Advances in green synthesis of nanoparticles

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ABSTRACT
Nanotechnology is a developing branch of pharmaceutical sciences wherein the particles extend in nanosizes and turn out to be more responsive when contrasted with their unique counterparts. In the past numerous years, the utilization of synthetic concoctions and physical strategies were in mould; however, the acknowledgment of their toxic impacts on human well-being and condition influenced serious world view for the researchers. Presently, green synthesis is the watch word for the combination of nanoparticles (NPs) by plants or their metabolites. This innovation is particularly compensating as far as decreasing the poisonous quality caused by the conventionally integrated NPs. In this review, we cover the perspectives by which metal particles can be integrated from green methods in the perspective of green methods utilized in the NPs combination. In the green strategies, plant metabolites and natural substances are utilized to orchestrate the NPs for the pharmaceutical and other applications. Some characterization methods are also reviewed along with applications of NPs.

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Introduction
Nanotechnology is the branch of science which deals with the examination of materials in nanorange, generally between 1 to 100 nm. It is a science that works at the nanoscale and gives various focal points to the diverse fields of science like dentistry, pharmaceuticals and bio-engineering [1]. Green chemistry approach is significant for the future prospect of nanomaterials. This area of nanoscience should culminate in the development of safe, eco-friendly NPs and should have wide acceptance in the nanotechnology [2]. Solvents and reducing operators utilized for the reduction of the NPs have great effect on morphology of incorporated particles like their size, physicochemical properties, shape and this morphology impacts on the utilization of NPs. "Top down" and "bottom
up” are the two unique methodologies for the amalgamation of NPs. In top-to-bottom approach, suitable bulk material is broken down into smaller fine particles by size reduction using various techniques like grinding, milling, sputtering, thermal/laser ablation, etc. while in bottom-to-top approach, NPs are synthesized using chemical and biological methods by self-assembly of atoms to new nuclei, which grow into nanosize particles while the “bottom-up” methods include chemical reduction, electrochemical methods and sono-decomposition [3]. Several advances report development of metal NPs that preclude surfactant and any other chemicals [4]. The green synthesis from microbes, parasites, plants and plants extracts and so on are reviewed in the consequent segments of this review (Figure 1).

**Components of synthesis of NPs**

Distinctive natural specialists respond contrastingly with metal particles prompting the arrangement of NPs so the exact instrument for synthesis combination through organic methods shall have to be considered. For the most part, NPs are biosynthesized when the micro-organisms, plant extracts snatch target particles from their condition and afterward transform the metal particles into the NPs through the catalysts produced by the cells itself. It can be characterized into intra-cellular and extra-cellular amalgamation depending upon the area where NPs are framed (Figure 1).

**Methodologies of NPs synthesis**

**Chemical approach.** In the chemical approach, the main components are the metallic precursors, stabilizing agents and reducing agents (inorganic and organic both). Reducing agents such as sodium citrate, ascorbate, sodium borohydride (NaBH₄), elemental hydrogen, polyl process, tollens reagent, N,N-dimethylformamide (DMF) and poly(ethylene glycol)-block copolymers are used [5].

**Physical approach.** Physical approach for synthesizing NPs is mainly “top-down” approach in which the material is reduced in size by various physical approaches like ultra-sonication, microwave (MW) irradiation, electrochemical method etc. In this approach, a tube heater is utilized at barometrical weight for integrating NPs by evaporation condensation. Evaporation condensation and laser removal are the most essential physical methodologies. The source material inside a pontoon focused at the heater is vaporized into a bearer gas. Utilizing this dissipation build-up procedure different NPs of Ag, Au, PbS and Cd have been synthesized and reported already [3].

**Green approach for synthesis of NPs**

Traditional methods are used from past many years but researches have proved that the green methods are more effective for the generation of NPs with the advantage of less chances of failure, low cost and ease of characterization [6]. Physical and chemical approaches of synthesizing NPs have posed several stresses on environment due to their toxic metabolites. Plant-based synthesis of NPs is certainly not a troublesome procedure, a metal salt is synthesized with plant extract and the response is completed in minutes to couple of hours at typical room temperature. This strategy has attracted much more attention amid the most recent decade particularly for silver (Ag) and gold (Au) NPs, which are more secure as contrasted with other metallic NPs. Generation of NPs from green techniques can be scaled up effortlessly and they are fiscally smart too. In light of their exceptional properties the greenly orchestrated NPs are currently favoured over the traditionally delivered NPs. Use of more chemicals, which are harmful and toxic for human health and environment, could increase the particle reactivity and toxicity and might cause unwanted adverse effects on health because of their lack of assurance and uncertainty of composition [7]. Green methods of synthesis are significantly attractive because of their potential to
reduce the toxicity of NPs. Accordingly, the use of vitamins, amino acids, plants extracts is being greatly popularized nowadays [8].

**Systems for green synthesis of NPs**

**Green synthesis from enzymes**

Well-defined structure and available purity of enzymes makes them preferable for green method of synthesis, e.g. Ag NPs were utilized to be combined by an enzyme induced growth process on strong substrates in NPs synthesis. The enzymes were incorporated in polymer multilayer-assembled membranes through electrostatic interactions to develop the direct and “green” synthesis of bimetallic Fe/Pd particles in a membrane domain [9]. The generation of Au NPs utilizing extracellular amylase for the decrease of AuCl₄ with the maintenance of enzymatic movement in the complex has been accounted for. Reaction surface strategy and central composite rotary design (CCRD) were utilized to upgrade a fermentation medium for the generation of α-amylase by Bacillus licheniformis at pH 8 [10]. A sulphite reductase enzyme purified from the E. coli by using ion exchange chromatography was used to develop a cell-free extract for the Au NPs synthesis having antifungal activity against human pathogenic fungi [11]. The nanoparticles (NPs) can be synthesized from agro-waste like Cocos nucifera coir, corn cob, fruit seeds and peels, wheat and rice bran, palm oil, etc. These compounds are rich in biomolecules like flavonoids, phenolic and proteins that could act as reducing agent for the synthesis of NPs [12]. In a reported method of reduction of NPs with beet juice the authors found that on decreasing the amounts of beet juice, larger size Ag NPs were obtained, which also showed much greater catalytic activity and stability than those prepared with NaBH₄ for the transformation of 4-nitrophenol to 4-aminophenol [13]. Green tea extracts were used to get bimetallic NPs of Fe/Pd for the first time as the extracts of green tea can act as both reductive as well as capping agent also [14]. Au NPs functionalized mediated with a redox enzyme can perform as an electron transmitter between the biocatalyst and the electrode and accordingly give a hybrid electrically dynamic biomaterial that can be utilized in different sensors applications [15].

**Green synthesis from vitamins**

Green combination of Ag and palladium nano-spheres, nanowires and nano-rods by utilizing vitamin B₂ (as reducing and capping agents) has been reported. The vitamin B₂ is used as the reducing agent for the synthesis of the nanowires and nanorods. This is a unique approach, in the field of green nanotechnology that suggests the use of natural agents in advancement of this field, for example their impact on different tumour cells [16]. Ascorbic acid is used as capping and reducing agent along with the chitosan as stabilizing agent due to the property of chitosan bonding with metal ions, NPs concentration is directly dependent on chitosan concentration used [17]. A simple method of developing NPs of uniform sizes produced by using ascorbic acid as the reducing and capping material is reported [18]. Water-soluble anti-oxidative agents like ascorbic acid further seem to be responsible for the reduction of Ag NPs in Desmodium triflorum. During glycolysis, plants produce a large amount of H⁺ ions along with NAD and acts as a strong reducing agent; this seems to be beneficial in the formation of Ag NPs [19].

**Microwave-assisted synthesis**

Nanowires, tubes and dendrites can be produced by altering the parameters like surfactants and metallic precursors and solvent. Spherical shaped nanomaterials can also be produced by this method [20]. Carboxyl methyl cellulose sodium is utilized as reducing and capping specialist for Ag NPs synthesis. Contrasted with general heating treatment, MW union is supportive of homogeneous heating and simple nucleation of noble metal NPs [21]. A fast NPs generation method (within few seconds) for the synthesis of Au, Ag, palladium and platinum in aqueous medium by MW irradiation method at 50 W is reported by using red grape pomace as a reducing agent [22].

**Bio-based methods**

Bio-based methods are more useful for the production of highly stable, well characterized and safer NPs than the chemical methods, which are usually not environmental friendly, less stable and not easy to scale up. There are few examples elucidated and elaborated in further sections of the review.

**Bacteria and actinomycetes**

Shivaji et al. developed Ag NPs stable in dark place for 8 months by using cell-free culture supernatants of psychrophilic bacteria Pseudomonas antarctica, Pseudomonas proteolytica, Pseudomonas meridiana, Arthrobacter kerguelensis, Arthrobacter gangotriensis, Bacillus indicus and Bacillus cerebensis [23]. Simon Ag suggested that particular gene is responsible for Ag resistance in bacteria and these bacteria can replace the use of Ag in case of burn to reduce chances of the Ag toxicity [24]. Silver nano-crystals of different compositions were successfully synthesized by Pseudomonas stutzeri AG259 [25] (Figure 2).

**Yeasts and fungi**

Silver nitrate was transformed into Ag oxide, forming well-dispersed NPs, by the action of F. oxysporum metabolically. The introduction of Ag particles to F. oxysporum, brought about the release of nitrate reductase ensuing development of exceedingly stable Ag NPs in solution [26]. Nano-platinum has been incorporated by the culture filtrate of Alternaria alternata, and the platinum NPs were characterized by various spectroscopic investigations (particle size 2–30 nm, spherical and triangular found the O–H stretching, C–H stretching (proteins and other organic residues), amide I (polypeptides) amide III bands (the random coil of protein)) [27]. The synergistic action of selenium NPs and the fungal C. albicans was observed after combination of selenium NPs with chitosan and fungi was used as reducing agent [28]. Extracellular
biosynthesis of AgNPs from Ag nitrate solution is reported by the fungus *Trichoderma viride* [29]. *Fusarium oxysporum* has been used to develop very stable Ag NPs of sizes 5–15 nm [30].

**Algae**
Cyanobacteria and eukaryotic green development genera, for instance, *L. majuscule*, *S. subsalsa*, *R. hieroglyphics*, *C. vulgaris*, *C. prolifera*, *P. pavonica*, *S. Platensis* and *S. fluitans* can be used as cost effective materials for bio recovery of metal out of the liquid courses of action [31]. Uma Suganya et al. inspected green synthesis of Au metal NPs by using blue green development. The product of AuNPs was a direct result of the reduction of Au$^{3+}$ particles of chloroauric destructive to Au0 by *S. platensis* protein [32].

**Plants and phytochemicals**
Combination of NPs utilizing plants is extremely practical, and in this manner can be utilized as a monetary and important option for the expansive scale generation of NPs [33]. In an exploration of different antioxidant constituents of the extracts of blackberry, blueberry, turmeric and pomegranate, the pomegranate was found to have the ability to produce more uniform size and shape NPs of Au and Ag in the range of 20–500 nm. These NPs could be used for the management of cancer and the antioxidant therapy [34]. *F. herba* isolate was used to reduce the platinum compound, the closeness of hydrogen and carbonyl in polyphenolic compound mainly goes about as fixing expert for metal particles [35]. Formation of NPs could be completed in salt solution within short duration of time depending on the nature of plant extracts; the main reason being the concentration of the extracts, metal salt, pH and contact. It has been discovered that decrease of AgNO$_3$ to AgNPs by dihydroquercetin, quercetin and rutin prompted the development of an intensive surface plasmon resonance (SPR) band, which suggests reduction of this constituent [36]. Kou and Varma reported a simple, green and fast (complete within 5 min) approach for the construction of Ag NPs by MW irradiation using beet juice as a reducing reagent. The prepared material displayed good photocatalytic activity for the degradation of methyl orange (MO) dye [37].

**Metals synthesized from green synthesis**

**Copper (Cu) and copper oxide (CuO)**
Colloidal heat combination process is utilized to get CuO nanomaterials. The incorporated CuO was decontaminated and dried to acquire distinctive sizes of the CuO NPs [38]. Manoj et al. reported a method of developing a bio-sensor for the detection of nitrite ions in the medium, this method includes use of CMC as substrate for developing highly stable and sensitive nanocomposite of Cu [39].

**Zinc oxide (ZnO)**
*Cassia auriculata* blossom extract was utilized for the treatment of fluid arrangement of Zn(NO$_3$)$_2$ to combine stable ZnO NPs with normal size extents 110–280 nm [40]. Alijan et al. observed the normal size of ZnS NPs to be 8.35 nm while being exceptionally steady and overwhelmingly spherical ZnS NPs were orchestrated utilizing a characteristic sweetener glycoside (250–300 times sweeter than sucrose) in the aqueous rough concentrate of *Stevia rebaudiana* that went about as a great bio-reductant [41]. ZnO and Ag/ZnO NPs obtained through green synthesis are also useful in clinical antimicrobial wound-healing bandages [42].
Cerium oxide (CeO$_2$)

Rocca et al. investigated the antioxidant effects of CeO$_2$ NPs as a potential pharmaceutical approach for the treatment of obesity [43]. Moreover, besides possessing fast electron transfer kinetics, CNP is an excellent co-immobilization material for a variety of enzymes such as cholesterol oxidase, glucose oxidase and horseradish peroxidase [44]. Extract of Gloriosa superba leaf displayed excellent antibacterial properties; CeO$_2$ NPs were of spherical shape with an average size of 5 nm [45]. Miri and Sarani conducted the cytotoxic investigation of cerium oxide NPs (CeO$_2$-NPs) biosynthesized utilizing the aqueous extracts of ethereal parts of Prosopis farcta, and demonstrated that the biosynthesized particles were consistently and roundly formed with a size of around 30 nm [46].

Cadmium sulphide (CdS)

Cadmium sulphide quantum dots were developed from the plant synthesis of CdS NPs by Biomass of Fusarium oxysporum get dots of sizes ranges between 2–6 nm [47]. A MW assisted method was used to produce CdS NPs of Trichoderma harzianum, a common biofungicide, it produced 3–8 nm spherical wurzite CdS NP after 72 h of biomass incubation with cadmium chloride and sodium sulphide [48]. In a study of Escherichia coli and Klebsiella pneumonia (isolated from the stool of healthy volunteer’s samples) it was found they possess the ability to produce CdS NPs. This kind of microorganisms can be used for synthesis of NPs and heavy metal absorption for detoxification of environment [49].

Silver and gold

Silver and Au NPs have been broadly considered for use in applications in a different scope of fields (e.g. optoelectronics, catalysis, sensing, medicine, etc.). Honey can increase the reduction speed as the concentration is increased in the NPs solution, NPs formed with the mediation of honey are having special characteristics such as bio-sensing, anticorrosive, catalytic and antimicrobial activity [50]. Francis et al. prepared Au and Ag NPs using M. glabrata leaf extract from their respective metal salt precursors by MW assistance. They open a new area for water purification because of their tremendous antimicrobial activity inhibiting pathogenic microorganisms like Bacillus pumilus, Staphylococcus aureus, Pseudomonas aeruginosa, Escherichia coli, Aspergillus niger and Penicillium chrysogenum [51]. An economic method was developed to synthesize Ag NPs of smaller than 140 nm sizes by using two different microorganisms Bacillus subtilis 10833 and Bacillus amylolococus 1853, problem with this method was lack of reproducibility, time consuming process (48 h) and impurity issue at some extent [52]. Shen et al. revealed an investigation in which they reported combination of Au NPs from various microorganisms. They compared three different cell free extracts, i.e. bacteria Labrys sp., yeast Trichosporon montevidense, and filamentous fungus Aspergillus sp., selected for AuNPs and at the end of experiment they reported the average sizes of the NPs were 18.8, 22.2 and 9.5 nm, respectively. They found that the fungus showed better results as compared to others [53]. Gonnelli et al. described gold NPs (AuNPs) from concentrates of Cucurbitapepo L. takes off. The examination was completed at various plant ages, from one to four months, and the generation of NPs (in term of size, shape and yield) was dependent on the concentration of chlorophyll and carotenoids in the extracts [46]. A green combination of Ag NPs was created, utilizing a low-toxic system of microemulsion and nanoemulsion with castor oil as the oily phase, Brij 96V and 1,2-hexanediol as the surfactant and co-surfactant individually. Geranium (P. hortorum) leaf aqueous extract was utilized as a reducing specialist [54].

Characterization

After the synthesis of NPs it is must to ponder the morphology and other conformational subtle elements by utilizing different spectroscopic strategies. The most widely utilized systems are: UV–vis absorption spectroscopy, X-ray diffraction (XRD), Fourier transmission infrared (FTIR) spectroscopy, dynamic light scattering (DLS), energy dispersive X-ray examination (EDAX), scanning electron microscopy (SEM), transmission electron microscopy (TEM) and so on (Figure 3).

UV–visible spectroscopy

Arrangement of NPs from UV–visible spectroscopy can be studied due of their surface plasmon reverberation assimilation band because of the consolidated wavering of conduction band electrons on the surface of metal NPs in reverberation with light wave. Subhapriya and Gomathipriya reported the bio-reduction of Ag nitrate to Ag NPs and estimated occasionally by UV–visible spectroscopy [55].

FT-IR

FT-IR spectroscopy is conducted to discover data about the diverse utilitarian gatherings from the pinnacle positions in the range, FTIR spectroscopy is used to examine the property of functional groups or metabolites present on the surface of NPs, which might be responsible for reduction and stabilizing of NPs and information about capping and stabilizing of the NPs [56].

Figure 3. Characterization techniques.
High resonance SEM

New age of high-resolution SEM (HRSEM) permits a determination superior to anything 1 nm, moving towards the determination of TEM. With this procedure, it is conceivable to break down collaborations, for example, the adsorption and take-up of metallic NPs by cells. TEM and SEM examination clarifies the morphology and size of the resultant NPs. TEM results uncover that the Ag NPs are round and monodisperse.

XRD spectroscopy

X-ray diffractograms of nano-materials give an abundance of data from phase creation to crystallite estimate, from cross section strain to crystallographic introduction, XRD is non-contact and non-destructive, which makes it ideal for in situ studies [57].

Other techniques for characterization of NPs are EDS and DLS, the energy dispersive spectroscopy (EDS) is used to separate the characteristic X-rays of different elements into an energy spectrum, is used for detection of elemental composition of metal NPs. Dynamic light scattering analysis of incident photons is used to determine the surface charge and the hydrodynamic radius of the NPs.

Applications of green nanotechnology

From recent years, dramatic changes in the interest of researchers developed for the green nanotechnology and number of science publications are expanding ceaselessly. Green NPs have differing impact on the utilization of metallic NPs. They assume an imperative part to expanding the utility of NPs in pharmaceutical field particularly.

Agricultural engineering

Nanosized ligno-cellulosic materials are gotten from harvests and trees, which had opened-up another market for inventive and worth nano-sized materials and things. Nano-fertilizer, nano-pesticides intertwining nano-herbicides, nano-coating, etc. are the applicability of NPs in this field.

Dentistry

Ag-NPs have been utilized in dental instruments and swathes. Joining of Ag-NPs into orthodontic glue can increase or keep up the shear bond nature of orthodontic cement while expanding its confirmation from microorganisms.

X-ray imaging

AuNPs have pulled in the primary consideration as a X-ray differentiate specialist since it speaks to a high X-ray retention coefficient, simplicity of engineered control, nontoxicity, surface functionalization for colloidal dependability and focused on conveyance.

Drug delivery

The broad features of AuNPs, for instance, remarkable optical, physicochemical properties, biocompatibility, viable flexibility, controlled dispersity and nontoxicity make them a compelling nano-carrier in drug delivery systems (DDSs).

Conclusions

The conventional methods of developing NPs are costly and produce very toxic product, so the need of hour is to reduce the risk of toxicity in the environment from the different chemicals used in the physical and chemical methods. The alternate approaches found to develop NPs is “green synthesis”. In this review we have focused on the biological methods to synthesize NPs in which the microorganisms like algae, fungi and plants are included. The green NPs have numerous applications in different fields like dentistry, pharmaceuticals, bio-sensing and many others. Most of plant-based products can be generated locally using the native resources in the developing countries where exclusively that material may occur. As an example, folks in Africa can use sorghum barn (which even animals do not eat) but very rich in phenolic compounds and even does not require extraction–addition of water does it all. This review highlights the information on the biosynthesis of metallic NPs and their applications in the pharmaceuticals.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

[1] Rafique M, Sadaf I, Rafique MS, et al. A review on green synthesis of silver nanoparticles and their applications. Artif Cells Nanomedicine Biotechnol. 2017;45:1272–1291.
[2] Varma RS. Greener approach to nanomaterials and their sustainable applications. Curr Opin Chem Eng. 2012;1:123–128.
[3] Mathur P, Jha S, Ramteke S, et al. Pharmaceutical aspects of silver nanoparticles. Artif Cells Nanomedicine Biotechnol. 2017;46:1–12.
[4] Nadagouda MN, Varma RS. Green synthesis of silver and palladium nanoparticles at room temperature using coffee and tea extract. Green Chem. 2008;10:859–862.
[5] Zhang X-F, Liu Z-G, Shen W, et al. Silver nanoparticles: synthesis, characterization, properties, applications, and therapeutic approaches. IJMS. 2016;17:1534.
[6] Abdelghany TM, Al-Rajhi AMH, Al Abboud MA, et al. Recent advances in green synthesis of silver nanoparticles and their applications: about future directions. A review. Bionanoscience. 2018;8:5–16.
[7] Hussain I, Singh NB, Singh A, et al. Green synthesis of nanoparticles and its potential application. Biotechnol Lett. 2016;38:545–560.
[8] Baruwati B, Polshettiwar V, Varma RS. Glutathione promoted expeditious green synthesis of silver nanoparticles in water using microwaves. Green Chem. 2009;11:926–930.
[9] Smuleac V, Varma R, Baruwati B, et al. Nanostructured membranes for enzyme catalysis and green synthesis of nanoparticles. ChemSusChem. 2011;4:1773–1777.
[10] Manivasagan P, Venkatesan J, Kang K-H, et al. Production of α-amylase for the biosynthesis of gold nanoparticles using Streptomyces sp. MBRC-82. Int J Biol Macromol. 2015;72:71–78.
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[11] Gholami-Shabani M, Shams-Ghafarokhi M, Gholami-Shabani Z, et al. Enzymatic synthesis of gold nanoparticles using sulfite reductase purified from *Escherichia coli*; a green eco-friendly approach. Process Biochem. 2015;50:1076–1085.

[12] Adelere IA, Lateef A. A novel approach to the green synthesis of metallic nanoparticles: the use of agro-wastes, enzymes, and pigments. Nanotechnol Rev. 2016;5:567–587.

[13] Kou J, Varma RS. Beet juice utilization: expeditious green synthesis of noble metal nanoparticles (Ag, Au, Pt, and Pd) using microwaves. RSC Adv. 2012;2:10283–10290.

[14] Smuleac V, Varma R, Sidkar S, et al. Green synthesis of Fe and Fe/Pd bimetallic nanoparticles in membranes for reductive degradation of chlorinated organics. J Membr Sci. 2011;379:131–137.

[15] Virkutyte J, Varma RS. Green synthesis of metal nanoparticles: biodegradable polymers and enzymes in stabilization and surface functionalization. Chem Sci. 2011;2:837–846.

[16] Nadagouda MN, Varma RS. Green and controlled synthesis of gold and platinum nanomaterials using vitamin B2: density-assisted self-assembly of nanospheres, wires and rods. Green Chem. 2006;8:516–518.

[17] Shao Y, Wu C, Wu T, et al. Green synthesis of Fe and Fe/Pd bimetallic nanoparticles in membranes for reductive degradation of chlorinated organics. J Membr Sci. 2011;379:131–137.

[18] Ahmad N, Sharma S, Singh VN, et al. Biosynthesis of silver nanoparticles from *Desmodium triflorum*: a novel approach towards weed utilization. Biotechnol Res Int. 2011;2011:1.

[19] Ahmad N, Sharma S, Singh VN, et al. Biosynthesis of silver nanoparticles from *Desmodium triflorum*: a novel approach towards weed utilization. Biotechnol Res Int. 2011;2011:1.

[20] Mallikarjuna N, Rajender S. Greener techniques for the synthesis of silver nanoparticles using plant extracts, enzymes, bacteria, biodegradable polymers, and microwaves. ACS Sustain Chem. 2013;1:703–712.

[21] Li AY, Kaushik M, Li C-J, et al. One-step green synthesis of gold and silver nanoparticles with ascorbic acid and their versatile surface post-functionalization. RSC Adv. 2016;6:33092–33100.

[22] Baruwati B, Varma RS. High value products from waste: grape pomace extract and antioxidant potentials of some citrus fruit. Resour Technol. 2017;3:516–527.

[23] Ahmed A-A, Hamzah H, Maarof M. Analyzing formation of silver nanoparticles from the filamentous fungus *Fusarium oxysporum* and their antimicrobial activity. Turk J Biol. 2018;42:54–62.

[24] Sarkar J, Acharya K. *Alternaria alternata* culture filtrate mediated bioreduction of chloroplatinate to platinum nanoparticles. Inorg Nano-Metal Chem. 2017;4:47365–369.

[25] Lara HH, Guibisier G, Mendoza J, et al. Synergistic antifungal effect of chitosan-stabilized selenium nanoparticles synthesized by pulsed laser ablation in liquids against *Candida albicans* biofilms. UN. 2018;13:2697.

[26] Fayaz M, Tiwary CS, Kaliachelvan PT, et al. Blue orange light emission from biogenic synthesized silver nanoparticles using *Trichoderma viride*. Colloids Surf B Biointerfaces. 2010;75:175–178.

[27] Ahmad A, Mukherjee P, Senapati S, et al. Extracellular biosynthesis of silver nanoparticles using the fungus *Fusarium oxysporum*. Colloids Surf B Biointerfaces. 2003;28:313–318.

[28] Bakir EM, Younis NS, Mohamed ME, et al. Cyanobacteria as nano-gold factories: chemical and anti-myocardial infarction properties of gold nanoparticles synthesized by *Lyngbya majuscula*. Mar Drugs. 2018;16:217.

[29] Uma Suganya KS, Govindaraju K, Ganesh Kumar V, et al. Blue green alga mediated synthesis of gold nanoparticles and its antibacterial efficacy against Gram positive organisms. Mater Sci Eng C. 2015;47:351–356.

[30] Rastogi A, Zivcak M, Sytar O, et al. Impact of metal and metal oxide nanoparticles on plant: a critical review. Front Chem. 2017;5:78.

[31] Nadagouda MN, Iyanna N, Lalley J, et al. Synthesis of silver and gold nanoparticles using antioxidants from blackberry, blueberry, pomegranate, and turmeric extracts. ACS Sustain Chem Eng. 2014;2:1717–1723.

[32] Dobrucka R. Biofabrication of platinum nanoparticles using *Fumaria herba* extract and their catalytic properties. Saudi J Biol Sci. 2016;26:31–37.

[33] Veisi H, Azizi S, Mohammadi P. Green synthesis of the silver nanoparticles mediated by *Thymbra spicata* extract and its application as a heterogeneous and recyclable nanocatalyst for catalytic reduction of a variety of dyes in water. J Clean Prod. 2018;170:1536–1543.

[34] Ahmad N, Sharma S, Singh VN, et al. Biosynthesis of silver nanoparticles from *Desmodium triflorum*: a novel approach towards weed utilization. Biotechnol Res Int. 2011;2011:1.

[35] Alijani HQ, Pourseyedi S, Torkzadeh Mahani M, et al. Green synthesis of zinc sulphide (znS) nanoparticles using stevia rebaudiana bertoni and evaluation of its cytotoxic properties. J Mol Struct. 2019;1175:214–218.

[36] Khattari M, Varma RS, Zafarnia N, et al. Application of green synthesized Ag, ZnO and Ag/ZnO nanoparticles for making clinical antimicrobial wound-healing bandages. Sustain Chem Pharm. 2018;10:9–15.

[37] Rocca A, Moscato S, Ronca F, et al. Pilot in vivo investigation of cerium oxide nanoparticles as a novel anti-obesity pharmaceutical formulation. Nanomedicine. 2015;11:1725–1734.

[38] Charbgoor F, Ramezani M, Darroudi M. Bio-sensing applications of cerium oxide nanoparticles: advantages and disadvantages. Biosens Bioelectron. 2017;96:33–43.

[39] Arumugam A, Karthikeyan C, Haja Hameed AS, et al. Synthesis of cerium oxide nanoparticles using *Gloriosa superba* L. leaf extract and their structural, optical and antibacterial properties. Mater Sci Eng C. 2015;49:408–415.

[40] Miri A, Sarani M. Biosynthesis, characterization and cytotoxic activity of CeO2 nanoparticles. Ceram Int. 2018;44:12642–12647.

[41] Cárdenas S, Issell D, Gomez-Ramírez M, et al. Synthesis of cadmium sulfide nanoparticles by biomass of *Fusarium oxysporum* f. sp. *lycopersici*. JNANOR. 2017;46:179–191.

[42] Bhadwal AS, Tripathi RM, Gupta RK, et al. Biogenic synthesis and photocatalytic activity of CdS nanoparticles. RSC Adv. 2014;4:9484–9490.

[43] Elsalam SSA, Taha RH, Tawfeik AM, et al. Antimicrobial activity of bio and chemical synthesized cadmium sulfide nanoparticles. Egypt J Hosp Med. 2018;70:1494–1507.

[44] Balasouorya ER, Jayasinghe CD, Jayawardena UA, et al. Honey mediated green synthesis of nanoparticles: new era of safe nanotechnology. J Nanomater. 2017;2017:1.

[45] Francis S, Joseph S, Koshy EP, et al. Green synthesis and characterization of gold and silver nanoparticles using *Mussaenda glabrate* leaf extract and their environmental applications to dye degradation. Environ Sci Pollut Res Int. 2017;24:17347–17357.

[46] Ghouri I, Cristea D, Croitoru C, et al. Characterization and antimicrobial activity of silver nanoparticles, biosynthesized using *Bacillus* species. Appl Surf Sci. 2018;438:66–73.
Shen W, Qu Y, Li X, et al. Comparison of gold nanoparticles biosynthesized by cell-free extracts of Labrys, Trichosporon montevideense, and Aspergillus. Environ Sci Pollut Res. 2018;25:13626–13632.

Rivera-Rangel RD, González-Muñoz MP, Avila-Rodríguez M, et al. Green synthesis of silver nanoparticles in oil-in-water microemulsion and nano-emulsion using geranium leaf aqueous extract as a reducing agent. Colloids Surf A Physicochem Eng Asp. 2018;536:60–67.

Subhapriya S, Gomathipriya P. Green synthesis of titanium dioxide (TiO2) nanoparticles by Trigonella foenum-graecum extract and its antimicrobial properties. Microb Pathog. 2018;116:215–220.

Shankar S, Rhim J-W. Amino acid mediated synthesis of silver nanoparticles and preparation of antimicrobial agar/silver nanoparticles composite films. Carbohydr Polym. 2015;130:353–363.

Anandalakshmi K, Venugobal J, Ramasamy V. Characterization of silver nanoparticles by green synthesis method using Pedalium murex leaf extract and their antibacterial activity. Appl Nanosci. 2016;6:399–408.