. The core size of nanoparticles decreased with increase of tea extract [56]. The leaf extract of henna comprises apiin, has the ability to reduce Au ions. The apiin concentration could be responsible for various sizes and shapes of gold and silver nanoparticles [57]. *Chenopodium albums* leaves extract have been used to synthesize quasi-spherical, 10-30 nm silver and gold nanoparticles [58]. Dubey *et al.* [59] used the fruit of *Tanacetum vulgare* for the formation of pH-dependent, spherical, triangular shape Ag and AuNPs and observed unique optical, catalytic and electronic properties of extracted bimetallic nanoparticles. Philip [60] used the persimmon leaf and mushroom in equal ratio of the solution of gold and silver ions to synthesize bimetallic Au and AgNPs. They also recorded morphology of nanoparticles depends on the time of reaction rate and concentration of the ionic solution. Zhan *et al.* [61] used *Cacumen platycladi* for the biogenic fabrication of AuNPs, they prepared the stimulated solution and found that the flavonoid and reducing sugar were the most reductive component during their synthesis. The leaf extract of *Abutilon indicum* was used by Mata *et al.* [62] for the synthesis of 1-20 nm, spherical shaped gold nanoparticles and recorded their cytotoxicity in cancer cells of colon. *Sauaeda monoica* leaf mediated synthesis of 12.96 nm spherical gold nanoparticles through the gold ions reduction and their antioxidant capacity was described by Rajathi *et al.* [63]. Leaves, stem and root extracts of a highly invasive and harmful weed *Ipomoea carnea* have been employed for biomimetic assembly of gold nanoparticles by Abbasi *et al.* [64]. They synthesized monodispersed spherical and polydispersed triangular, hexagonal, polygonal, rod and truncated triangular shape in sizes ranging 3-40 and 10-100 nm and found proteins and polysaccharides in the plant extract were accountable for the reduction of Au ions to AuNPs and their stability. The reducing and capping potential of *Phoenix dactylifera* for the synthesis of 32-45 nm gold nanoparticles was explored by Zayed & Eisa [65] and recorded carbonyl and hydroxyl interaction in flavonoids, tannins, carbohydrates and phenolic acids in stabilization of nanoparticles. Das & Velusamy [66] used the leaf extract of *Sesbania grandiflora* for the green synthesis of 7-34 nm AuNPs and recorded their efficacy as catalyst in degrading chemical dyes. The crude aqueous flower extract of *Mimosa pudica* with aqueous chloroauric acid was used to synthesize highly stable 24 nm gold nanoparticles. The fast reduction of Au^{3+} ions at room temperature was found without use of other reducing or alleviating agent [67]. The aqueous plant extract of three plants *viz. Mentha piperita*, *Melissa officinalis* and *Salvia officinalis* were used in the synthesis of AuNPs and their properties were compared. It was found the synthesis of nanoparticles was concentration specific [68]. The juice extract of *Citrus limon*, *Citrus reticulata* and *Citrus sinensis* juice was used for the synthesis of 15-80 nm polymorphic gold nanoparticles by the reduction of $HAuCl_4$ [69]. The mean average size of nanoparticles for *C. limon*, *C.*

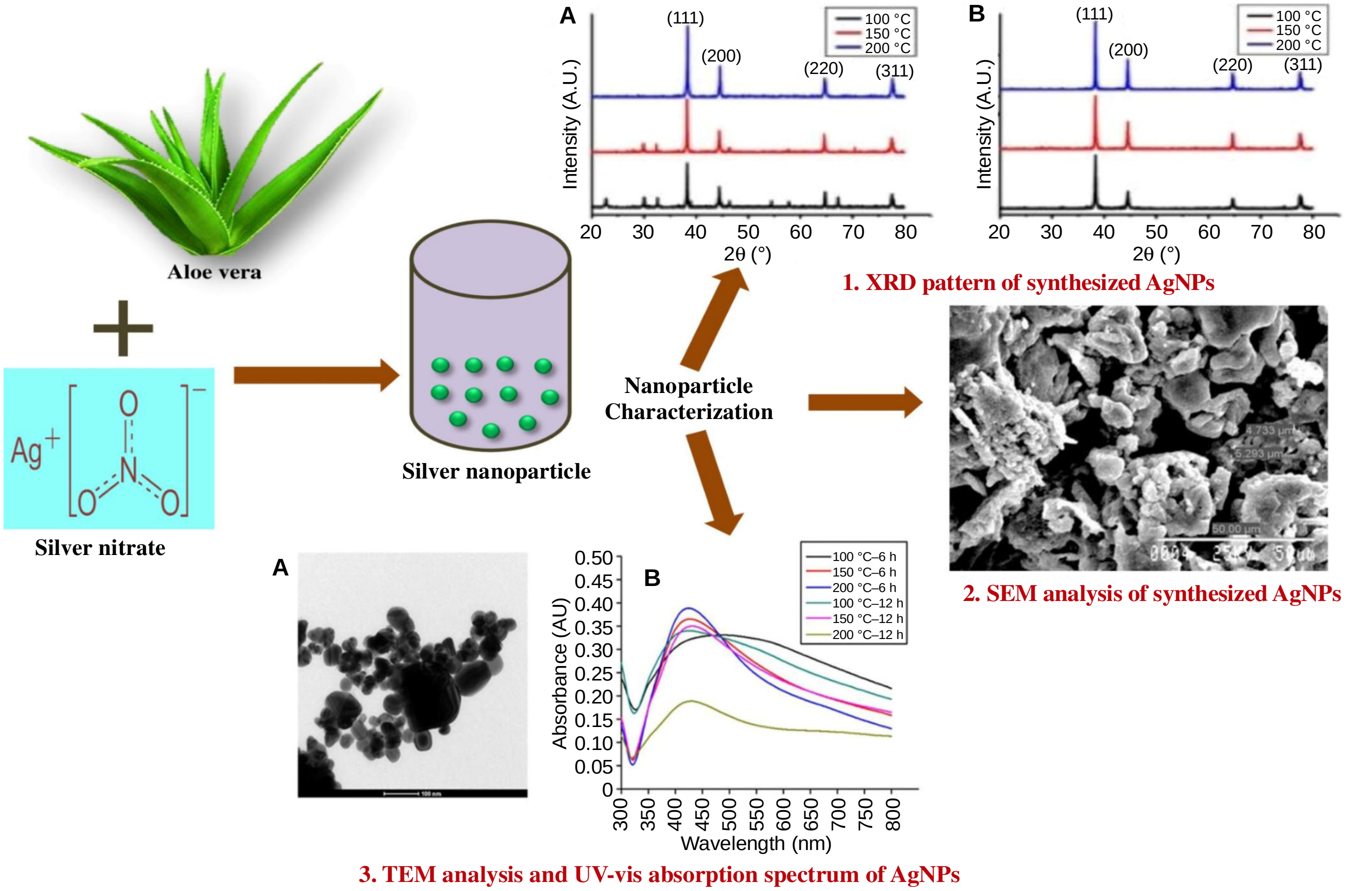

Fig. 2. Synthesis of silver nanoparticle by using aloe vera extract: 1. XRD patter of silver nanoparticle at various temperature; 2. SEM image of AgNPs; 3. TEM analysis and UV-visible absorption spectra study at different temperature and incubation period [37]

reticulata and *C. sinensis* were measured 32.2, 43.4 and 56.7 nm, respectively using DLS. Fig. 2 depicts the basic plan of the biogenic synthesis of nanoparticles.

Plant extracts used in the synthesis of other nanoparticles: Apart from the biogenesis of silver and gold nanoparticles, several different ranges of nanoparticles have been synthesized using diverse parts of plants that have the capacity to reduce ionic solutions. Spherical Ag and Ti nanoparticles have been synthesized using the leaf extract of *Euphorbia prostrate* [70]. The leaves of plant *Ginkgo biloba* have the potential to reduce copper ions and impart a role in synthesis of 15-20 nm, spherical copper nanoparticles [71]. Likewise, the leaf extract of *Cocos nucifera* has been successfully used in the production of lead nanoparticles (47 nm, spherical), which has antibacterial and photocatalytic activity [72]. *Catharanthus roseus* has been found significant for the synthesis of 40 nm, spherical palladium nanoparticles that have catalytic action on the degradation of dye [73]. The peel of banana has potential as a reducing phase for cadmium sulfide nanoparticles of 1.48 nm [74]. The fruit of *Artocarpus gomezianus* plant has been used in manufacturing ZnNPs (> 20 nm, spherical) and found their uses in luminescence, photocatalytic and antioxidant activities [75]. *Citrus medica* fruit was used for copper nanoparticle synthesis with size 20 nm and showing antimicrobial action [76]. *Lawsonia inermis* and *Gardenia jasminoides* leaf extract were used for hexagonal (21 nm) iron nanoparticle production [77]. In addition to the above nanoparticles, several other nanoparticles were also synthesized by using various plants exhibiting different shapes and sizes.

Synthesis of nanoparticles by using fungus: Approximately, 70000 species of fungi have been identified as a potential candidate to synthesize nanoparticles [78]. During the synthesis of nanoparticles from fungus, the biomineralization procedure was accomplished *via* reducing metal ions through intracellular and extracellular enzymes [79] (Fig. 3). Commonly *Aspergillus*, *Rhizopus*, *Fusarium*, *Verticillium*, *Trichoderma* and *Penicillium* species have been used for biosynthesis of nanoparticles [78]. Where, the basic principle is exchange of the electron from a donor molecule to the ion responsible for the precipitation of nanoparticles. Various biomolecules and secondary metabolites found in fungus species *viz.,* flavonoids, saponins, alkaloids, tannins, carboxylic acids, steroids, peptides, vitamins, enzymes, amino acids, polysaccharides, quinones have potential to exchange electron [80]. Further, certain enzymes of fungus species (phytochelatin, glutathione reductase FAD-dependent and α-NADPH dependent nitrate reductase) have potential to reduce ions of hazardous metal and to produce nanoparticles [81]. Many microorganisms, including fungi produce nanoparticles either intra- or extracellularly.

Intracellular synthesized fungal nanoparticles: This method encompasses ion transport internally into microbial cells due to prevalence of enzymes and produces nanoparticles.

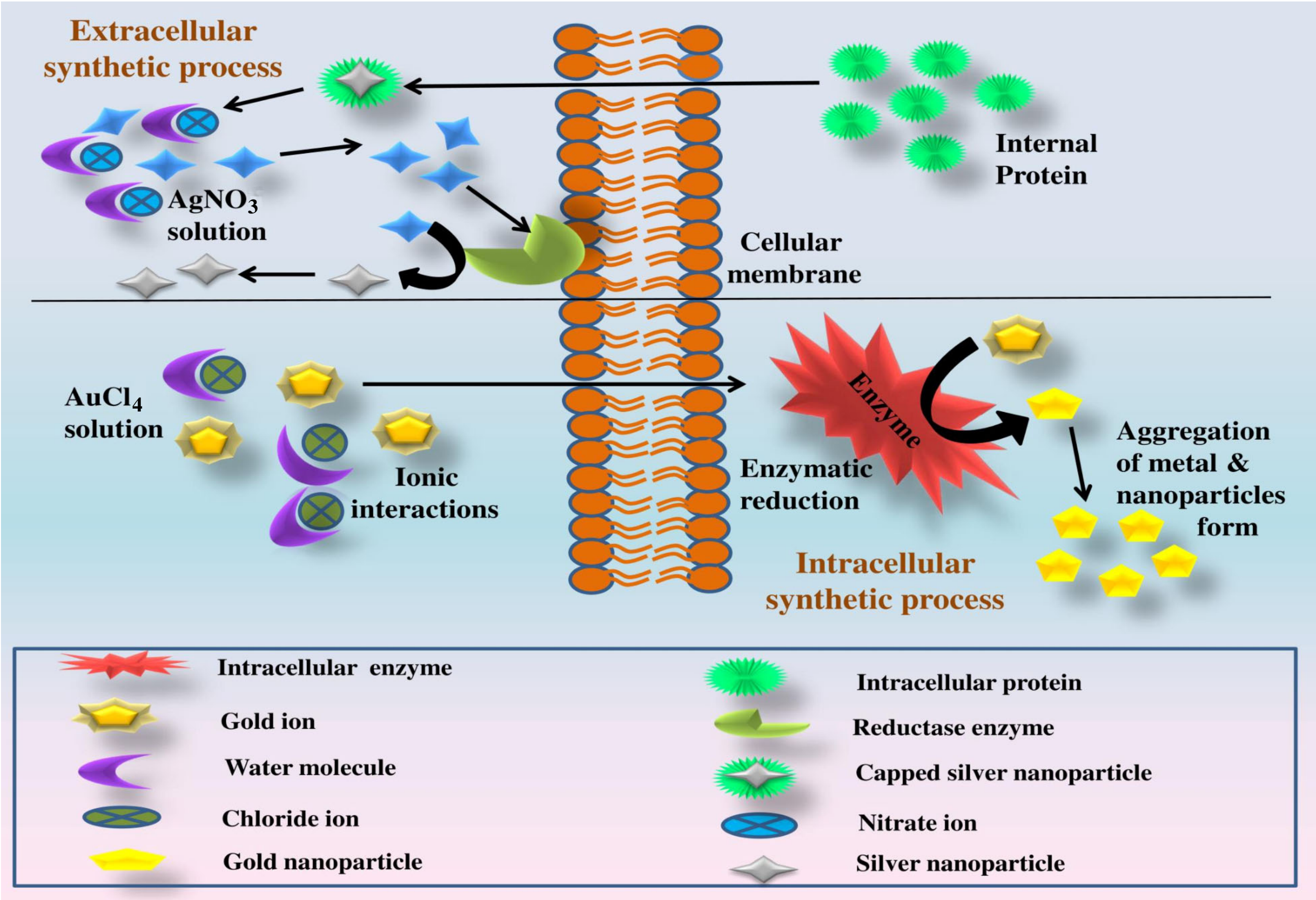

Fig. 3. Mechanism of extracellular and intracellular synthesis of nanoparticles by using various fungal species [82]

An intracellular level synthesis of nanoparticles creates a concern like a cellular component contiguous within the body and implicates transport of a particular ion in the microbial cells, where cell wall of the microorganism plays a significant role. An electrostatic force generates because of opposite charge of cell wall (-ve charge) and metal ions (+ve). The metal ions reduce into nano form of metal and diffused off through the cell wall due the available enzyme of cell wall in microorganism [82]. The nanoparticles produced inside an organism may be smaller in size due to enzymatic activity and other situations. The nanoparticles' size is conceivably correlated to particles nucleating into the body of a microbial cell. *Rhodopseudomonas capsulate* and *Rhodococcus* sp. have been used to synthesize AuNPs; while *Morganella* sp., *Plectonema boryanum*, *E. coli* K12, *Geobacillus* sp. strain ID17 to synthesize AgNPs; *Lactobacillus* strains used for both Ag and AuNPs, *Pseudomonas stutzeri* to Ag & Cu; *Clostridium thermoaceticum* to Cd and *Escherichia coli* to Pd, Pt nanoparticles intracellularly [49,83].

Extracellularly synthesized fungal nanoparticles: The extracellular manufacture of nanoparticles has become more significant to intracellular synthesis. In particular, the nitrate reductase enzyme assists in the process of bioreduction of metal ions for the synthesis of metallic nanoparticles (MNPs). Fungi are well recognized to form nanoparticle extracellularly because inside the cell more enzymes and secretory components are present which take part in the reduction of nanoparticle size and capping formation of nanoparticles, due to this reason intracellularly synthesized nanoparticles size was found reduced than extracellularly formed nanoparticles [84].

AgNPs have been extracellularly synthesized by diverse fungi *viz.*, *Trichoderma viride*, *Aspergillus flavus*, *Phyllanthus amarus*, *Fusarium culmorum*, *Pediococcus pentosaceus*, *Rhizopus nigricans*, *Pestalotia* sp., *Fusarium semitectum, Trichoderma aspercellum*, *Pleuratus sajor caju*, *Phoma infestans*, *Penicillium fellutanum*, *Phaenerochaete chysosporium*, *Aspergillus oryzae*, *Neurospora oryzae*, *Thraustochytrium* sp., *Volvariella volvacea*, *Penicillium Citrinum*, *Colletotrichum* sp., *Fusarium solani*, *Agaricus bisporus*, *Cladosporium cladosproides*, *Verticillium luteoalbum*, *Phoma glomerata*, *Trichoderma harzianum* and *Coriolus versicolor* [85].

While *Stenotrophomonas malophilia*, *Rhodopseudomonas capsulate*, *Lactococcus garvieae*, *Arthrobacter gangotriensis*, *Pseudomonas aeruginosa*, *Bacillus thuringiensis*, *Rhodococcus* sp., *Thermomonospora* sp., *Cornebacterium* sp., *Ureibacillus thermosphaericus*, *Lactobacillus* strains, *Pyrobaculum islandicum* have been used in synthesis of AuNPs extracellularly.

Trichoderma viride was explored to synthesize CdS, *Fusarium culmorum* to Pb, Cu; *Hypocrea lixii*, *Trichoderma harzianum* to Cu; *Pediococcus pentosaceus* to Pt; *Helminthosporum solani* to Pt, Zn, Cu; *Phoma glomerata* to Pb, *Alternaria alternate* to Cd; *Cochlibolus lunatus* to Cu, Al; *Aspergillus oryzae*, *Thraustochytrium* sp. to Zn; *Fusarium oxysporum* to Ni nanoparticles extracellularly [60,85,86].

Nimble creation of silver nanoparticles: Various methods have been explored for the synthesis of silver nanoparticles using different plant extracts and microorganisms. The silver nanoparticles are synthesized from several ubiquitous fungi species including *Fusarium*, *Rhizoctonia*, *Penicillium*, *Pleurotus*, *Trichoderma*, *Aspergillus*, *etc*. Beside above, *Trichoderma virde*, *T. reesei*, *F. oxysporm*, *F. semitectum*, *F. solani*, *A. niger, A. flavus*, *A. fumigatus*, *A. clavatus*, *Pleurotus ostreatus*, *Penicillium brevicompactum*, *P. fellutanum*, an endophytic *Rhizoctonia* sp., *Epicoccum nigrum*, *Chrysosporium tropicum* and *Phoma glomerata* have been used to synthesize AgNPs. The intracellular synthesis of silver nanoparticles was executed in *Verticellum* species as well as in *Neurospora crassa*. Looking at their broad implementation in many spheres, it is paramount to facet environmentally sound AgNPs [86].

Synthesis of gold nanoparticles A variety of fungal species have been utilized as a provenance of gold nanoparticles. The gold nanoparticle synthesis has been examined using various fungi such as *Aspergillus, Fusarium*, *Neurospora*, *Verticillium* and yeasts. Extracellular synthesis of gold nanoparticles was established through the extract of fungi *Aspergillus niger*, *Fusarium oxysporum* and *Candida albican* fungi. *Verticillum* species and some *Candida* species are also used to synthesize AuNPs intracellularly. Additional fungal species such as *Lentinula edodes*, *Penicillium* species were used for the production gold of nanoparticles [49].

Miscellaneous fabrication of nanoparticles: Various fungi have been used for the fabrication of diverse nanoparticles *i.e.* titanium, cadmium sulfide and selenide nanoparticles. Moreover, various fungi (*Mucor javanicus*, *Fusarium oxysporum* and *Verticellum* species) were used to synthesize various other metal nanoparticles apart from Ag and AuNPs. Few quantum dots of cadmium selenide were also developed by *Fusarium oxysporum* and selenium nanosized particles by *Alternaria alternate*. Titanium nanoparticle was synthesized with *F. oxysporum*, *A. flavus* and *S. cereviseae*. In addition to this, *F. oxysporum* was used in the synthesis of platinum nanoparticle, barium titanate nanoparticle, bismuth oxide nanoparticle, silica nanoparticle and strontium carbonate crystals. *Candida glabrata*, *Trametes versicolor* and *Schizosaccharomyces pombe* have been used to synthesize the cadmium sulfide nanoparticles. The white-rot fungus *Phanerochaete chrysosporium* has been entrenched to synthesize elemental selenium nanoparticles [87].

Algal nanoparticle synthesis: Several algae are as a source of variegated nanoparticles with three biogenic steps as preparation of algal solution by heating in distilled water or organic solvent, second is ionic metallic compounds preparation based on the molar concentration and third is the incubation of both algal solution and ionic compound solution with constant stirring for a conclusive period in control condition [88]. The nanoparticle synthesis by algae depends on the dose given and the type of algae used in the synthesis. It takes fugitive time for the synthesis than other biogenic gadgets. Hence, maneuvering of nanoparticles by algae has been paramount in the field of nanotechnology.

Synthesis of gold and silver nanoparticles: A large number of algae (*Sargassum wightii*, *Fucus vesiculosus*, *Turbinaria conoides* and *Stoechospermum marginatum*) have been used in fabrication of silver nanoparticles. The use of nanoparticles synthesized by algae is gaining importance because of their various pursuits like antiseptic, antifungal, antibacterial and anticancer. *Chaetomorpha linum*, *Ulva faciata*, *U. reticulata* and *Enteromorpha flexuosa* have employed for biogenesis of disparate AgNPs [89]. The marine algal species are promisingly useful for the synthesis instead of other species. *Spirulina platensis* are also used to synthesize crystallized silver nanoparticles [90]. Menon *et al*. [91] used an edible blue-green alga (BGA) *Spirulina platensis* for silver and gold bimetallic nanoparticles and also silver, gold nanoparticles individually. Marine algal synthesized AgNPs has coherent against *Klebsiella* sp, *Escherichia coli*, *Pseudomonas aeruginosa* and *Proteus vulgaris*.

Chlorella vulgaris has the capability to bind tetrachloroaurate ions and turn out into gold nanoparticles due to algal reducing property. Nearly, 90% of algal-bound gold nanoparticles have metallic and crystal assemblage in inner and outer surface of their cell membrane because of tetrahedral, icosahedral and decahedral organizations. The intracellular synthesis of AuNPs has been delineated in *Tetraselmis kochinensis* and brown alga *Fucus vesiculosus*. Additionally, several seaweeds and microalgae like *Navicula atomus* and *Diadesmis gallica* have been found proficient to produce AuNPs and nano-complexes of silica and gold. The biomedical solicitation of algal-synthesized nanoparticles encompasses antibacterial, anticancer, antifungal and wound healing activity. Synthesis of copper oxide nanoparticles by using brown algae *Bifurcaria bifurcate* showed antibacterial activity against Gram-negative (*Enterobacter aerogenes*) and Gram-positive bacteria (*Staphylococcus aureus*). Some specific microalgae have been found feasible to produce assorted nanoparticles *viz*., silver, gold, platinum and cadmium [89]. The various source of nanoparticle synthesized by biologically available materials has been presented in Table-1.

Feasibility of biosynthesized nanoparticle: The nanoparticles or other nanomaterials have become ground breaking in the current commercial applications. In the past decade, nanoparticles were well thought out due to their size-dependent physical and chemical assets. Currently, they have moved in a profitable assessment period [92].

Pharmacological application of biologically synthesized nanoparticles

Radiant opportunities in medical science: The simple or complex nanosized inorganic particles show unique properties, which illustrates an important material in the progress of innovative nano-devices [93]. Nanoparticles have precise emergent awareness in the field of nano-medicine because of their ability of precise drug delivery in the finest dosage range and increase the therapeutic efficacy of the drugs [94]. The efficient application of nanoparticles in cell imaging along with photothermal curative applications depends on optical properties of nanoparticles. The improvement of hydrophilic nanoparticles such as drug carriers has signified over the past few years as an important challenge. Iron oxide nanoparticle, super paramagnetic with accurate surface chemistry can be used for various purposes especially *in vivo* applications like MRI contrast enhancement, immunoassay as well as tissue repair purification of biological fluids hyperthermia, drugs delivery and cell split-up. Altogether, these biomedical applications with nanoparticles have ensured magnetization value [95].

Antibacterial activity and their action of mechanism: Silver nanoparticles were examined in pathogenic organism, these highly disrupting cell membrane polymer subunits. In bacterial system, there is disturbance in mechanism of protein synthesis as well as disruption in cell membrane because of repulsive action of nanoparticles [96]. The gold, silver nanoparticles and their interactions with bacterial cell membrane showed the cell cycle functions [97]. The silver nanoparticle by *Citrus sinensis* peel has played significant activity against *Staphylococcus aureus*, *Pseudomonas aeruginosa* and *Escherichia coli* [98]. The green synthesized metallic nanoparticle has additional potential in comparison to amphotericin

TABLE-1
UTILIZATION OF BIOLOGICAL MATERIALS FOR THE SYNTHESIS OF VARIOUS NANOPARTICLES

S. N.	Plant sources	Common name	Used part	Nanoparticle	Size	Shape	Characterization	Ref.
1.	*Clitoria ternatea*	Butterfly pea	Leaf	Silver	20 nm	ND	UV-VIS, FTIR, SEM, XRD	[23]
2.	*Dianthus caryophyllus*	Clove pink	Flower [petal]	Silver	ND	ND	UV-VIS, FTIR, DLS, Chemiluminescence	[24]
3.	*Hyacinthus orientalis*	Hyacinth	Flower	Silver	ND	ND	UV-VIS, FTIR, DLS, Chemiluminescence	[24]
4.	*Pelargonium graveolens*	Geranium	Leaf	Silver	16-40 nm	ND	UV-vis, TEM, FTIR, XRD	[25]
5.	*Pinus brutia*	Turkish pine	Bark	Silver	10-40 nm	Spherical	UV-vis, TEM	[26]
6.	*Abutilon indicum*	Kanghi	Leaf	Silver	106 nm	ND	UV-vis, FTIR, XRD	[27]
7.	*Pelargonium*	Geranium		Silver	1-10 nm	ND	TEM, EDS	[29]
8.	*Datura stramonium*	Datura	Leaf	Silver	16-40 nm	ND	UV-vis, TEM, EDS	[30]
9.	*Dioscorea bulbifera*	Air potato	Tuber	Gold	ND	Triangle, hexagon	UV-vis, FTIR, XRD, DLS, FSEM-EDS	[31]
10.	*Melia azedarach*	Neem	Leaf	Silver	18-30 nm	Spherical	DLS, SEM, XRD, FTIR, zeta potential	[33]
11.	*Eclipta prostrata*	False daisy	Leaf	Silver	35-60 nm	ND	UV- vis, SEM, TEM, XRD, FTIR	[34]
12.	*Eucalyptus globulus*	Blue gum	Leaf	Silver	1.9-4.3 nm	ND	UV-vis, XRD, TEM, SEM-EDX, FTIR, TGA analysis	[35]
13.	*Syzygium cumini*	Black plum	Bark	Silver	20-60 nm	Spherical	UV-vis, AFM, SEM	[36]
14.	*Aloe barbadansis*	Aloe vera	Leaf	Silver	70.70 ± 22-192.02 ± 53 nm	ND	XRD, SEM	[37]

15.	*Ocimum sanctum*	Holy basil	Leaf	Silver	18 nm	Circular	UV-vis, AAS, XRD, TEM, DLS, FTIR	[38]
16.	*Ocimum sanctum*	Holy basil	Leaf	Silver	29 nm	Face-centered-cubic	UV-vis, XRD, SEM, FTIR	[39]
17.	*Musa acuminata*	Banana	Peel	Silver	23.7 nm	Spherical	UV-vis, XRD, SEM, TEM, FTIR	[41]
18.	*Cinnamomu-m camphora*	Camphor wood	Leaf	Silver and gold	55-80 nm	Triangular or spherical	UV-vis, TEM, EDX, FTIR	[42]
19.	*Ficus benghalensis*	Banyan	Leaf	Silver	5-35 nm	Spherical	XRD, zeta potential	[43]
20.	*Cassia auriculata*	Matura tea	Leaf	Gold	ND	Spherical & triangular	TEM	[46]
21.	*Syzygium aromaticum*	Clove	Bud	Gold	4-150 nm	Polygonal & triangular	TEM	[46]
22.	*Allium cepa*	Onion	Bulb	Gold	~100 nm	Spherical and cubic	UV-visible, XRD, SEM, TEM	[47]
23.	*Phyllanthus amarus*	Bhui Amla	Leaf	Gold	65-99 nm	Hexagonal to spherical	UV-vis, TEM, FTIR	[48]
24.	*Coriandrum sativum*	Dhania	Leaf	Gold	7 to 58 nm	Spherical, decahedral, triangular	TEM	[49]
24.	*Terminalia chebula*	Black myrobalan		Gold	6-80 nm	ND	UV-vis, TEM	[50]
25.	*Cassia fistula*	Golden shower	Bark	Gold	55-98 nm	ND	UV-vis, SEM, FTIR	[52]
26.	*Beta vulgaris*	Sugar beet	Bulb	Gold	25 nm	Spherical	UV-vis, TEM, FTIR	[53]
27.	*Pelargonium graveolens*	Geranium	Leaf	Gold	16-40 nm	Decahedral, isohedral, triangular, rod	UV-vis, XRD, FTIR, TEM	[44]
28.	*Aloe barbadansis*	Aloe vera	Leaf	Gold and silver	70.70 ± 22-192.02 ± 53 nm	Triangles and spherical	SEM, XRD	[55]
29.	*Camellia sinensis*	Tea plant	Leaf bud	Gold	2.94-45.8 nm	Hexagonal	UV-vis, TEM, DLS, XRD	[56]
30.	*Chenopodium albums*	Wild spinach	Leaf	Gold	10-30 nm	Quasi-spherical	UV- vis, TEM, EDX, XRD, FTIR	[58]
31.	*Abutilon indicum*	Kanghi	Leaf	Gold	1-20 nm	Spherical	TEM, FTIR	[62]
32.	*Sauaeda monoica*	Saudea	Leaf	Gold	12.96 nm	Spherical	SEM, TEM, EDX, XRD, FTIR	[63]
33.	*Ipomoea carnea*	Glory plant	leaf, stem and root	Silver-gold bimetallic	3-40 & 10-100 nm	Triangular, hexagonal, polygonal, rod and truncated triangular	UV-vis, SEM, TEM, XRD, FTIR	[64]
34.	*Phoenix dactylifera*	Date palm	Leaf	Gold	32-45 nm	Spherical	TEM, FTIR	[65]
35.	*Sesbania grandiflora*	Vegetable humming-bird	Leaf	Gold	7-34 nm	Spherical	UV-vis, FE-SEM, TEM	[66]
36.	*Euphorbia prostrate*	Prostrate sandmat	Leaf	Silver, titanium	12.82 ± 2.50 nm	Spherical	UV-vis, XRD, AFM, FTIR, GC-MS	[70]
37.	*Citrus limon, Citrus reticulata and Citrus sinensis*	Lemon, Mandarin orange, Orange	Fruit juice	Gold	32.2 nm, 43.4 nm & 56.7 nm respect.	Prism and spherical	UV-vis, TEM, SAED, XRD, DLS	[69]
38.	*Ginkgo biloba*	Maiden hair tree	Leaf	Copper	15-20	Spherical	TUV-vis, TEM, EDS, FTIR	[71]
39.	*Cocos nucifera*	Coconut	Leaf	Lead	47 nm	Spherical	UV-vis, XRD, GC-MS, EDAX	[72]
40.	*Catharanthus roseus*	Cape periwinkle	Leaf	Palladium	40 nm	Spherical	UV-vis, TEM, XRD, GC-MS, FTIR	[73]
41.	*Musa acuminata*	Banana	Peel	Cadmium sulfide	1.48 nm	ND	XRD, TEM, FTIR	[74]
42.	*Artocarpus gomezianus*	Artocarpus	Fruit	Zinc	20 nm	Spherical	UV-vis, XRD, SEM, TEM	[75]
43.	*Citrus medica*	Fingered citron	Fruit	Copper	20 nm	ND	UV-vis, XRD	[76]
44.	*Lawsonia inermis & Gardenia jasminoides*	Henna & Gardenia	Leaf	Iron	21 nm	Hexagonal	TGA, FTIR, AFM, TEM, SEM, XRD	[77]

ND = Not determined

and fluconazole commercial antibiotics. Plant imitative silver nanoparticle caused membrane damage, fungal intracellular components and destroys of cell function in *Candida* species [99]. Azam *et al.* [100] investigated the potential of antimicrobial activity of various nanoparticles such as zinc oxide (ZnO), iron oxide (Fe_2O_3) and copper oxide (CuO) nanoparticles against Gram-negative bacteria (*E. coli*, *P. aeruginosa*) and Gram-positive bacteria (*S. aureus* and *B. subtilis*). The significant antibacterial activity was observed by ZnO NPs while Fe_2O_3 nanoparticles showed the fragile antibacterial properties. Mahapatra *et al*. [101] examined the antimicrobial activity of CuO NPs towards *K. pneumoniae*, *S. Salmonella paratyphi* and *P. aeruginosa*. It was concluded that nanoparticles cross the cell membrane of bacterial cell through the membrane receptor, diffusion and endocytosis, *etc*. which cause damage to the crucial enzymes and also interrupt the function of different cell organelles in bacteria, which further generate ROS and induces cell death (Fig. 4).

Antioxidant activity: There are numerous cellular damages for instance cancer, atherosclerosis and brain damage triggered by free radicals. ROS are producing free radicals for instance hydrogen radicals, superoxide dismutase and hydrogen peroxides. The bimolecular compounds as flavonoids, proteins, sugars, fatty acids, phenolic, glycoprotein and lipids are resilient to switch the free radical [102]. The silver nanoparticles showed the stronger potential compared to other commercial standards, *etc*. The tea leaf extracts contain flavonoids and phenolic substances hence nanoparticles synthesized from tea showed high antioxidant property [103].

Anticancer activity: Numerous diseases are produced by disturbance in enzymatic parameters and biochemical alterations in which one is cancer (an uncontrolled cell proliferation). The biosynthesized nanoparticle is used to control the overgrowth of cell and their mechanisms of cell system [104]. There are cancer cells *i.e.* Hela cell lines, HCT116, Hep 2, *etc*. which is regulated by nanoparticles. Several studies have recently recognized that plant derived nanoparticles control the tumor cell growth [105]. The plant derived silver nanoparticles regulate action of enzymes and cell cycle [106]. The normal cell function and cell proliferation are induced by free radicals which can be controlled by green synthesized nanoparticles. Even though, the mild concentration of AuNPs may involve in an apoptosis machinery of malignant cell [107]. The cell metabolism is also regulated by AgNPs in the MCF-7 cancer cell. The different types metallic nanoparticles can be used in medical field and biosynthesized nanoparticles may resolve the malignant deposit [108].

Antidiabetes activity: In the blood, uncontrolled level of sugar is called as diabetes mellitus which is controlled by synthetic insulin, food and balanced diet, *etc*. At this time, green synthesized nanoparticles may be a marginal source of drug to resolution of diabetes mellitus. Among various nanoparticles, AuNPs is a best agent for diabetic patients [109]. The AuNPs

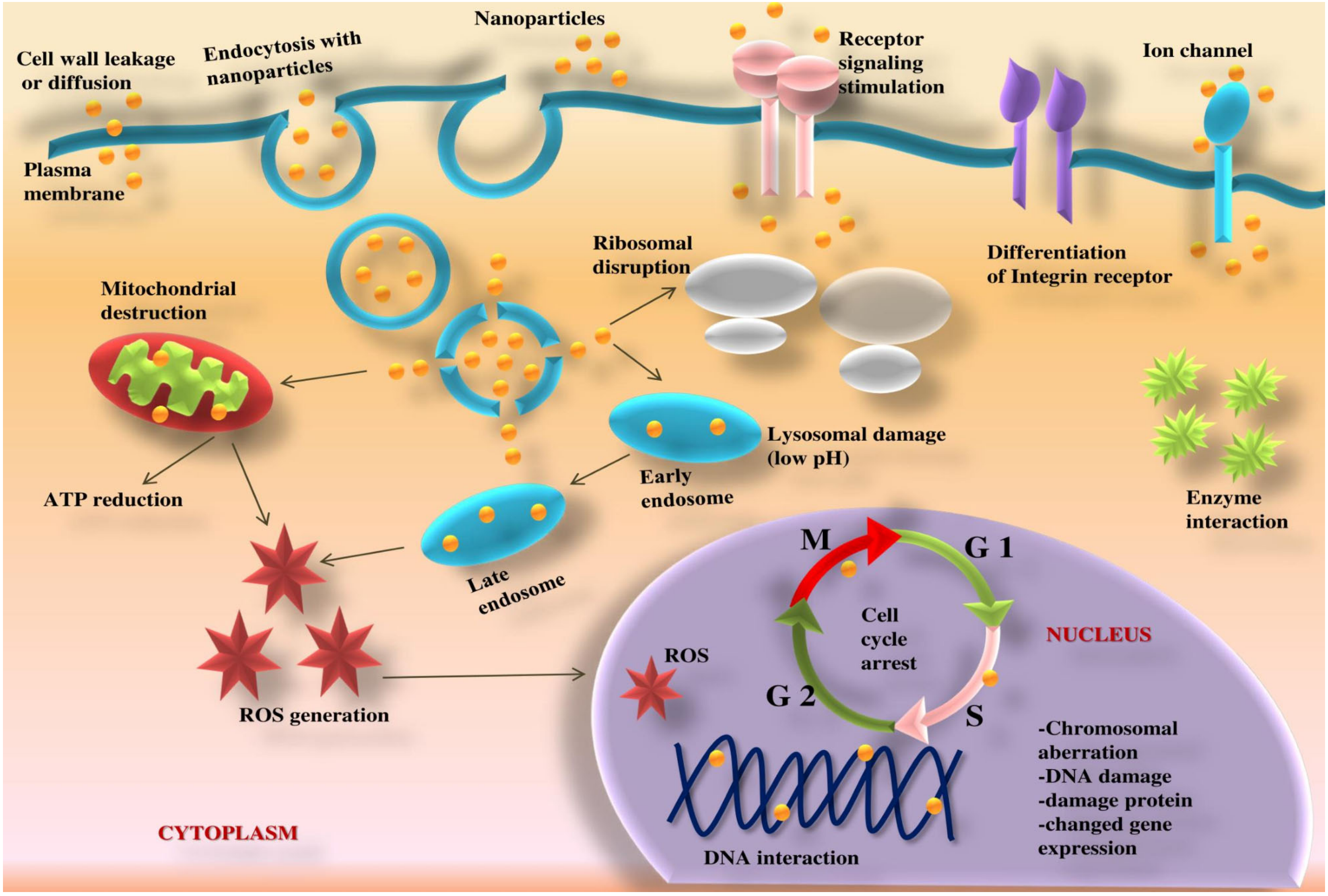

Fig. 4. Antibacterial activity of biologically synthesized nanoparticles and their mechanism of action on bacterial cell [100,101]

reduces the level of liver enzymes *e.g.* uric acid, serum creatinine, transaminase and alkaline phosphatase in diabetes mice. The decrease level of glycosylated haemoglobin was observed in treated gold nanoparticles and fetched it up to the normal range. In animal model, silver nanoparticles produced by *Sphaeranthus amaranthoides* repressed acarbose sugar [110] and α-amylase activity [111].

Antiviral effects: Plant derived nanoparticles take major role in controlling the viral pathogen growth. When virus enters the host cell, it spreads fast and rapidly because of their exponential multiplication, green synthesized AgNPs may resolve this problem. The reverse transcription mechanism in early stage of anti-HIV was efficiently performed by bio-AgNPs [112]. The biosynthesized metallic nanoparticles were bind with gp120 of viral membrane, as they have multiple binding sites for the virus. The biosynthesized nanoparticles worked against with the cell associated virus and cell free virus [113]. Furthermore, the gold and silver nanoparticles are found more effective in HIV-1 life post-entry stage cycle. Hence, the MNPs may act effectively for antiviral drug against various viruses, specifically retroviruses.

Commercial application of green synthesized nanoparticles

Cosmetics: The MNPs are being utilized as a preservative agent in cosmetic and pharma coating materials [114]. There are some nanoparticles like Au, Pt and Ag MNPs are mostly applied in soap, shampoo, detergent, shoes, *etc*. The chemically synthesized nanoparticles cause side effect, by reason of using of green synthesis nanoparticles is a substitute source for human health care.

Nutritional increments: Certain nanoparticles have been found as source of nutritional requirements during their growth and reproduction and to prevent skeletal abnormalities [115]. For example, application of green synthesized Mn_3O_4 as dietary supplements in freshwater prawn *Macrobrachium rosenbergii* has given significant results [115]. It improved the metabolic activities and antioxidant defending systems. It also improved glutamic pyruvate transaminase, glutamic oxaloacetate transaminase and antioxidants enzymatic activity. It has increased the body weight, over all development and survival of *M. rosenbergii*. It was recommended to use as a diet supplements for other aquatic animals [115].

Food engineering: The metallic nanoparticles are used for biosensors; these sensors are useful in industries for preserving the food products, they control the pathogens as well as cost effective. Nanosilver is useful for instrument coating because of its stability in heat and also no interaction in sample [116].

Environmental monitoring of biologically synthesized nanoparticles

Electrochemical sensing: The green synthesized MnO nanoparticle was used in an electrochemical sensing [117] for detection of *p*-nitrophenol. Their electrocatalytic activity showed a good low limit and sensitivity against detection to *p*-nitrophenol. It was recommended to use the green synthesized MnO nanoparticles in other chemical sensors too [117].

Waste water managements: In day to day life the use of nanoproducts are mounting rapidly. These eco-friendly nanoproducts are available in the market and are commonly being used in home made products, water purifier, facial cream, bone and tooth cements [118]. Platinum, silica and silver nanoparticles are used in cosmetics, personal care and as ingredients in perfumes, sunscreens, mouthwash, anti-aging creams, hair care and toothpastes [119]. Silica nanoparticles have been exploited in various commercial products including control of pest and in non-agricultural applications.

Dye degradation action: The active oxygen species ($O_2^{\bullet}$, O_2^-, $HOO^{\bullet}$ and OH^-) are accountable in degradation of dye into a less toxic organics [120]. A large number of environmental pollutants, carcinogenic agents and well non-degradable dyes are produced by paper and textile industries. The photocatalytic technique (Fig. 5) has been found effective in degradation of various dyes [121]. Manganese dioxide nanoparticle effectively degrades Safranin O and Congo red dyes. Green synthesized nanoparticles degrade Congo red dye in a short time in comparison to chemically synthesized nanoparticles. It may be due to difference in their size and shape [120]. The degradation of Safranin dye was observed through photocatalytic mechanism by using both green reduction and chemical reduction process.

Conclusion

The biological synthetic approaches of nanoparticles are turning out into the most important contrivance. In present scenario, an extensive life needs are required, which can be facilitated by using nanoparticles. The biosynthesized nanoparticles have been a crusader in medical science, especially in therapeutic analysis, diseased tissue imaging and drug delivery. The conclusive purpose of the study is to investigate those nanoparticles, which are not intended to obstruct the normal biology of the organism, but have extraordinary therapeutic index and also not hazardous to the environment. Numerous synthetically manufactured nanoparticles cannot be employed because of their safety testing upshots, which demonstrated them unfeasible in toxicological perspectives. The study advocates that the biogenesis of nanoparticles should be progressively considered as a prompt, eco-friendly and effortlessly ascended technology.

CONFLICT OF INTEREST

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

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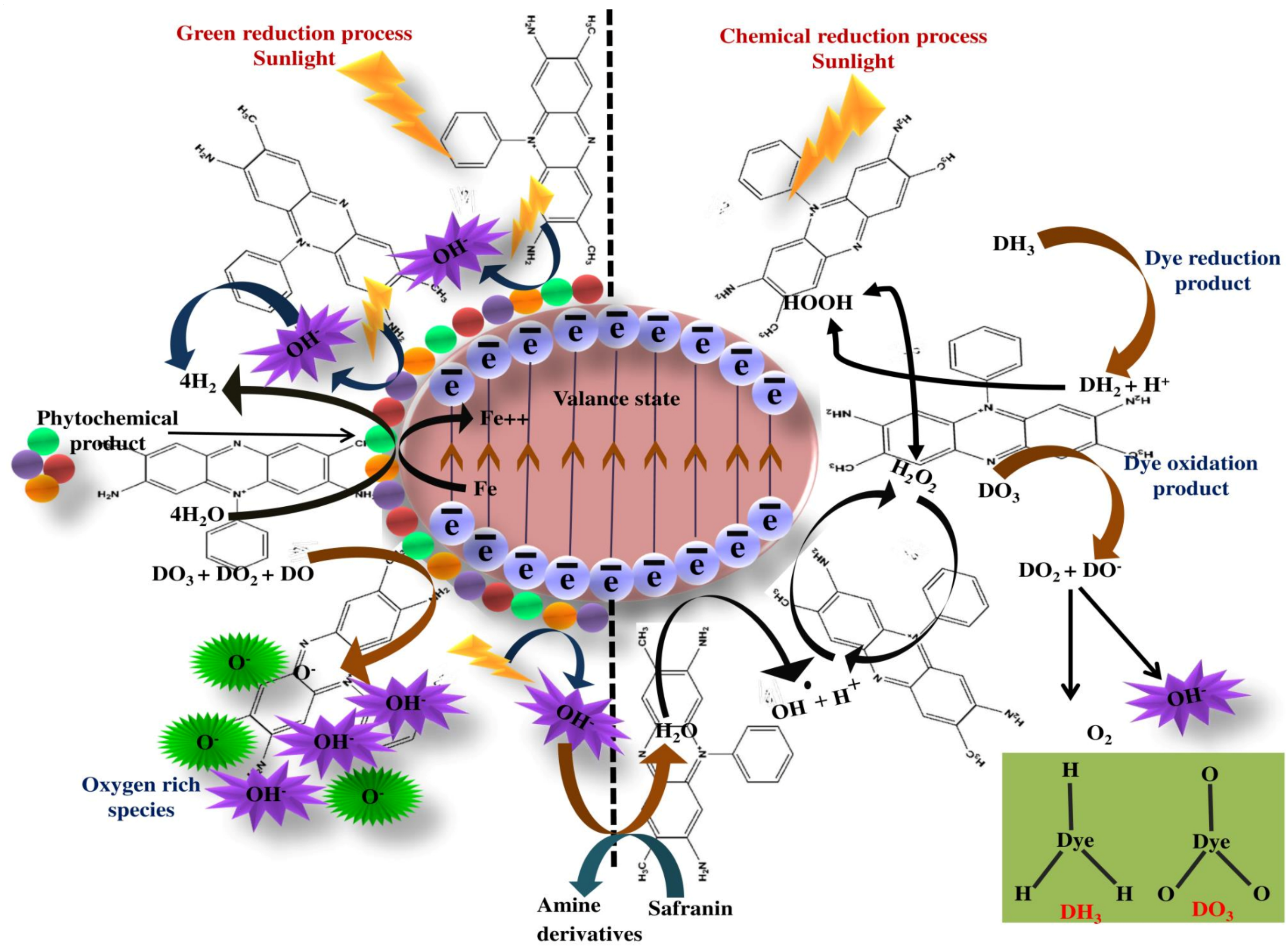

Fig. 5. Photocatalytic mechanism of Safranin dye degradation by biologically and chemically synthesized nanoparticles [121]

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