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Herbal Green Nanomaterials and Their Applications

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Synonyms

Green nanomaterials; Green nanotechnology; Herbal green nanomaterials

Definition

With growing awareness of environmental deterioration, measures such as clean technology and green technologies have been developed to safeguard and prevent it from oblivion (extinction). Environmentally friendly goods and processes may be achieved by selecting green material technology and putting it to good use in planning and decision-making. Indeed, in the development of nanotechnological technologies, numerous treatments and herbal-based products can increase their efficacy. Using plant, bacterium, algae, and fungal products to synthesize green materials minimizes the number of harmful byproducts created in the process. Several studies have recently shown that plant extracts work as a viable precursor for the safe synthesis of nanomaterials such as cobalt, copper, silver and gold, palladium and platinum, and zinc oxide magnetite. For instance, because of its unique metal tolerance and excellent production of gold, biosynthesis of metal nanoparticles (NPs) utilizing medicinal plants has gained much interest. Instead of using dangerous and synthetic chemical procedures, NPS is a viable option. These green herbal compounds are crucial in various fields, including remediation, heavy metal detecting, chemical and gas sensors, and the helpful catalysis of dangerous chemical processes. Pharmaceutical technologies are expected to incorporate more nano-plant materials in the near future to cure and prevent illness. In the long run, this is the greatest option for people and the environment alike.

C. Baskar et al. (eds.), *Encyclopedia of Green Materials*,
https://doi.org/10.1007/978-981-16-4921-9_57-1

Introduction

Herbal and therapeutic plant extracts have only recently been used in the creation of nanoparticles. Significant efforts are being made worldwide to develop and deploy technology for the manufacturing of herbal-based consumer products to give better healthcare solutions for the population at large. Because of their minuscule size, nanoparticles are essential building blocks in nanotechnology because they may serve as an effective medicine delivery mechanism. This minimizes adverse effects and toxicity while yet delivering the medication at the desired location at the correct amount. Nanotechnology is primarily concerned with synthesizing nanoparticles of various sizes, shapes, chemical compositions, and controlled dispersion for biological and medicinal purposes (Rajeshkumar et al. 2012). Although there are several chemical and physical ways for effectively creating well-defined nanoparticles, they are both time-consuming and expensive. The creation of environmentally friendly nanoparticles with reduced toxicity is a hot topic these days. Natural biological material synthesis methods must be built in safe approaches to achieve this goal. Some research has suggested employing microorganisms and vascular plants to synthesize nanoparticles using biological approaches (Islam et al. 2008). Many studies have shown that green nanotechnology approaches can emit harmless byproducts throughout the synthesis process. This occurrence might be explained by the biocompatibility and biodegradability of the compounds utilized in nanoparticle formation, which are degraded by enzymatic substances. Plants also utilize biochemical components as nutritive elements for their own metabolic processes by storing them in their tissues (Zhao et al. 2021). Alternatives to chemical and physical techniques for the creation of nanoparticles include bacteria, plant extract, and plant biomass (Kang et al. 2018).

Biological Synthesis of Herbal and Medicinal Plants-Mediated Nanoparticles

Green Synthesis

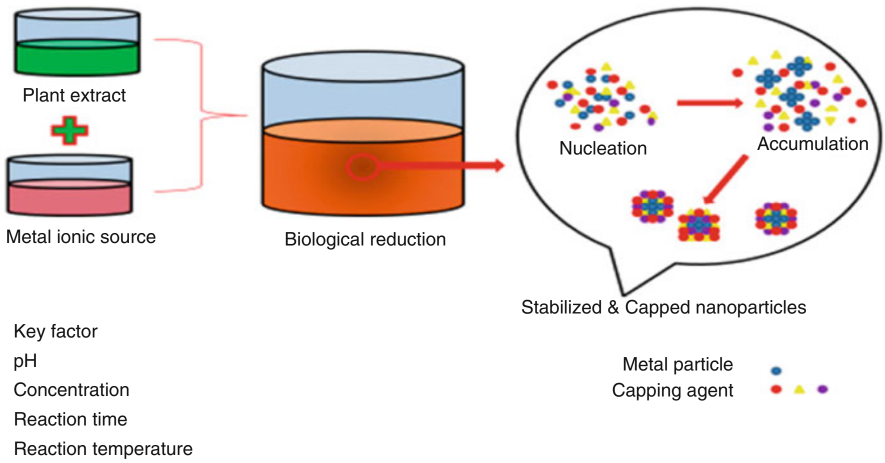
Using plant products in the synthesis of nanoparticles is referred to as "green" synthesis, and it is known as low-cost, high-efficiency, and environmentally benign (Hullmann and Meyer 2003). In industry, a cost-effective and environmentally beneficial process can produce huge quantities of green products. High-pressure, high-temperature, and harmful chemicals are all avoided in the production process when using green synthesis methods. Green synthesis is known as green synthesis by synthesizing nanoparticles using plants, bacteria, fungus, algae, and other microorganisms. Green nanoparticles are more stable, have a wider range of sizes and forms, and can be made more quickly than other biological agents. Furthermore, green synthesis nanoparticles are more effective in bioactivity than chemically manufactured nanoparticles (Hristozov et al. 2009).

Herbal Medicine and Nanoparticles

Due to the synergistic activity generated by all active ingredients working together, the therapeutic efficacy of herbal medicines is determined by the combined function of all active components. Each of the active ingredients is interconnected and plays a critical part in the whole formula. Because herbal remedies tend to be nonsoluble, they have lower bioavailability, requiring more frequent administration or a larger dose, making them low-class drugs for therapeutic use (An et al. 2019).

Green Synthesis of Metal Nanoparticles

In plants, metallic ions and hyperaccumulation are reduced biologically (Nalawade et al. 2012; Mosa et al. 2016). Using plants to produce metallic nanoparticles has been deemed more environmentally beneficial due to their unique properties, and they are also employed in detoxifying applications. Figure 1 depicts the biological production pathway of metal nanoparticles (Sarma 2011).



Herbal Green Nanomaterials and Their Applications, Fig. 1 Using plant extracts in the biological production of nanoparticles (Verma et al. 2019)

Plants' active biomolecule content and concentration and their interaction with aqueous metal ions control nanoparticle shape and size. During the chemical and biological production of nanoparticles, the metal ion precursors derived from metal salts are reduced, which causes a color change and a quantitative indicator of nanoparticle formation in the reaction mixture. The development of ecologically acceptable technologies is complicated by the possibility that nanoparticles generated from reducing agents are detrimental in general (Singh et al. 2016). Plant extracts are combined with a metal–salt solution to make nanoparticles. Nanoparticle manufacturing begins right away with the biochemical reduction of the salt solution, and the change in color of the reaction mixture reveals that nanoparticles have been produced.

Extraction of Phytochemicals

At least three different studies have shown the use of biological extraction methods to get phytochemicals (Linga Rao and colleagues (Rao and Savithramma 2011)). More than one research study have documented phytochemicals' biological extraction. A team of researchers led by Linga Rao have developed a new approach to solving the Zargar et al. problem (Zargar et al. 2011). There is evidence to support the use of Vitex negundo L in the environmentally friendly manufacture of silver nanoparticles. Using an oven drier at 40 °C for 48 hours to dry the leaves, then grinding the powder, and storing it in dark glass vials at −20 °C, the leaves were prepared for future study. Overnight at 40 °C, 20 g of this powder was extracted with methanol (1:10 w/v) using a shaking water bath. The vacuum pump re-extracted the residue after filtering using Whatmann filter paper no. 1. The solvent was completely evaporated in a rotating vacuum evaporator set to 40 °C. The concentrated extract was stored at 4 °C in the dark until it was needed. Another study was carried out by Masurkar and colleagues (Masurkar et al. 2011). They claimed to have produced silver nanoparticles fast using *Cymbopogan citratus* (Lemongrass). This chapter describes a variety of studies in which herbal and medicinal plant extracts were combined with gold and silver to create stable nanoparticle dispersions.

Silver Nanoparticles

Due to their low toxicity and effectiveness against bacteria, viruses, and other eukaryotic microorganisms at extremely low concentrations, silver nanoparticles offer several benefits over other nanoforms. The technology for synthesizing and characterizing nanoparticles has advanced significantly in recent years. Following Ag in antibacterial action are the metals listed below: As compared to other elements, gold is preferable over lead, copper, cadmium, and chromium (Correia et al. 2018). Water filters for the home, clothes respirators, contraceptives, cosmetics, detergents, antibacterial sprays, nutritional supplements, laptop keyboards, mobile phones, and children's toys are currently on the market, all claiming to leverage Ag nanoparticles' antimicrobial characteristics to their advantage. For silver nanoparticle implementation and manufacture, it is critical to focus on green synthesis to overcome the environmental hazard posed by the extensive use of chemicals. Green Ag nanoparticles were made using plant extracts, biomacromolecules, and peptides (Sherje et al. 2018). There is a highly cost-effective and straightforward approach to synthesizing green Ag nanoparticles utilizing plant tissues such as roots and leaves, stems, seeds, fruits, etc. This meets the need of the scientific community while also eliminating environmental dangers. The exact method by which metal nanoparticles are made from plant extracts is still a mystery. However, it has been observed that reduction, aggregation, and nanoparticle creation coincide (Mehrad et al. 2018). It is possible that biological compounds such as terpenoids, flavones, and ketones can serve as capping agents in plant-based synthesis processes as well as reducing agents. Nanoparticle agglomeration is prevented, and toxicity is reduced, thanks to these capping agents. Most scientists agree that if the coating agents exhibit biological activity, metal nanoparticles and the capped compounds will work together synergistically.

Gold Nanoparticles

Gold nanoparticles (AuNPs) are employed in many fields: biosensing, catalysis (Sen et al. 2013), electronics, enzyme electrodes, superconductors (Sun and Xia 2002), and cancer therapy, among others. The use of AuNPs in DNA identification, genetic medicine, and nanocatalysis is particularly extensive. AuNPs have outstanding optical, plasma resonance, and bioconjugation capabilities that help them maintain their stability while also allowing them to be easily coupled with biological molecules. AuNPs are also used in the detection and treatment of malignant tumors, according to the article. For the synthesis of gold nanoparticles, many chemical techniques are known, all of which require the reduction of gold cations (Au + or Au3+) to zerovalent (Au0) using a reductant. These techniques leave unreacted reagents or undesired byproducts in the Au colloidal solution, making the AuNPs unsuitable for biological use. A growing body of research has been done on the bioreduction potential of many microbes and plants since the first indication that living systems can reduce metal ions to zerovalent state. To synthesize nanoparticles, including gold nanoparticles, TCM herbal extracts have been employed in various research. Traditionally, Chinese medicine (TCM) is recognized for its high effectiveness and low risk of adverse effects. Traditional Chinese medicine (TCM) has several components that may be isolated and studied individually for their various pharmacological actions. These activities include immunological advantages as well as anti-infective and antitumor properties. As an example, Dendrobium officinale is a widely used TCM with a long history of pharmacological research (Dendrobium officinale Kimura et Migo, DO) (Teng et al. 2020) (Table 1).

Copper and Copper Oxide Nanoparticles

Plant extracts have been used to make a variety of copper (Cu) and copper oxide (CuO) nanoparticles. CuNPs derived from magnolia leaf extract were stable 40–100 nm nanoparticles that have been produced by biological synthesis. CuNPs also show antibacterial efficacy against *Escherichia coli* cells, according to the research. *Syzygium aromaticum* (clove) extracts produced CuNPs with a spherical to granular form and a mean particle size of 40 nm. A common milk hedge called *Euphorbia nivulia* was used to make copper nanoparticles (CuNPs). Latex contains peptides and terpenoids that aid in the

Herbal Green Nanomaterials and Their Applications, Table 1 A representative of nanoparticles synthesized by various plants

Plant	Nanoparticle	Size (nm)	Shape	References
Aloe vera	Au & ag	50 to 350	Spherical, triangular	(Hua et al. 2012)
Aloe vera	In_2O_3	5 to 50	Spherical	(Centi and Perathoner 2011)
Citrullus colocynthis	Ag	31	Spherical	(Tsai et al. 2013)
Curcuma longa	Pd	10 to 15	Spherical	(Cardellina 2002)
Diopyros kaki	Pt	15 to 19	Crystalline	(Williamson 2001)
Eucalyptus macrocarpa	Au	20 to 100	Spherical, triangular, and hexagonal	(El-Samaligy et al. 2006)
Mangifera indica	Ag	20	Spherical, triangular, and hexagonal	(Verma et al. 2019)
Rhododendron dauricum	Ag	25 to 40	Spherical	(Chen et al. 2006)
Psidium guajava	Au	25 to 30	Spherical	(Lawrence and Rees 2000)
Pyrus sp. (pear fruit extract)	Au	200 to 500	Triangular, hexagonal	(Zhang et al. 2010)
Terminalia catappa	Au	10 to 35	Spherical	(Goel et al. 2008)

stability of nanoparticles. According to research, these nanoparticles are also harmful to human adenocarcinomic alveolar basal epithelial cells (Verma et al. 2019).

Palladium and Platinum Nanoparticles

An extract of *Cinnamomum zeylanicum* was used by Satishkumar et al. to make palladium nanoparticles. Aside from the change in concentration and reaction pH caused by synthesis, the bark extract's temperature, concentration, and form were unaltered. There have also been palladium nanoparticles generated from *Annona squamosa* (custard apple) extract that are 75-85 nm in size. There are 20-60 nm diameter palladium nanoparticles with a cubic crystal symmetry in the core made from *Camellia sinensis* (tea) and *Coffea arabica* (coffee) (Abdelfatah et al. 2021). Satishkumar et al. developed palladium nanoparticles using cinnamon bark extract (*C. zeylanicum*). Thermal, concentration, and reaction pH of bark extract changed during synthesis but not particle shape or reaction pH size (15 to 20 nm). There have also been palladium nanoparticles generated from *Annona squamosa* (custard apple) extract 75-85 nm in size. Extracts from *Camellia sinensis* (tea) and *Coffea arabica* (coffee) were used to manufacture palladium nanoparticles with diameters ranging from 20 to 60 nm with cubic crystal symmetry in the core (coffee) (Mondal et al. 2011). For the nanoscale scale, plant wood was utilized. Lignin from red pine (*Pinus resinosa*) was used to make palladium and platinum nanoparticles, for example, by Coccia et al. (Chandran et al. 2006).

Titanium Dioxide and Zinc Oxide Nanoparticles

These critical metal oxide nanoparticles were made using a range of plant extracts. For example, Roopan et al. observed that *Annona squamosa* peel could successfully form TiO2NPs, whereas the decoction of the leaves of *Nyctanthes arbor-tristis* L. (Oleaceae) spherical particles ranging in size from 100 to 150 nm (Petros and DeSimone 2010). *Eclipta prostrata* leaf extracts have the potential to create particles ranging in size from 36 to 68 nm. *Catharanthus roseus* leaf extract was employed by Velayutham et al. to create TiO2NPs with irregular shapes and sizes ranging from 25 to 110 nm. Using TiO2, suspensions against *Bovicola* *ovis* (the sheep louse) and *Hippobosca maculate* are shown to be both *larvicidal* and *adulticidal* (hematophagous fly). When TiO2NPs were synthesized from an extract of *Psidium guajava*, they were examined for their antioxidant and antibacterial properties against *Pseudomonas aeruginosa*, *Staph aureus*, *Proteus mirabilis, Aeromonas hydrophila, and E. coli*, among other pathogens. The antioxidant and antibacterial properties of TiO2NPs at nanoscale and bulk scales were also investigated (Seil and Webster 2012).

Green Nanoparticle and Its Applications

The bulk characteristics of metals are vastly different from their nanoscale dimensions. Various functions of metals and their nanoparticles in the human body have been identified. By combining them with physiologically active substances, they become active. Nanoparticles and conjugated molecules can sometimes work together synergistically. Medicinal properties predominate among the extracts used in green synthesis. Herbal extracts benefit from nanoparticle conjugation. Green nanoparticles have been shown to date to exhibit anticancer, drug delivery, antimicrobial, antianemic, antiarthritic, antidiabetic, and antioxidant capabilities (Verma et al. 2019).

Drug Delivery Using Herbal Green Nanoparticle

Metal nanoparticles deliver medications to specific organs with great efficiency because of their large surface-to-volume ratios. Nanoparticles can deliver medications to the site of action and modulate their effects because of their limited volume. Metal nanoparticles' hollow spheres can be used to load drugs or to tag them on the surface. They demonstrate drug release techniques that are long-term in nature. The noncytotoxic green gold nanoparticles of 40 nm are ideal for medication delivery. Green gold nanoparticles made from *Punica granutum* fruit peel extract may also be useful for cancer treatment delivery targeting (Saini et al. 2019) (Table 2).

Conclusion

In the pharmaceutical sector, health and beauty goods, and research, green nanotechnology is one of the most promising and challenging fields of nanotechnology in the near future. Several roadblocks need to be cleared before these wonder molecules can be fully utilized. Prior to choosing the herbs that form the basis of these molecules, they must be thoroughly inspected. When making a choice, keep in mind the biological activity as well as the structural benefits, the capacity to be conjugated, the toxicity profile, and so on. Techniques used to make different nanoparticles vary substantially depending on what kind of particle is being created. Researchers should be concerned about producing a set of conventionally standardized technique developments for nanoparticle synthesis because numerous synthesis techniques are currently used. Since traditional methods and standards can finally classify nanoparticles, this advancement might advance the technology and give nanoparticles a more scientific name. It will improve our knowledge of nanoparticles and increase our ability to produce them. Most studies are done in vitro/ ex vivo. Hence toxicity in vivo models should be prioritized for overall system toxicity evaluations as this is where most of the research is done. For this reason, it is difficult to determine which component was used as a reducing agent or capping material and which nano-biomolecule is truly responsible for the therapeutic effect. Another essential aspect is the dose, which is difficult to estimate due to the presence of both herb and nanometal in the herb-nano-metal combination. This means that the dose that will be used to make the final decision will be difficult to predict since it will be different from the stated dose of the herb and the bulk metal. Finally, each technology brings with it a new set of issues, each with advantages and disadvantages. If these problems can be solved, this technology will continue to be researched, developed, and used for many years to come. To make herbonanoceuticals a miracle medicine for future therapies, steps must be done

Herbal Green Nanomaterials and Their Applications, Table 2 Applications of various nanoparticles (herbal and synthetic) for diverse therapeutic purposes

Nanoparticles used	Characteristics	Therapeutic purpose	References
Gold nanoshells, which stimulate the appropriate pro- or anti-immunity pathways; silica-based nanoparticles, polyethylene glycol, or polyester biobeads; natural polymers based on polysaccharides such as alginate, inulin, or chitosan	Faster and more sensitive delivery nanodevices; better, more secure, and biocompatible; entrapping of antigens for delivery to specific cells and controlled silver release as indicated by the biodegradation rate; gold nanoparticles as an adjuvant, assimilation of particular biomolecules, and improved interaction With cells and cell take-up	Vaccine adjuvant	(Gregory et al. 2013)
Herbal nanoparticles containing natural compounds such as β-carotene, curcumin, and epigallocatechin gallate; gold nanoparticles; nanocapsules; fluorescent nanoparticles; and iron oxide nanoparticles	Target definition, increased solubility and bioavailability, toxicity abatement, wider physiological adaptability, and cost-effectiveness	Cancer therapy	(Tiwari et al. 2012)
Liposomes, dendrimers, and gold nanoparticles	Low toxicity, little immunogenicity, competent, and highly bioadaptable	DNA delivery	(Saini et al. 2019)
Liposomes, niosomes, nanomicelles, polymeric nanoparticles, solid lipid nanoparticles, dendrimers, conjugates, and calcium phosphate nanoparticles	Enhanced effectiveness with negligible harm to surrounding tissues, enhanced safety profile, better spreadability on the ocular surface, improved bioavailability because of lessened medication binding to pigments, and managed drug release	Ocular delivery	(Agarwal et al. 2018)

to tackle these problems using herbonanometal formulation, i.e., herbonanoceuticals.

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