Archives of Nanomedicine: Open Access Journal
DOI: 10.32474/ANOAJ.2023.02.000138
ISSN: 2637-6660

Review Article

Environmentally Safe Metallic Nanoparticles and their Medical Applications: Review

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Received: July 13, 2023 **Published:** August 15, 2023

Abstract

Metallic nanoparticles (MNPs) particularly the ones that are composed of silver, gold, copper, zinc, iron, and selenium revealed a noticeable role in medical applications like drug delivery systems, imaging, and therapeutic purposes. However, commercial production of these nanoparticles produces harmful byproducts to the environment and organisms. This is considered as a big limitation due to the increase in regulatory requirements to preserve environment. Therefore, the trend was shifted to focus on biosynthesis of MNPs and reduces the hazardous effect of many chemicals' byproducts of the industry. Consequently, MNPs that is synthesis using plant, bacteria, algae, and fungi emerged as an environmentally safe, cost-effective process for biomedical applications. Phytochemicals that exist in the biomaterial extracts, such as phenols, terpenoids, flavonoid, enzymes and cofactors are reducing agents for metal salts and stabilizing agents for the newly formed MNPs. This review describes the many types of metal nanoparticles and highlights their biosynthesis strategies. Furthermore, the review aims to discuss the applications of the biosynthesized nanoparticles fields in medical field, including drug delivery, anticancer and antimicrobial drugs, imaging systems and biosensor detectors.

Keywords: Nanotechnology, metal nanoparticles, plant, microorganism, and green chemistry

Introduction

Nanotechnology of inorganic particles is a promising field of research in which substance is controlled at the molecular level and it is an important approach in different medical fields and therapeutic activities [1,2]. Nanoscale structures have distinct features such as the particle size, charge and morphology [3]. Furthermore, nanoparticles have homogeneous sizes, shapes and controlled dispersity structure of approximately 1 to 200 nm in size [4]. Recently, inorganic nanoparticles became an essential part of drug delivery and imaging technology [5]. The surface to volume ratio of particles is inversely proportional to their size. Particularly metallic nanoparticles (MNPs) are of high importance due to their small size and large surface to volume ratio which lead to chemical and physical differences in MNPs properties compared to large particles of the same chemical composition [6,7]. Biological efficiency of MNPs can be improved by increasing the specific surface area due to the increase in their energy and catalytic activity [4,8,9]. These specific characters of MNPs i.e. morphology, size and concentration are usually examined using a Scanning Electron Microscope (SEM) [10] , Transmission Electron Microscope (TEM) and Dynamic Light Scattering (DLS) [11]. Additionally, differential Scanning Calorimetry (DSC) and X-Ray Diffraction (XRD) analysis predicts the crystalline phase of the prepared MNPs [11,12]. Since Middle Ages, the dissolved gold was recognized to have a curative power for many diseases such as dysentery, epilepsy, heart and tumors [13]. Gold and silver have exclusive physical, chemical, biological and optical features that are utilized in a range of applications and products [14]. These metals at the nanoscale molecular size offered great research opportunities in treatment and diagnosis of diseases due to their physicochemical nature [15].

The MNPs have significant antibacterial properties which are of important interest against resistant strains [16]. Moreover, zinc oxide and iron oxide have anticancer activity [19, 20]. MNPs were investigated in a range of immunotherapeutic treatments as a delivery system for immunomodulators [21]. MNPs were synthesized, modified and coupled with antibodies, ligands, and drugs which allow them to be applied in magnetic technologies, target analysis, targeted drug delivery, biotechnology and diagnostic imaging [22]. Several metallic nanoshells and nanocages were used as contrast agents such as, gold, iron oxides and silver nanoparticles in imaging sensory system due to their optic properties [23]. Generally nanoparticles are characterized by their size, shape, surface area, and poly dispersity [6]. Additionally, the formation of MNPs are confirmed by Ultraviolet-visible spectral analysis [24]. The MNPs were used to produce biosensors for imaging, diagnostic purposes, to detect pathogen and monitor the different stages of contaminant with low cost [25]. Platinum and palladium are broadly used in cosmetic products, medical health care and food packaging and other anti-bacterial applications [26]. Gold and platinum particles have a large surface area-to-volume ratio and high electron transfer processes which make them ideal entrants for applications as electrochemical sensor [27]. Gold and silver nanoparticles were found to have a broad antimicrobial activity, so they can be used as disinfectants in medical treatments [13, 28]. Silver, silica and platinum nanoparticles are used as ingredients in various products such as sunscreens, anti-ageing creams, toothpastes, mouthwash, hair care products and perfumes [29].

Modified silica nanomaterials are used as pesticide in a variety of applications. While, gold, silver and platinum nanoparticles are broadly used in various commercial products such as shampoo and detergents [30].MNPs were synthesized by different methods; physicochemical and biological. Biological method is performed using plants or biological systems. Plant derived nanoparticles produces safe byproducts with easy and simple techniques. Moreover, the cost of plant synthesized nanoparticles is relatively low [7, 31].The present review summarizes the types and synthesis methods of metal nanoparticles with emphasis on their biosynthesis in a simple, low cost and echo-friendly approach. Also, the review concentrates on the applications of the biosynthesized nanoparticles in a wide spectrum of potential fields of medical biology including catalysis, targeted drug delivery, cancer treatment, antibacterial agents and as biosensors detectors and imaging systems.

Synthesis of Metal Nanoparticles

In general, there are two strategies for MNPs synthesis: Bottom-Up and Top-Down methods (Figure 1). MNPs can be synthesized using chemical and biological methods by self-assembling atoms to new nuclei which grow into a particle of nanoscale. MNPs can be synthesized using chemical and biological methods by using bottom up approach using several techniques [32]. One of the biggest advantages of this method is that a large quantity of nanoparticles can be synthesized in a short period of time. Different organic and inorganic reducing agents are used in this method such as sodium borohydride (NaBH4), sodium citrate and others [33]. Accordingly, reducing agents are used for reduction of metals in aqueous or non-aqueous solutions before capping agents are used for size stabilization of the nanoparticles [34]. On the other hand, the top to bottom approach is suitable for bulk material break down into fine particles. MNPs can be synthesized using conventional methods: chemical and physical methods by size reduction with various techniques [35,36] (Figure 2).

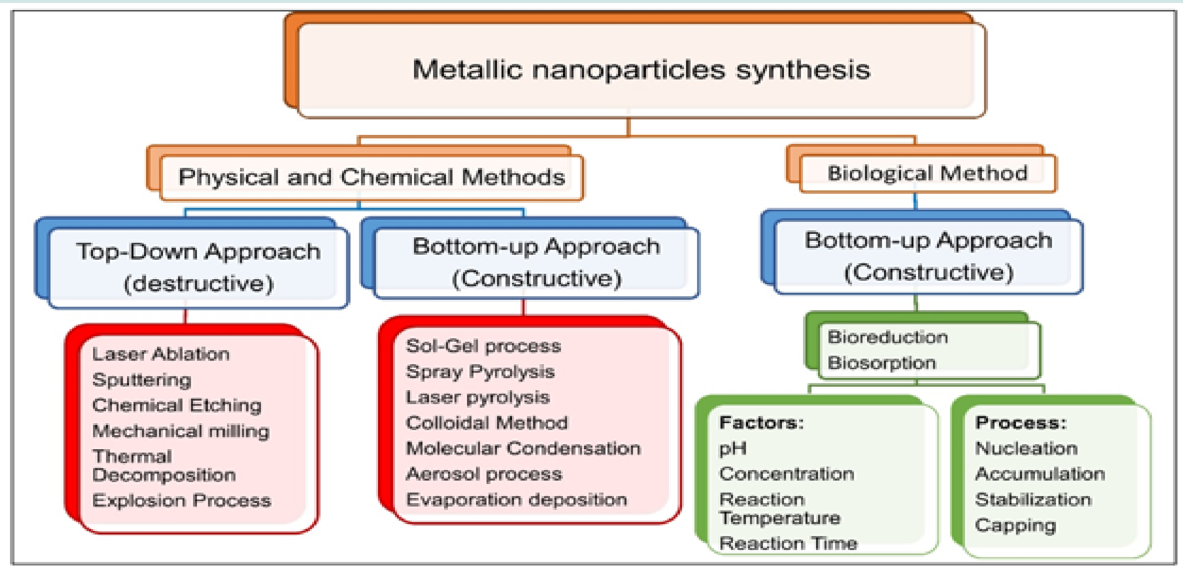

Figure 1: Approaches and methods of MNPs synthesis.

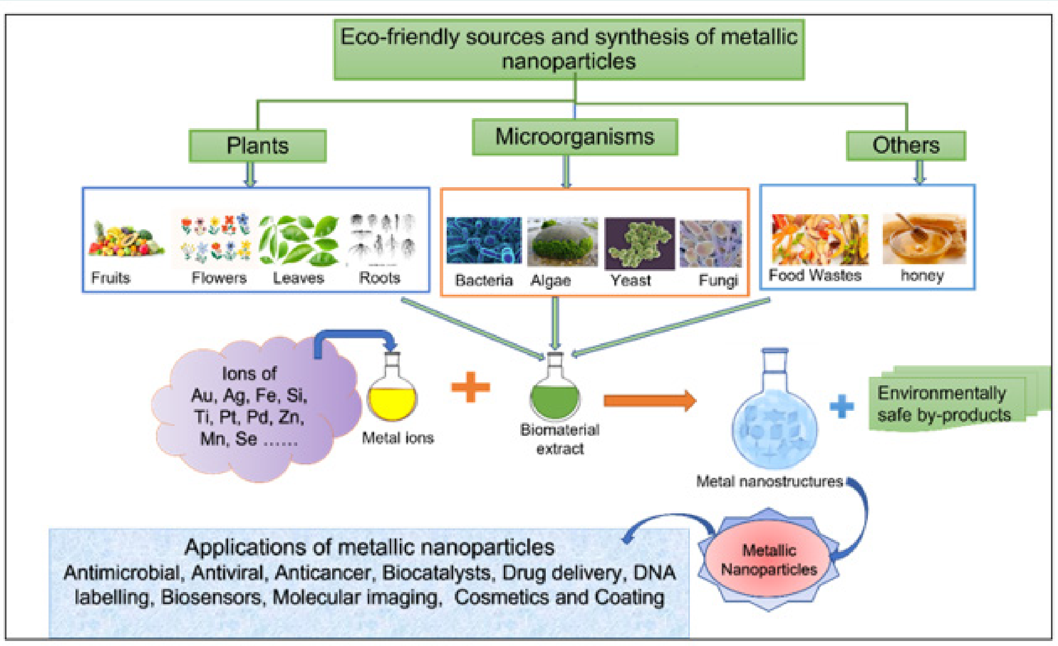

Figure 2: Illustration of various methods of MNPs and their applications.

Physicochemical synthesis of metal nanoparticles

Physical method (conventional method) includes, ball milling, diffusion flame, thermal evaporate, spray pyrolysis, plasma arcing ultra-thin films, , sputter deposition, and lithographic techniques synthesis of nanoparticles [37]. Whereas chemical methods include sol–gel tec, chemical solution deposition process, electrodeposition, chemical vapor, soft chemical method, Langmuir Blodgett method, catalytic route, hydrolysis co-precipitation and wet chemical method [38-40]. Since a long time, metal nanoparticles produced physically and chemically using high radiation and highly concentrated stabilizing agents that are harmful to the environment and living organisms [36,41].

Biosynthesis of metal nanoparticles

Biosynthesis of MNPs is an environmentally safe method inexpensive with low toxic wastes and applying green ecological processes [42]. The use of biomaterials such as plants, bacteria, fungi and marine organisms is an important source for the development of MNPs with improved safety profile [26]. Other biological methods that use eco-friendly resources like macroalgae (seaweed) and microalgae (cyanobacteria) [43]. The microbial enzymes or the plant phytochemicals with antioxidant or reducing properties are usually responsible for the reduction of metal compounds into their respective nanoparticles [6,44]. Biogenic metallic nanoparticle synthesis is two types: 1) bioreduction of metal ions into more stable forms concurrently with oxidation of an enzyme or biomaterials. 2) biosorption of metal ions from an aqueous or soil sample onto the organism itself without the input of energy. The metal ions bind to the cell wall of plants, bacteria, and fungi, and their peptides [45-47].

Physicochemical synthesis vs. biosynthesis of metal nanoparticles

The evaporation/condensation and tube furnace techniques were previously used to produce MNPs. Unfortunately, these techniques occupied a large space, need a lot of time to achieve thermal stability and increased the temperature around the source material [48]. In addition, a typical tube furnace requires high energy [28, 49].Moreover, the above mentioned technique result in the discharge of materials into the environment, particularly, the used chemicals were toxic and led to non-ecofriendly by-products. The major environmental receptors of nanomaterial and their byproducts are soil and water [50]. This is the main reason which takes the lead to the biosynthesis of nanoparticles via green methods that employ nontoxic chemicals and becomes environment friendly processes [51]. The synthesis of MNPs using biological objects like plant extract and microorganisms to as an alternative to chemical and physical methods in an ecofriendly manner has developed in a staggered pace in the recent years as an environmentally safe approach [52, 53]. Biological synthesis of nanoparticles is a single step bioreduction method with less consumption of energy [46]. Hence, there is an increasing demand towards phytochemistry and other biological processes to develop an ecofriendly approach which has several advantages such as reliability, simplicity and cost-effectiveness [9]. However, there is a significant variation in chemical compositions of plant extract from different parts of the world that may lead to different results in different laboratories. This is a major drawback of metallic nanoparticles production using plant extracts as reducing and stabilizing agents. In order to overcome this problem, plant biomolecules, which are responsible for mediating the nanoparticles production for rapid single step protocol, shoud be identified [32].

Plants Biosynthesis of Green MNPs

Biological synthesis using plants has been considered as a reliable and convenient method for the biosynthesis of nanoparticles. The plant biomass produces nanomaterials by a process called biomineralization and the metal accumulation process in plants has revealed that metals are usually deposited in the form of nanoparticles [54] [22]. Plant extracts are very cost effective and eco-friendly and thus can be an economic and efficient alternative for the large-scale synthesis of nanoparticles [22].The use of live plants, whole plants extracts and plants tissue for reducing metal salts to nanoparticles has attracted considerable attention during the past three decades [42]. Naturally, plants physiology has allowed the use of single part extracts or the whole plants in the synthesis of metallic nanoparticles [55]. The source of the plants extracts is known to influence the MNPs characteristics because different extracts contain varied concentrations and combinations of organic reducing agents [22].

Mechanism of plant produced green metallic nano particles

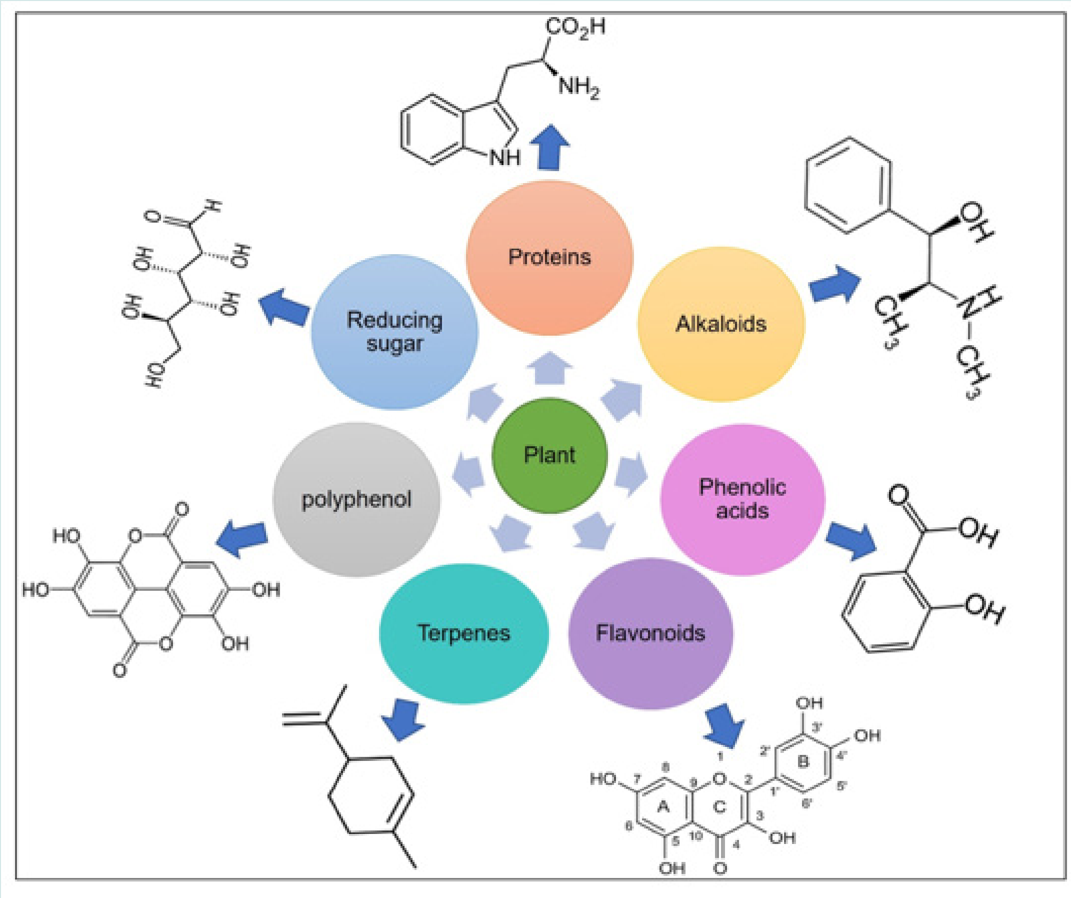

Figure 3: Schematic representation of the different plant constituents

The plant extract contains different biomolecules such as proteins, sugars, amino acids, enzymes and other traces of metals. Some plants express peptides or have a modified cell wall which binds to metal ions to form stable complexes in the form of nanoparticles [45] Plant crude extract contains secondary metabolites such as polyphenols, sugars, phenolic acid, flavonoids, alkaloids, terpenoids and proteins in which these compounds are mainly responsible for the reduction of metallic salts (metal ions) into MNPs [56] For example, quercetin is a flavonoid with a very strong chelating activity Figure 3 because it can chelate at three positions involving the carbonyl and hydroxyls at the C3 and C5 positions and the catechol group at the C3' and C4' site [57]. These groups chelate various metal ions such as iron, copper, zinc, palladium and cobalt. Once flavonoids adsorbed onto the surface of metals, they initiate metal nanoparticle formation (nucleation), aggregation, and bio reduction stage [58,59]. There are three phases of MNPs synthesis using plant extracts and plants; activation phase, growth phase, and termination phase [60]. When the time of the growth phase increases, nanoparticles accumulate to form a mixture of irregularly shaped nanoparticles. During the termination phase, nanoparticles develop into energetically favorable conformation; and this process influenced the plant extract capability to stabilize metal nanoparticles [61]. The size and shape of nanoparticles depend on their localization in the plant and possibility of nanoparticle movement and penetration into various tissues. These factors could influence the level of metal deposition around the existing nanoparticles, and the prospect of new nucleation events [3]. The variability in the size and shape of nanoparticles produced in the whole plants may prevent their usage. The ability of plants to reduce metal ions is limited, so the efficiency of metal nanoparticle synthesis depends on the electrochemical potential of an ion [54]. Thus, the ability of a plant extract to effectively reduce metal ions may be significantly higher in the case of ions having a large positive electrochemical charge than ions with a low electrochemical charge [62]. Brassica juncea and Medicgo sativa accumulate silver nanoparticles to a high level when grown on silver nitrate as a substrate [50,63,64]. Silver nanoparticles were biosynthesized by reacting the methanolic biomass of Eucalyptus hybrida leaf with aqueous solutions of silver nitrate at ambient temperature.

These greenly formed AgNPs were confirmed by UV–visible spectroscopy, X-ray diffraction patterns, Scherrer's formula and scanning electron microscopy (SEM) with Energy dispersive X-ray (EDX) patterns [51]. Generally, the proposed mechanism of biological synthesis of silver nanoparticles is the reaction of silver nitrate with plant extract [65]. The leaf extract of several plants were used to prepare gold and silver nanoparticles that have a size range of 10-30 nm. These spherical nanoparticles were observed at higher leaf extract concentration and were visualized using the transission electron microscope (TEM) imaging. Many examples of plant aqueous extracts like Azadirachta indica leaves [66] and natural rubber latex extracted from Hevea brasilensis [67] Bio reduction, in which metal ions are chemically reduced into more biologically stable forms. Many organisms can utilize dissimilatory metal reduction, in which the reduction of a metal ion is coupled with the oxidation of an enzyme. This results in stable and inert MNPs that can then be safely removed from a contaminated sample [55]. The bioreduction extract is simply mixed with a solution of the metal salt at optimum conditions of temperature, pH for completion of reaction [45]. It was found that the reaction rate and concentration of constituents control the shape and size of nanoparticles. Several nanoparticles were biosynthesized in different shapes like spherical, rod, cubic, triangle and also in different sizes [43]. These metabolites are strongly involved in the bioreduction process. The proposed reaction of positively charged metal ions (M+) were reduced into metallic (Mo) nanoparticles in the presence of metabolites and redox enzymes [68].

Biosorption mechanism of nanoparticle involves the binding of metal ions from an aqueous or soil sample onto the organism itself, such as on the cell wall, and does not require the input of energy. Certain bacteria, fungi and plants express peptides or have a modified cell wall which binds to metal ions, and these can form stable complexes in the form of nanoparticles [55]. Also, pure MNPs can be formed reduction of the metal ions by reducing sugars and terpenoids, which acted as stabilizing agents [69]. Saravana Kumar proposed a simple microwave method for green synthesis of highly stable Tamarindus indica AgNPs [70]. Muñoz et al performed a biosorption mechanisms of Ag+ for the synthesis of AgNPs by the biomass from Botryosphaeria rhodian which is a genus of pathogenic fungi in the family Botryosphaeria [71].

Effect of protein constituent of plant on MNPs biosynthesis

Proteins that exist in a plant extract may significantly affect the formation of nanoparticles. Protein's amino acid sequence and structure should be optimized for the efficient production of nanoparticles [54]. Tryptophan, tyrosine, arginine, and lysine possess superior ability to reduce metal ions. While peptides that consist of different amino acids are capable of strongly binding metal ions. They are poorly suited as biometrics for the synthesis of nanoparticles due to entropic effects. Peptides comprising amino acids that weakly bind tetrachloroauric acid ions, such as glutamic or aspartic acids, are inefficient in the synthesis of nanoparticles because of rapid dissociation of the peptide - metal ion complex [62]. Therefore, the most suitable peptides for the formation of metal nanoparticles contain amino acids with strong binding and reducing activity e.g., tryptophan [72].

Advantages of using plants for MNPs biosynthesis

There are many advantages of using plants for the synthesis of nanoparticles as they are easily available, safe to handle and contain plenty of metabolites that may help in reduction [37]. Various parts of a plant such as stem, root, fruit, seed, callus, peel, leaves and flower are used in the synthesis of MNPs in various shapes and sizes by biological approaches (Table 1). Biosynthesis reaction can be altered by a wide range of metal concentration and amount of plant extracts in the reaction medium, thus different sizes and shapes of the nanoparticles are derived from plants resources [52]. It is worth considering that nanoparticle formation using whole plant may be harmful to the plant, soil and environment.

Microbial Biosynthesis of Green MNPs

The biological reduction and mineralization of soluble metal ions to form nanoparticles are intrinsic actions of several bacteria to get rid of the metal ions toxicity. The microbial ability to exchange electrons was noticed many years ago [73]. Pantidos and Horsfall prepered an overview of some of the eco-friendly methods of biological metallic nanoparticle synthesis. They concluded that; bacteria are relatively cheap to cultivate and have a high growth rate compared to fungi or plants. However, fungi have the advantage of producing very high yields of secreted proteins, which may increase nanoparticle synthesis rate [55] Actualy, mycelia of fungi provide a much higher surface area than bacteria and this area could be used to support the interaction of metal ions and fungal reducing agent. Fungi also have the advantage when extracellular nanoparticles are produced, allowing for a more efficient way of extracting nanoparticles. Fungi can be used more easily in large-scale reactors than bacteria. Some examples of microorganisms synthesizing inorganic materials include magneto tactic bacteria for magnetite nanoparticles [74] Eukaryotic organisms such as fungi may be used to grow nanoparticles of different chemical compositions and sizes [9]. Bacteriophage, viruses that infect bacteria, were used in the development of metal with nanoscale features. Bacteriophages can be easily manipulated due to their simple structure [75].

Biosynthesis of Green MNPs using Food Waste and Honey

Table 1: Examples of biologically synthesized MNPs from the year 2018-2021.

#	Biological Source	Common name	Part used	Metal	References
1	Cassia auriculata	Matura tea tree	Leaves	SeNPs	[90]
				ZnONPs	[91]
2	Psidium guajava	Guava	Leaf	FeNPs	[92]
				CuONPs	[93]
3	Citrus sinensis.	Sweet orange	Peel	AgNPs	[77]
				Au NPs	[78]
4	Agathosma betulina	Buchu	Leaf	ZnONPs	[94]
5	Camellia sinensis	Green tea	Leaves	ZnONPs	[16]
				AgNPs	[95]
				MgONPs	[96]
				AuNPs	[97]
6	Ananas comosus	Pineapple	Fruit	Ag and Ag-Au core-shell NPs	[98]
7	Cassia auriculata	Matura tea	Flower	AgNPs	[99]
				ZnNPs	[91]
8	Curcuma_longa	Turmeric	root	CuO, NiO and Cu-Ni Bimetallic Hybrid	
					[100]
9	Lysimachia foenum-graecum-Hance	Ling xiang cao	Herbed	AgNPs	[101]
10	Bee	Insect	Honey	AgNPs	[83]
					[82]
					[102]
11	Bee	Insect	Honey	CaONPs	[81]
12	Thermophilic filamentous	Fungi	Extracellular, Intracellular and Autolysate extract.	AuNPs	[103]
13	Fusarium semitectum	Fungi	Extracellular,	SeNPs	[17]
14	Escherichia coli	Bacteria	Extracellular,	AgNPs	
15	Exiguobacterium aurantiacumm	Bacteria	Extracellular,	AgNPs	[104]
16	Brevundimonas diminuta	Bacteria	Extracellular,	AgNPs	
17	Escherichia coli	Bacteria	Extracellular,	AgNPs	[105]
18	Micrococcus yunnanensis	Bacteria	Extracellular,	AuNPs	[106]

19	Mycobacterium sp.	Bacteria	Extracellular,	AuNPs	[107]
20	Padina boryana	Brown Algae	Extract of whole organism	PdNPs	[108]
21	Galdieria sp	Microalga	Extract of whole organism	AgNPs, FeNPs, ZnNPs	[109]
22	Penicillium duclauxii	Yeast & Fungus	Seed borne	AgNPs	[110]
23	Passiflora edulis	Passion fruit	waste extract of peels	AgNPs, AuNPs	[76]
24	Medicago sativa	Alfalfa	Seeds	ZnONPs	[111]
25	Ceropegia bulbosa Roxb	Patadtumb-adi	Tuber	SeNPs	[19]
26	Bacillus megaterium	Bacteria	cell-free extract	SeNPs	[112]
27	Magnetospirillum magneticum AMB-1	facultative anaerobic bacterium	Genetic Tuning	Fe_3O_4NPs	[113]
28	Halobiforma sp.	Haloarcha-eon	Intracellular	Fe_3O_4NPs	[114]
29	M13 Bacteriophage	Virus	Protein	FeNPs	[115]
30	Tobacco mosaic virus	bulky Virus	Coat protein	AuNPs	[116]
31	Tobacco mosaic virus	bulky Virus	Coat protein	AuNPs PdNPs	[117]

Nguyen et al., declared that agricultural waste materials have been widely used for green synthesis of inorganic nanoparticles because they are environmentally safe with low cost. Therefore, they used Passiflora edulis peels waste for biosynthesis of silver and gold nanoparticles. The greenly synthesized AuNPs and AgNPs nanoparticles were found to have strong antibacterial (e.g., against Escherichia coli, Bacillus subtilis, and Staphylococcus aureus) and catalytic activity (e.g., reduction of nitrophenols and degradation of toxic organic dyes) [76] (Table 1). The utilization of the reductive potency of a common food wastes such as orange peel has been reported to prepare MNPs [76-78]. Lots of diverse wastes are produced every year which are harmfull to life. To solve the environmental problems and pollution; wastes can used in the synthesis of different metals and metal oxide nanoparticles and nano-fibers as ecofriendly and low-cost products [79]. Honey mediated green synthesis is a relatively novel concept used during the past few years to synthesize gold, silver, carbon, platinum, and palladium nanoparticles. Honey acts as both a stabilizing and a reducing agent and functions as a precursor in nanoparticle synthesis. This method usually requires room temperature and does not produce toxic byproducts. Honey mediated nanoparticles synthesis is a simple, cost effective, rapid, and safe method which provides valuable end products with numerous applications in diverse fields [80]. Many examples of MNPs were produced using honey i.e., Calcium oxide (CaO) nanoparticles were biologically synthesised using the honey of Trigona [81]. Also, AgNPs were synthesized using honey constituents [82,83] (Table 1).

Factors affecting the green synthesis of metallic NPs

The plant selection influences the rate of reaction in nanosynthesis and primarily depends on its ease of availability, medicinal importance, and presence of phytoconstituents. The selection of a relevant plant part is based on maximum phytochemicals availability [84]. Optimum concentration with maximum reducing potential should be taken into consideration during plant selection. The amount and the production rate are important [85]. An important stage in the formation of metal nanoparticles is the agglomeration of reduced metal atoms to nanoparticles. This process depends on many factors and determines several properties of a nanoparticle such as its size and shape. The smaller nanoparticles are produced faster [86]

Optimization of the bioreduction conditions in the reaction mixture is a critical factor. Particularly, the biocatalyst and substrate concentrations, pH, contact time, temperature and stirring speed should be controlled and optimized (Figure 4). As an example, pH, temperature, and incubation time of nanoparticles play a vital role in controlling the shape and size of the inorganic nanoparticles [53]. Temperature is one of the key factors dominating the size and shape of nanoparticles. With the increase in temperature, the rate of reaction also increased, which enhances the synthesis of nanoparticles, and consequently particle size decreases. It was reported that polydisperse particles with a size range of 5- 300 nm was obtained at lower temperature while a higher temperature supported the formation of smaller and spherical particles. pH also plays an important role in the biosynthesis of nanoparticles .The higher pH facilitates a large number of nanoparticles with smaller diameter [87]. Fungi and bacteria require a comparatively longer incubation time for the reduction of metal ions, while water soluble phytochemicals require much lesser time. Therefore, compared to bacteria and fungi, plants are better candidates for the synthesis of nanoparticles [88]. Whatever the choice of biological system may be used; bacteria, fungus, plant, or others, all MNPs need to be studied carefully and the risks of such nanoparticles must be assessed [89].

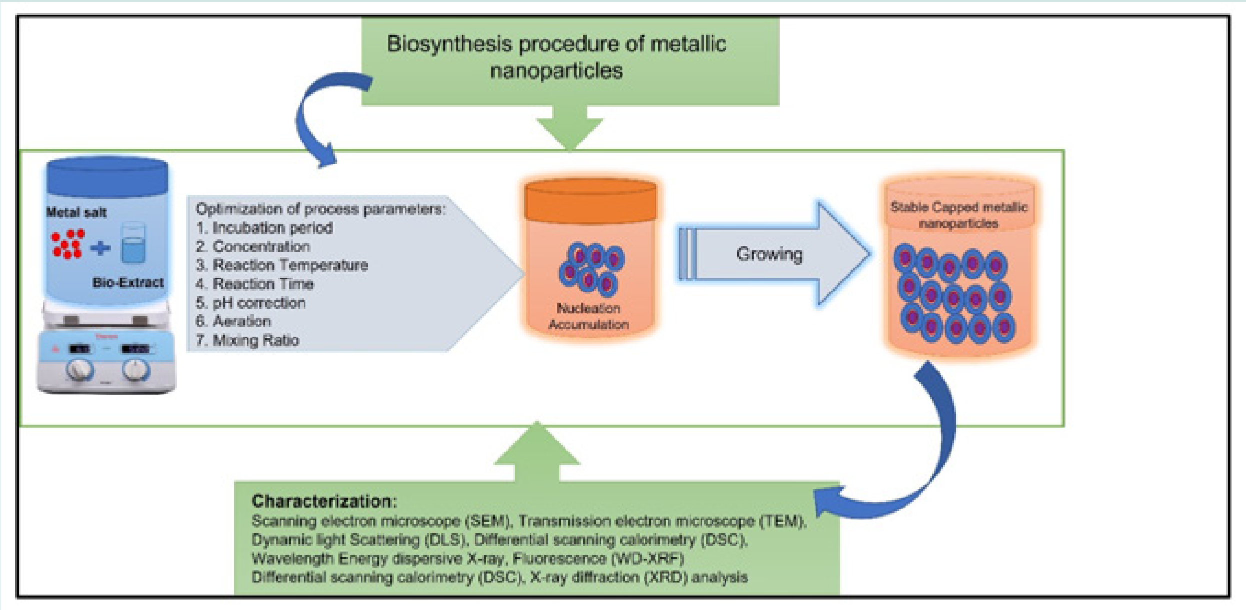

Figure 4: Scheme of mechanism and characterization of MNPs.

Medical applications of biologically produced metallic NPs

Metallic nanomaterials have various applications in different fields such as electrical, magnetic, optical, energy, electronic devices, environment, food industry and medicine [53]. Furthermore, metallic nanomaterials have been used for investigative reasons in diagnostic kits, imaging and magnetic resonance imaging (MRI), The metal nanomaterials revealed a significant therapeutic activity in medical science and drug delivery [52] [17,22]. Biosynthesized nanoparticle effectively controlled oxidative stress, genotoxicity, and apoptosis related changes. Additionally, nanoparticles have broad applications in agriculture industry and plant sciences [118]. Many MNPs such as gold, zinc oxide and iron oxide have anticancer activity [20]. MNPs were investigated in a range of immunotherapeutic treatments as a delivery system for immunomodulators; antigens, cytokines, and for induction of tumor antigen release [21]. Nano-pharmaceutical formulations and products are rapidly expanding which include nano-emulsion, nisosomes, liposomes hydrogel and polymeric NPs [6]. Furthermore, radiometals nanoparticles revealed many benefits in imaging with activity [119].Nanosilver particles (AgNPs) are the most popular over other metals because of their distinctive physicochemical, and biological properties [48]. AgNPs are stable at normal conditions, exhibit small loss of their optical frequency, non-toxic have high thermal and electrical conductivity and their cost is lower than gold and platinum [120]. Many years ago, MNPs that contain silver (AgNPs) were recognized as safe antimicrobial agents that can effectively kill pathogens even at very low concentrations [32]. Silver nanoparticles were used to fight many types of bacteria, fungi, worms and virus, such as human immunodeficiency virus (HIV) [121].

The proposed antimicrobial mechanisms of AgNPs involve bacterial cell walls destruction, reactive oxygen species production and DNA structure damage [122]. Silver nanoparticles also used in sunscreens products [123].Wongyai et al., synthesized gold nanoparticles using extract of the plant Cryptolepis buchanani. Roem and Schult. The activity of these AuNPs were investigated for antibacterial activity against Staphylococcus aureus, methicillin-resistant Staphylococcus aureus, and Acinetobacter baumannii. Actually, the greenly synthesised and fully charchterised AuNPs showed good antibacterial activity against the above mentioned strains [18]. Al Saqr et al., used aqueous extracts of the fresh peel of Benincasa hispida as a reducing and stabilizing agents AuNPs which were characterized by Fourier transform infrared spectroscopy, UV-Visible spectroscopy, transmission electron microscopy (TEM), and dynamic light scattering (DSC). The succssefully synthesized green AuNPs were screened in vitro as anticacer treatment [124].Plants extract mediated synthesis of MNPs for biomedical applications was considered the most beneficial biological method. Acordingly, using plant extracts is less the time consuming process compared to microorganisms [22, 32].Zinc oxide nanoparticles have many medical applications like antibacterial, antifungal, anti-diabetic, anti-inflammatory, wound healing, antioxidant and optic properties. Green synthesis and characterization methods of ZnONPs using different biological sources for imaging of neurotransmitters in brain tissues [125].Gloriosa superba tuber extract was used to synthesis platinum and palladium nanoparticles for the purpose of induction of apoptosis in breast cancer invitro using MCF-7 adenocarcinoma cell line [126]. Platinum salts were reduced (Pt+4 to Pt°) by phytochemicals constituents of the aqueous Zahidi dates extract to produce platinum nanoparticles. PtNPs showed high toxic effect on cancer cells lines and antibacterial activity against Pseudomonas aeruginosa and Streptococcus pyogenes [127].

Conclusion

There is a growing interest in MNPs and their green chemistry. The relation between plant sciences and nanotechnology has the potential to develop an attractive association between green revolution and nanotechnology with realistic prospects for minimizing and eliminating generations of toxic chemicals that destroy living organisms and environment. Nanosized dosage systems have the potential for enhancing the activity and overcoming problems related to phytomedicines. The synthesis of MNPs using various plants extracts which provide simple and efficient strategy for the synthesis of nanomaterials emerged as a safe alternative to conventional methods. Whatever the choice of biological system; plant, bacteria, fungus or food wastes… etc. They all need to be studied carefully and the risks of such nanoparticles should be assessed.

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DOI: 10.32474/ANOAJ.2023.02.000138