MINI REVIEW

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# Nanoparticle synthesis approaches at a glance

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**ABSTRACT:** Nanotechnology has opened a new era for scientists and engineers to build nanomaterials with diverse applications. Nowadays, nanotechnology plays a vital role in each and every sector due to its extraordinary physical and chemical properties. It deals with development and synthesis of variety of nanoparticles (NPs), which ranging from 1 to 100 nm. The major approaches used for the synthesis of NPs are top to bottom and bottom to up which mainly included physical, chemical and biological methodologies. This mini review highlights synthesis of NPs through various approaches specifically targeted biological route.

**Keywords:** Nanotechnology, Nanoparticles, Synthesis, Approaches

## 1. Introduction

Nanotechnology is a field of science dealing with synthesis and development of variety of NMs. Nanotechnology can be defined as atomic and molecular scales manipulation of the matter. Norio Taniguchi, a Japanese researcher, was the first person who used the term "Nanotechnology" in 1974 [1]. The field of nanotechnology is based on perception and constructing the matter at nanoscale dimensional range of 1–100 nm [2]. Such manipulations at nanoscale results in novel chemical, physical and biological features. Nanotechnology deals with interdisciplinary research including a wide spectrum of scientific and technological disciplines such as chemistry, material sciences, physics, engineering and biotechnology [3]. Stupendous growth has been observed throughout the world in the field of nanotechnology with an exponential growth expected in future as a result of wide array of applications nanotechnology has to offer [4]. Nanotechnology is an inspirational advent of modern basic and applied sciences. Currently, Nanotechnology has been described as revolutionary discipline due to its probable influence on industrial applications [5]. Nanotechnology is equipped with plausible solutions to an array of problems currently being faced in various domains. Nanotechnology has emerged as centre of cogitation for research in the current era of science, technology and innovation. Due to its multifarious applications in various disciplines like biotechnology, water treatment, textile engineering, metal-based consumer products, electronic, bioengineering, information storage and optoelectronics, characterization and synthesis of nano-metallic particles like platinum, silver and gold has unfolded as important domain of research [6].

The core building blocks of nanotechnology are NPs [7]. There are two distinct forms of nanotechnology i.e. dry and wet nanotechnology. Dry nanotechnology is concerned with objects that are prepared by men whereas wet nanotechnology utilizes living materials for biosynthesis of various substances. One of the emerging domain in nanotechnology deals with the interaction of two modern giants, the nanotechnology and biotechnology, dealing with formulation of biosynthetic devices and environmental friendly processes of nanoscale materials. This is known as Nano-biotechnology [4].

## 2. Nanoparticles

The last few years have captivated a number of researchers from a variety of fields to synthesize NPs especially that of zero-valent metals owing to their unique properties exhibited in both biological and physical systems. The term NP is used to describe particles that vary in size from 1-100 nm [7]. They are considered as the spearheads of the exponentially growing nanotechnology discipline [8]. Due to its smaller size and large surface area, characterization and formulation of nano-metallic particles has become centre of contemplation as compared to their bulk counterparts as it offers improved applications and enhanced properties. Several nano-metallic particles have been formulated so far out of which, NPs like gold, platinum, silver and copper have been abundantly reported [9]. There are four main types of NPs as evident from literature which includes organic NPs, inorganic NPs, semi-conductor NPs and noble metallic NPs. Organic NPs includes carbon based NMs like fullerenes. Magnetic NPs are included in the category of inorganic NPs. Oxides of metals like zinc and titanium are the examples of semi-conductor NPs while noble metallic NPs includes silver and gold etc. [10]. The most studied type of NPs among these are the metallic NPs [11], the studies on which can be dated back to 19th century when Michael Faraday synthesized gold colloid solution in 1850s [12]. Interaction of metallic NPs with light was demonstrated by Mie [13]. Literature also shows that gold NPs have been used by ancient romans for preparation of stained glass [14]. There are two approaches currently under the use for NP formulation and fabrication namely top down and bottom up approaches [15], that have been described briefly in Figure 1. Top-down approach, also known as microfabrication method [8] utilizes physical approaches like cutting and milling in order to shape the materials into desired conformation and order. It usually involves techniques like lithography, sputtering, etching, and ball mill assisted grinding etc. [16]. Bottom up approach for preparation of NPs is the most widely used method that involves self-assembling of tiny molecules or atoms to form larger subunits. Such procedures help in effectively controlling the shape and size of desired materials in accordance with desired application by varying the reaction conditions like pH, temperature etc. or the concentration of precursor material. Products with high precision accuracy can be formulated with such approaches [8].

Several chemical and physical methods have been adopted thus far for the production of NPs which includes (i) sol gel method; (ii) co-precipitation; (iii) hydrothermal/solvothermal; (iv) micro-emulsion; (iv) inert gas condensation; (v) sono-chemical method; (vi) microwave assisted synthesis; (vii) Chemical vaporization method; (viii) spark discharge generation; (ix) pulsed laser ablation; (x) laser pyrolysis/ photochemical synthesis; (xi) spray pyrolysis; (xii) flame spray pyrolysis and (xiii) thermal plasma synthesis [2].

## 3. Physical Approaches

Various physical approaches including laser ablation and evaporation-condensation are used for NP synthesis resulting in production of variety of nano-metallic particles such as gold, silver, fullerene, lead sulfide and cadmium sulfide have been synthesized through physical processes. Physical methods poses several advantages over chemical counterparts like solvent contamination nonappearance in thin film preparations and uniform distribution of nano-metallic particles [17].

Silver NPs synthesis have been achieved using small ceramic heaters having a local heating originator. Vapors that evaporate cools down rapidly since the temperature gradient of the heater surface within the vicinity is steep when compared to a tube furnace. This results in production of large concentrations of min sized NPs. This type of physical method is useful for generation of NP in long-term experiments [18]. Laser ablation technique can also be utilized for synthesizing silver NPs from metallic bulk materials [19]. The characteristics and ablation efficiency of produced silver NPs depend upon several factors including laser pulses duration within different time regimes, wavelength of the laser intruding the metallic target, the laser fluency, effective liquid medium and ablation time duration, with the aid or in complete absence of [20]. An added advantage with this technique is the non-existence of chemical constituents in the solution while prepared metal colloids which results in un-contaminated and pure colloidal metals [21].

## 4. Chemical Approaches

Chemical approaches for NP synthesis focuses on chemical based reduction of NPs aided by inorganic and organic reducing agents. Some of the commonly used

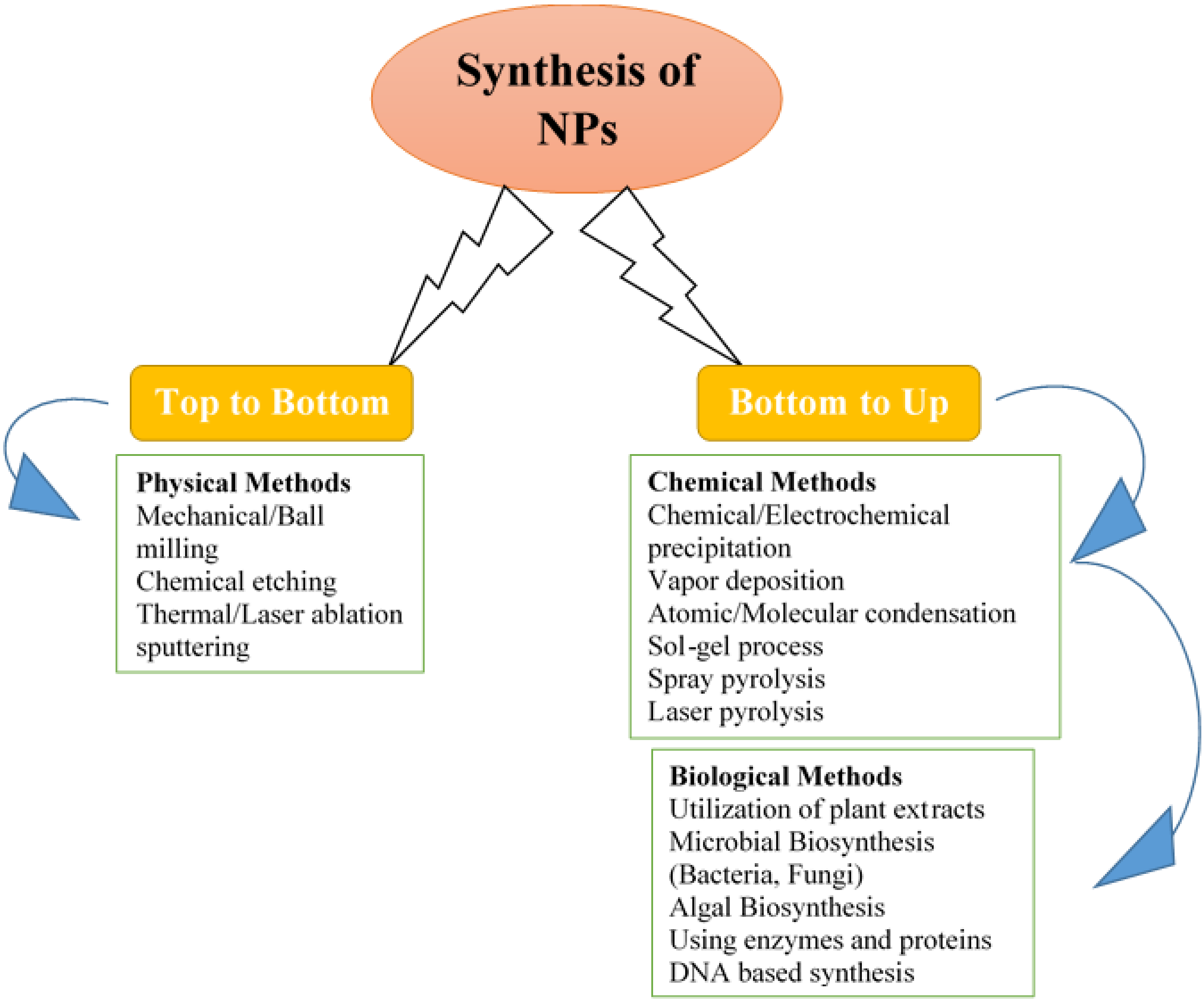



**Figure. 1** Methodologies for synthesis of NPs

reducing agents include ascorbic acid, sodium citrate, polyols, tollen agents, sodium borohydride, elemental hydrogen, ethylene glycol and DMF (dimethylformamide). These reducing agents can be utilized in both aqueous and non-aqueous solutions. The antecedent reducing agents have been reported to reduce ionic silver ($Ag^+$) which results in formation of metallic silver ($Ag^0$). This in turn induces agglomeration of metallic silver into oligomeric clusters. The process finally ends with the conversion of these clusters into metallic colloidal silver particles [22]. While using chemical approaches for NP formulation, protective agents must be used to improve stability of NPs. These stabilizing agents prevent NPs from binding to the surrounding NPs and helps in preventing NPs agglomeration [23].

## 5. Biological Methods

Biological approaches involves the uses of microorganisms like fungi, bacteria and plants for the synthesis of NPs. It also involves biomolecules, protein and enzymes. Biologist mainly performed this method and considered it as an ecofriendly method. In biological methodology, mostly plants are using nowadays due to easily availability and also rich source of metabolites. This simple method is known as “green synthesis”.

## 6. Green synthesis

The remarkable potential of Nanotechnology, since its dawn, has exhibited its concrete worth in numerous unlikely areas as NPs. Catauro *et al.* (2004) stated that the physical or chemical methods comprising of toxic chemicals, which pave a way as precursors to convert the bulk materials into these tiny NPs, are used in NPs synthesis in conventional techniques [24]. Decreasing the harmful techniques usage for NP synthesis is one of the aims of current study. A prominent solution to this is Green Chemistry which facilitates the synthesis of anticipated products in chemical reaction processes by bypassing the harmful transitional derivatives. The identification of multifunctional environment friendly reagents has come to being by Green chemistry principles' incorporation into nanotechnology. These reagents have a potential to be used as capping and reducing agents [25].

Approximately a decade ago, researchers familiarized the application of green chemistry principles into the nanotechnology. Synthesis of novel products by exploiting the environment friendly materials is governed by these environment friendly nano-technological processes [26]. Biological macromolecule (i.e. lipids, carbohydrates, nucleic acids and peptides or proteins), plant extracts and plant metabolites are utilized in such processes. The advantages, like comparatively less amount of harmful waste production and energy efficiency, of NPs synthesis through biological route are well documented by now. The basic along with purpose-oriented investigations, either in industrial field or in academia for the development and enterprise of GNPs (Green NPs), are emboldened by green nanotechnology [27]. Ahmad *et al.* (2003) stated that the life-saving nano-pharmaceuticals, standby green energy production devices and the design of smart electronic devices have made use of these green NPs [28].

The use of microorganisms like fungi, bacteria and plants for the synthesis of NPs both extra and intracellularly have been reported in several biological approaches [29]. These approaches along with the possible applications of their resulting product have been briefly described in Figure. 2. For NPs synthesis, being deprived of toxic chemicals and offering natural capping agents, plants offer a far better stand. Furthermore, the NPs synthesis by plant extracts is superior to microbial synthesis approaches in a way that it lessens the cost of microorganism isolation augmenting the cost competitive feasibility [30].

Every so often, other biological synthesis processes for NPs comprising of microbial cultures' complicated retaining procedures lack behind the advantages offered by plant and their extracts [31]. Various such NPs synthesis experiments have already been initiated. They are being implied for the various metal NPs synthesis for example *Penicillium sp.*[32], *Fusarium oxysporum* [33], and *Bacillus subtilis* etc. [34]. A list of different NPs synthesized using microorganisms is given in **Table 1**.

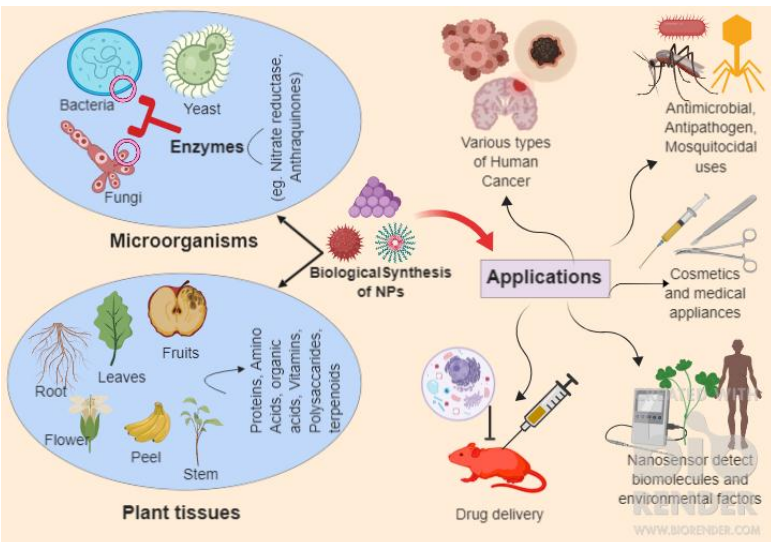
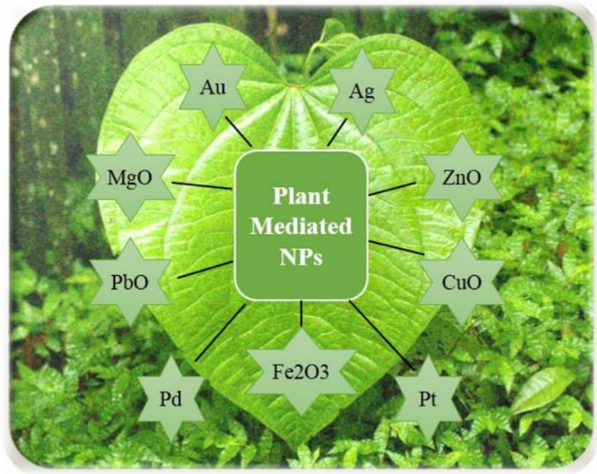



**Figure. 2** Different routes and potential applications of Green Synthesized NPs

**Table 1:** List of different metal NPs synthesized from various microorganisms.

| Microorganisms | Synthesized NPs | References |
|---|---|---|
| *Penicillium aculeatum* | Au | [35] |
| *Yarrowia lipolytica* | Au | [36] |
| *Trichoderma viride* | Ag | [37] |
| *Bacillus methylotrophicus* | Ag | [38] |
| *Shewanella algae* | Pt | [39] |
| *Enterobacter sp.* | Hg | [40] |
| *Zooglea ramigera* | Se | [41] |
| *Shewanella sp* | Se | [42] |
| *Enterococcus faecalis* | Se | [43] |
| *Desulfovibrio desulfuricans* | Pd | [44] |

Nevertheless, for ecofriendly and green synthesis of NPs, plant extracts mediated synthesis methodology is the most implemented technique. It also bears the distinctive gain of the fact that plants are easily available, source of numerous valuable metabolites, safe to handle and widely spread [45]. Since the early 1900s plant extracts are known to possess the ability of metal ions reduction. Even though it was not well understood that what the nature of reducing agents was. With regard to the simplicity of living plants or the whole plant extract and plant tissue used for metallic salts reduction to NPs, within the last 30-years significant attention is paid in this field. The exploitation of plant extracts for making NPs is simpler as compared to use of plant tissues and whole plant. Currently, the prominently growing focus is plant extract mediated synthesis. For NPs synthesis, plant extracts may act both as stabilizing agents and reducing agents. Several features of NPs are affected by the source of plant extract. Normally, mixing an aqueous solution of the relevant metal salt with the aqueous extract is involved in the plant extract-mediated bioreduction. Only few mins are needed for the reaction to occur at room temperature. Mittal *et al.* (2013) stated that the bioreduction process is moderately complicated as it involves number of different chemicals [46]. Figure 3 shows some of the major NPs synthesized with the help of plant material while Figure 4 shows the generalized process of NP production and its potential applications.



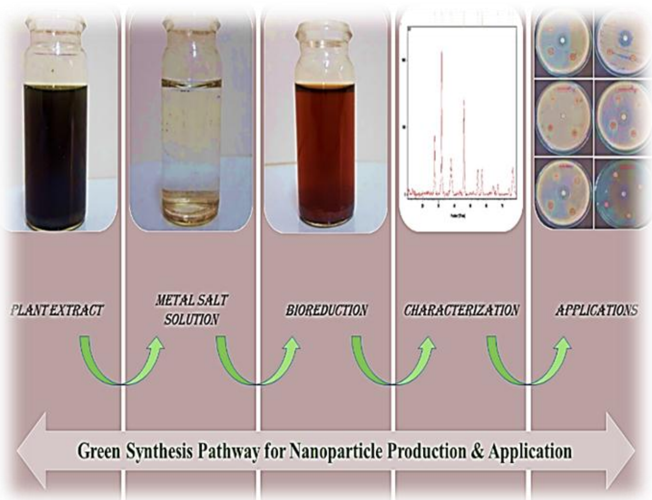




**Figure. 3** Different NPs synthesized using plants.

**Figure. 4** Generalized pathway for Green Synthesis of NPs.

Novel secondary metabolites like terpenoids, alkaloids, flavonoids and phenolic acid, accountable for metallic ions conversion into bulk metallic NPs, are present in plant crude extract. For synthesis of eco-friendly NPs, redox reaction continuously embroils these primary and secondary metabolites. Biosynthesized NP as documented in several investigations efficiently regulate the apoptosis related changes, genotoxicity and oxidative stress [47]. Similarly, several medicinal plants including *Medicago sativa* (Alfalfa), *Helianthus annus, Zea mays, Cinamomum camphora, Oryza sativa, Geranium sp., Magnolia kobus, Sorghum bicolour, Capsicum annuum, Basella alba, Saccharum officinarum* and *Aloe vera* have been used in numerous investigations for NPs synthesis in the field of biological industries and pharmaceutical applications. Moreover, Kasthuri and Rajendran. (2009) reported that methanolic extract of *Eucalyptus hybrid* has been exploited for silver NPs green synthesis [48]. A list of plant mediated synthesis of NPs is given in Table 2.

**Table 2:** List of different metal NPs synthesized from various plant extracts.

| Plant materials | Synthesized NPs | References |
|---|---|---|
| *Melia azedarach* (leaf extract) | Ag | [49] |
| *Piper longum* (leaf extract) | Ag | [50] |
| *Papaver somniferum* (Pod extract) | Au | [51] |
| *Euphorbia hirta* (leaf extract) | Au | [52] |
| *Terminalia arjuna* (leaf extract | Au | [53] |
| *Mangifera indica* (leaf extract) | Fe | [54] |
| *Punica granatum* (peel extract) | Cu | [55] |
| *Physalis alkekengi* (plant extract) | Zn | [56] |
| *Passiflora caerulea (leaf extract)* | Zn | [57] |
| *Anacardium occidentale* (leaf extract) | Pd | [58] |
| *Vitis vinifera* (raisin extract) | Se | [59] |

## 7. Conclusion

Nanotechnology is buzzword in scientific area nowadays with its multiflorous applications. Nanoparticles have greater surface area and significant outcomes as compared to the particles in their bulk form. It has been synthesized through various methodologies like Physical, Chemical and Biological. Biological method used very commonly as it does not produce noxious chemicals. Green synthesis of plant nowadays attracted many researchers as due to rich source of metabolites and easily availability. Various research presented potential applications of green synthesized nanoparticles. More studies are recommended to minimize the toxicity of these NPs and further advancement in this field will revolutionize the human civilization from every aspect.

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## Competing Interests:

The authors declare that they have no competing interests.

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## Authors' Contribution

All the authors contribute equally to this paper.