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REVIEW **Open Access**

Medicinal herbs as a panacea for biogenic silver nanoparticles

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Abstract

Background: Scientists created a new area known as "green nanotechnology" by combining the concept of sustainability with nanotechnology. Its goal is to eliminate the use of chemicals in nanoparticle manufacturing by replacing them with plant-based materials. Green synthesis is promoted as the best alternative to the traditional method of nanoparticle synthesis in this new domain. Plants that constitute a major portion of our biodiversity are embraced with inherent potentiality to be transformed as miracle medicine due to its phytochemicals. These phytochemicals efficiently replace the classical wet chemical ingredients involved in nanoparticle synthesis by upgrading to greener method for its synthesis. By incorporating plant-based sources as the chief ingredient of nanoparticle synthesis, we are able to reduce the hazards of greenhouse gas emissions and enlighten the insights of our scientific community with nanotechnology for green innovation. Hence, this review simultaneously aims at promoting plant extracts as the most efficient as well as renewable recipe for green synthesis of silver nanoparticles and preparing earth for a greener tomorrow.

Methodology: Scientific articles and publications were selected from reputed journals and sorted out with pertinent keywords of this review. Electronic sources like Google Scholar, PubMed, Research Gate, Science Direct, Wiley Online Library, Web of Science and Scopus were searched for potential articles and recent breakthroughs published in the area of silver nanoparticle synthesis via green chemistry and biological methods using plant extracts. Scientific names of medicinal plants were checked using botanical databases like Plant List and International Plant Names Index.

Conclusion: This review pinpoints on empowering better life on earth by protecting it from hazardous effects of conventional nanotechnological production through replacing the former with sustainable green synthesis approach. Ergo, it outlines that by incorporating plant-based sources as the chief ingredient of nanoparticle synthesis, we are able to reduce the hazards of greenhouse gas emissions in turn by slowing down increasing climate change disasters globally and enlighten the insights of our scientific community with nanotechnology for green innovation.

Keywords: Green synthesis, Silver nanoparticles, Medicinal plants, Green nanotechnology, Plant extract

Background

> *"Both medicinal plants, and a sacred connection to place, heal body, mind, and spirit, and encourage humans to be mindful and loving stewards of the Earth"*
>
> *Deb Soule*

From these well-known lines, it is apparent that medicinal plants, with their wondrous potency, frequently enliven our souls with synergetic zeal and maintain a healthy relationship with Mother Nature. To put it another way, we might consider medicinal plants to be a magical recipe that aligns with our aspirations of shaping a better world, which is at the heart of the ideas of sustainable development. The basic definition of sustainable development has been engraved on our minds since infancy, but we have yet to take the promise to adopt it and advocate for it among our peers.

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Nature and its resources have suffered the most in this modern world of increasing disparities created by different anthropogenic actions, either directly or indirectly. We're all aware that nature is frequently referred to be feminine (Mother Nature) due to its great power and dynamic capacity to pour immense care and love on its siblings while simultaneously defeating all sorrow. Mother Nature protects her flora and fauna in the safest possible way. We, as humans, torment this ecosystem to such an extent that we frequently forget about the valuable treasure it hides in its lap. The most valuable treasure is medicinal plants, according to legend.

> *"Mother nature has the power to please, to comfort, to calm, and to nature one's Soul."*
>
> *Anthony Williams*

From these well-known phrases, it is apparent that Mother Earth, who nourishes and nurtures all of nature's biotic elements, has an indigenous treasure trove of medicinal plants that serves as a magical potion for her offspring. Because of their ethnopharmacological relevance, medicinal plants are known for their innate healing power. It encompasses a diverse range of plants, from little herbs to enormous trees, all of which are classified into different families within the Kingdom Plantae. Ayurveda, which has produced several therapeutic medicinal concoctions from medicinal plants, has a long history of effective use in Indian culture and tradition. As time goes on, technological advancements have led to the advancement of phytochemical and pharmaceutical sciences, providing us with a thorough understanding of the composition and biological activities of a variety of therapeutic plant products.

Nanotechnology is defined as the contemporary field of research concerned with the design, synthesis, and manipulation of particle structures ranging in size in the region of 1–100 nm (Remya et al. 2017). Nanoparticles are either organic or inorganic based on the constituent employed in its synthesis. The former is carbon based, while latter is noble metal or magnetic type.

Nanoparticles have been incorporated into nascent fields like Herbal and medicinal plant biology, which has resulted in a novel strategy of drug delivery and have been hailed as a magical ingredient in the creation of these magnificent inserts.

According to Kim and Song (2010), the synthesis of nanoparticles using noble metals is being more cosmopolitan among our society due to its inexplicable use in various consumer products ranging from toothpastes, soaps to detergents along with its use in the pharmaceutical industry. Xu et al. (2006) denoted that inorganic nanoparticles are frequently used for drug delivery due to its unique features such as ease of use, good functionality, biocompatibility, ability to get targeted into a specific cell and controlled release of drugs. For decades we are aware that nanoparticles are synthesized by chemical or physical approach. Out of them, the former involves the use of evaporation, condensation and laser ablation, while latter involves the use of reduction in metal ions in solution under conditions favorable for the synthesis of small metal aggregates (Abou El-Nour et al. 2010; Iravani et al. 2014). When looking into silver nanoparticle synthesis, the most popular one is chemical synthesis which sounds to be expensive as well as unfriendly to nature. Hence, the nascent biological approach incorporating phytochemicals from plant-based sources was employed to cover up the discrepancies and enhance its yield (Dawadi et al. 2021).

Green innovation took birth out of the repeated thought process and action plans of scientists.

Plants and its counterparts are extensively used in synthesis of nanoparticles. It is often mediated via intracellular or extracellular means, where latter involving boiling of plant extract or crushing of leaves is the mostly employed type (Rai and Yadav 2013). Further when technology progressed the green route of synthesis was chosen for replacing non-ecofriendly byproducts with eco-friendly ones. This greener route utilizes biotic entities of the environment as its incredible ingredient by altering the classical ingredients in physical and chemical methods of synthesis (Reddy et al. 2012). In other words, for smooth operation of these green route of AgNPs synthesis, the phytochemical composition of the plant extract involved is an inevitable part. Among these, the phytosynthesis of AgNPs was found to be easier than other nanoparticles, namely gold, platinum and palladium nanoparticles. Silver nanoparticles sparkle out among other metallic ones due to its remarkable physiological properties that pertain to the inherent potentiality of silver in our nature, which includes the antibacterial properties of zerovalent silver and the ability of silver salts to easily form zerovalent silver via reduction. In 2020, Lade and Shaneware remarked that formation of silver nanoparticles occurs only when water-soluble components ($AgNO_3$, plant-based capping and stabilizing agents—secondary metabolites) are converted into water-insoluble form (nanoparticles). It is believed that during the green synthesis, $Ag+$ is reduced in a single step reaction to a colored silver sol, which later on due to hyper-reactivity undergoes nucleation and increases in size. As per Balciunaitiene et al. (2021), the phytochemicals like flavonoids and proanthocyanidins are involved in the bioreduction in silver salts by acting as both capping and reducing agents at the same time.

By altering parameters like extract concentration, temperature and pH, size of AgNPs synthesized can be regulated. Studies state that extract concentration plays a dual role toward AgNPs size by regulating the presence or absence of capping and reducing agents. Briefly, it can be denoted that former at lower levels cause agglomeration of quasispherical AgNPs, whereas at higher levels results in symmetrical ones. Likewise, temperature possesses a direct relation with growth of AgNPs. Not only that, even polar solvents like methanol and ethanol do control AgNPs size by involving in its preparation and purification (Dawadi et al. 2021).

Review methodology

This review incorporates scientific literature published in the English language. Several electronic databases such as Google Scholar, PubMed, Web of Science, Research Gate, Springer Link, ScienceDirect and Scopus along with Google search engine were elaborately reviewed for retrieving information on pertinent keywords like green synthesis, medicinal plants, silver nanoparticles, green nanotechnology, respectively. Scientific articles and publications were selected from reputed journals and sorted out for extracting scholarly information on green synthesis of silver nanoparticles from plant-based sources. Scientific names of medicinal plants were checked using botanical databases like Plant List and International Plant Names Index.

A generalized search was further carried out using Google search engine to capture more documents, reports and theses from other reputed sources. The information gathered was saved on personal computers. All papers collected were screened and analyzed by assessing their titles and abstracts.

Main text

A step toward greener technology

Green nanotechnology combines the utilization of plant elements with the word green, resulting in a field rich with benefits for safeguarding the safety of life on Earth. As a result, its essential ideals are built on the fundamentals of green chemistry and green engineering (Verma et al. 2019). It was developed as a cleaning technique to eliminate the environmental and human health dangers created by rising nanotechnology production, and to replace them with environmentally friendly manufacturing methods that promote environmental sustainability. Hence, it aims to create nanomaterials that are both cost-effective and energy-efficient by using renewable recipes instead of hazardous ones. This unshakable love and harmony that nanotechnology instills in green chemistry frequently result in an unavoidable partnership that benefits humanity by providing cleaner technologies that commit to adopting a green nano-approach to scientific growth (Schmidt 2007).

Green nanotechnology, according to scientists, is a beneficial application of nanotechnology that reduces costs and dangers while also improving the environment's resilience. Green nanotechnology, more than likely, heralds the dawn of a new age, proclaiming nature's proclivity to eliminate both health and environmental concerns posed by conventional nanomaterials by replacing them with environmentally benign alternatives. As a result, as a corollary principle, it incorporates reduced pollution or waste prevention. Advances in eco-nanotoxicological research support the use of natural resources in the development of nanomaterials as a reliable solution to environmental issues. Green nanotechnology goods are created by combining the essence of aspects such as recycling, energy efficiency, safety, renewable resources, and so on under one roof (Nasrollahzadeh et al. 2019a, b).

The need to embed the goal of sustainable development into the roots of nanotechnology prompted the development of green nanotechnology. Hood (2004) described nanotechnology as an efficient cure for mitigating, preventing, and minimizing harm caused to nature and its fellow beings in 2004. Green nano-manufacturing, according to Dornfeld et al. (2013) is a valuable breakout of technology that can carve out harmless, low-cost, and adaptable nanoproducts without releasing harmful by-products. The two inseparable aims that underpin the deep core of green nano are process and product, which includes multi-skilled nanomaterials used for renewable energy generation, pollution assessment, environmental remediation, and wastewater purification (Khan 2020).

When nanoscience is combined with green chemistry, it tends to define the latter's sustainability principles. Nano-based solar cells, water treatment, energy storage devices, nanogenerators, thermal energy, and catalysis are among the six primary fields discovered as a result of this research. Green nanotechnology has successfully managed to eliminate fouling and aspires to produce newer harmless ones that are inbuilt with the ability to tackle our current environmental challenges since the beginning of nanomaterial design (Iavicoli et al. 2014). Green chemistry principles, according to Anastas and Kirchhoff (2002), are valuable assets that aid in the expansion of nanotechnology for sustainable development. Green chemistry was born into the scientific world with a strong motive to use chemicals more safely and effectively, according to Andraos (2005).

Green chemistry is defined by Naidu et al. (2008) as "chemistry that can design, develop, and generate chemical products without the risk of producing toxic waste or hazardous end products throughout the entire synthesis." The 12 green chemistry principles emphasize the importance of generating safer, cleaner, and more sustainable nanomaterials that are both environmentally benign and biodegradable (Fig. 1). Not only do these tenets focus on lowering hazardous solvent usage, improving product design for end-of-life, and improving energy efficiency and chemical techniques, but they also make it easier to synthesize and process greener and safer nanomaterials (Anastas and Eghbali 2010). Due to intrinsic strengths such as cost-effectiveness, versatility, eco-friendliness, non-toxic nature, and ease of processing, green chemistry has won over other techniques in the quest to protect mother earth and her fellow creatures from the wrathful repercussions of age-old practices (Majeed et al. 2018). This greener way of synthesis is viewed as an undiscovered zone of nanoscience and nanotechnology due to the traditional wet chemical routes for nanoparticle processing, yet it is sensitive to dramatic evolution due to its attitude of creating zero pollution to Mother Nature (Kharissova et al. 2013).

As a result, green chemistry can be said to have a direct and indirect function in the biosphere's ecological equilibrium. According to Fischer and Chan (2007), their main goal is to frame nonhazardous nanomaterials synthesizing techniques as an alternative to toxic ones that cause nanotoxicity difficulties in nature. When nanoparticles are manufactured using environmentally friendly procedures and used in the cleanup process, the term "green" takes on new meaning and value. Furthermore, Ramya and Subapriya (2012) state that biological synthesis methods using plants are the best for green nanomaterial synthesis. Green synthesis is the term for these types of synthesis. Despite being manufactured in a green manner, these nanoparticles are chemically equal in terms of efficacy and other factors. It must lead to the development of a safer version of sustainable nanotechnology as a nature-loving method (Yoshida et al. 2011).

Phytonanotechnology

> *"The proper use of science is not to conquer nature but to live in it"*
>
> *Barry Commoner*

From these well-known remarks, it is evident that empirical research should not be used to exploit Mother Nature, but rather to foster a healthy relationship with her. This idea has motivated scientists to develop a better kind of science known as green science, which is based on eco-friendly principles. Green science was developed to foster a close relationship between nature and its offspring. Its central value of healing is strangely linked to the blooming of flowers in the spring. Later on, this cleared the way for the emergence of a new field known as phytonanotechnology, which has an intrinsic desire to comfort nature's lap with its magical flora elixir. It is defined as the use of nanotechnology in plant science and plant production systems to aid in the development of smart crops (Wang et al. 2016a, b).

Phytonanotechnology heralds the start of a new era in which green chemistry and phytonanotechnology are inextricably linked. As a result, it is described as a

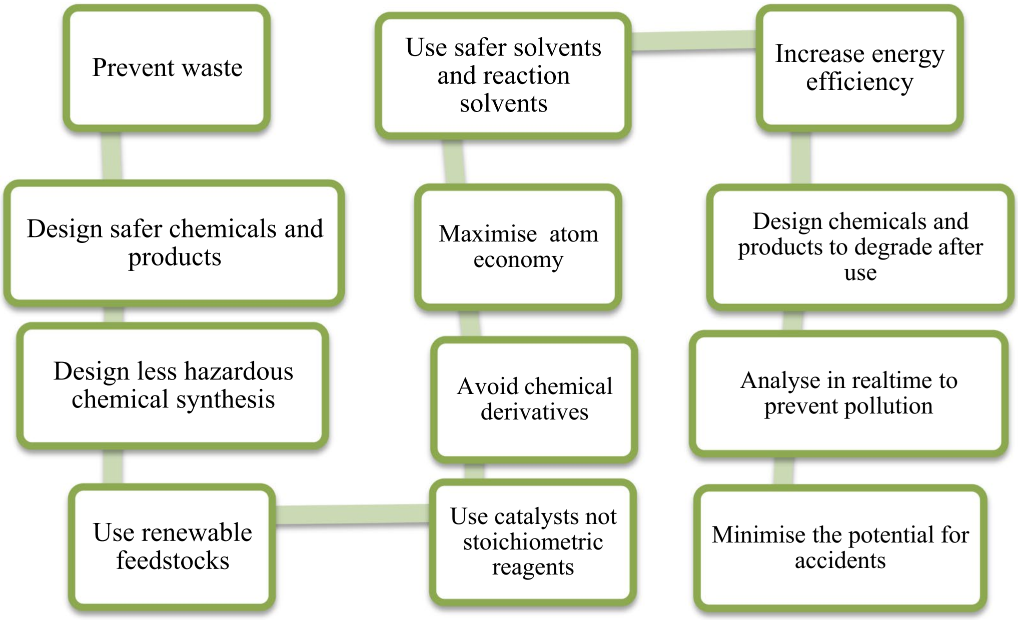

Fig. 1 Green chemistry is framed upon 12 cardinal principles' that act as the secret essence of green nanotechnology (Schmidt 2007)

cost-effective and environmentally benign non-conventional plant-based strategy to nanoparticle synthesis that replaces harmful chemicals with non-toxic plant bio-components for achieving long-term production sustainability (Elemike et al. 2020). It also has various advantages over physical and chemical approaches, such as biocompatibility, scalability, simplicity, stability, and environmental friendliness (Karupannan et al. 2020). The emergence of a new method for biologically synthesizing nanoparticles using vitamins, carbohydrates, plant extracts, biodegradable polymers, and microorganisms as reductants and capping agents, which has rekindled hope for a more environmentally sustainable ecosystem. According to Iravani (2011), extracts of plant materials are treated as the best option for stimulating increased nanoparticle synthesis. Green synthesized nanoparticles are considered more advanced than previous methods of synthesis due to their reproducibility, cost-effectiveness, and inherent stability (Kalaiarasi et al. 2010).

Scientists discovered that the green synthesis serves as a cornerstone for this unique technology after delving considerably deeper into its inner core. The biological method to nanoparticle production works in tandem with green synthesis (Fig. 2). It gleams as a first step in the new nanotechnology epic's quest for 100% sustainability. Green synthesis, according to Duan et al. (2015), is the pioneer stage for designing unique nanomaterials in an eco-friendly method that is non-hazardous to human beings and has the potential to reshape the nanomanufacturing process.

Gawande et al. (2013) said that by taking a more environmentally friendly approach to nanomaterial development, we are indirectly laying the groundwork for the development of both safer and more sustainable nanoproducts that will help to make the world a better place.

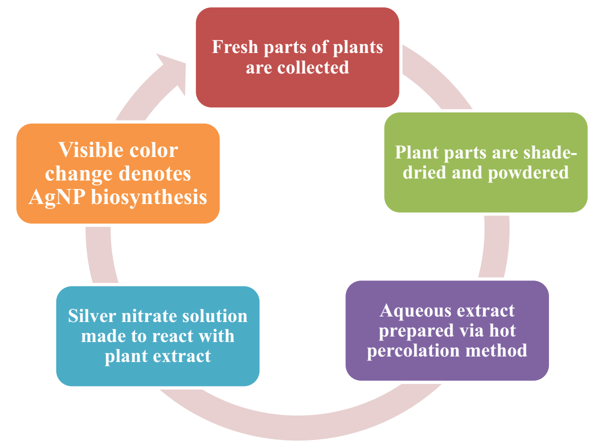

Fig. 2 Basic protocol for AgNPs synthesis via green route

This demonstrates how natural resources are used as adjutants to hazardous synthetic counterparts throughout the process (Kumar et al. 2015).

Due to the considerable benefits it sustains, the biological path chosen for nanoparticle manufacturing appears to be more useful than traditional physical and chemical procedures. The substitution of chemical reducing and capping agents with biological components from the plant-based extract is the most important of them. Secondary metabolites make up the majority of the biological components it contains (phytochemicals). Flavonoids are important in the assembly of nanoparticles because of their antioxidant properties and the free hydrogen generated during the keto-enol conversion process (Jain et al. 2009; Jayaseelan et al. 2011; Jacob et al. 2012), while phenolic acids' antioxidant effectiveness is determined by the metal-chelating activity of their aromatic rings, followed by their biosynthesizing ability. Similarly, alkaloids and organic acids are used as reducing agents in nanoparticle production due to their proclivity for releasing a reactive hydrogen atom and tautomerization of keto-enols (Nishino et al. 1999; Pankhurst et al. 2003; Parial and Pal 2015). They are thought to be involved in the redox reactions that produce nanoparticles from bulk (Vijayakumar 2013; Makarov et al. 2014).

Extracellular or intracellular mechanisms are used to carry out the essential metal ion reduction in the green route of nanoparticle formation. The former allows an aqueous plant extract to interact with the aqueous metal solution, whereas the latter requires interaction with the aqueous metal solution by a living plant or plant biomass. Individual phytochemicals were engineered to react with metal solutions as technology evolved (Dauthal and Mukhopadhyay 2016). Green production of nanoparticles follows the traditional bottom-up method, according to Sangeetha et al. (2011) and Raveendran et al. (2003), which emphasizes oxidation and reduction as the main processes. This technique was described by Ahmed et al. (2016) as atoms self-assembling into nuclei and growing into nanoparticles. Every portion of the plant appears to be a treasure in nanoparticle synthesis since it serves as a substrate for this green synthesis. Leaves, seeds, flowers, fruits, fruit peels, stems, bark, and roots are all part of it (Maniam et al. 2020).

The mechanism to be used during nanoparticle creation via the green approach is still a mystery. The specific process remains unknown since plant bio-components perform the functions of reducing, stabilizing, and capping agents. An intellectual attempt to carve out a deep understanding of the biochemical mechanisms underlying the synthesis of nanoparticles using plant-based materials is to instill a deep understanding of the biochemical mechanisms underlying the synthesis of nanoparticles using plant-based materials as a cost-effective alternative to traditional methods (Akhtar et al. 2013).

Additionally, the synthesis of nanoparticles can be divided into three stages: activation, growth, and termination (Klaus et al. 1999; Si and Mandal 2007; Kim et al. 2010; Khatoon et al. 2017). During the early phase/activation phase, metal ions are reduced, which is followed by nucleation. To put it another way, the activation phase marks the recouping of metal ions from their parent compound through the influence of biomolecules found in plants, as well as the nucleation of condensed metal ions shortly after the transformation of respective higher oxidation states to zero-valent form (Malik et al. 2014).

Nanoparticles spontaneously aggregate to create larger diameter forms throughout the growing process. A surge in this process frequently triggers the formation of nanotubes, nanorods, and nanotriangles, among other things (Makarov et al. 2014). More precisely, the growth phase entails the amalgamation of metal ions into metal nanoparticles with greater thermodynamic stability, but shape that varies widely. The termination process determines the ultimate structure of nanoparticles. These biosynthesized nanoparticles are embossed to a stable state during the termination stage by capping with plant metabolites (Sajjad et al. 2018). Plant extract's capacity to stabilize metal nanoparticles causes conformational changes in nanoparticles throughout this process. According to Tripathy et al. (2010), the reaction that occurs during synthesis is as follows:

$$\mathrm{Ag}^{+} + \mathrm{NO}_3^{-} + \text{plant extract} \rightarrow \text{AgNPs} + \text{byproducts}.$$

Water-soluble components such as $AgNO_3$, plant-based capping and stabilizing agents (secondary metabolites) are converted to water-insoluble form (nanoparticles) during the manufacture of silver nanoparticles (Lade and Shanware 2020a, b).

Silver, gold, platinum, copper, zinc, iron, palladium, and titanium are among the metal nanoparticles obtained by the green approach. Silver nanoparticles are the most common type of nanoparticle. The unusual use of AgNPs as a component of roughly 50% of nanoproducts is firmly supported by a broad range of scientific papers dating back to 2015 (Gil-Sánchez et al. 2019). Aside from these applications, AgNPs are used in a variety of other fields of science, including catalysis, biomedicine, biological imaging, sensing, photonics, optoelectronics, pharmaceuticals, pollution control, and drug delivery (Ghaedi et al. 2015). This is owing to their inherent characteristics, such as excellent conductivity, chemical stability, and catalytic activity, which endow them with antiviral, antibacterial, antifungal, anti-inflammatory, antiseptic, and biocidal properties (Ahmed et al. 2016).

Greener method for silver nanoparticles synthesis (AgNPs)

In today's age of scientific empowerment, an ocean of reports about AgNPs synthesis from plants may be found all over. Mother Earth, which provides a calm haven for an ocean of therapeutic plants, frequently persuades her biological system to work as bio-lab houses for optimal nanoparticle production. Plants and microbes are considered to be biological systems. Plants, which are rich in antioxidants, are frequently used in the production of nanoparticles. Furthermore, by boosting biocompatibility, accessibility, and simplicity of the entire process to be eco-friendly, this green technique allows the use of water as the extraction solvent (Nasrollahzadeh et al. 2019a, b). Green synthesis is a bottom-up technique (Fig. 2) in which biogenic reduction is carried out by extracts of natural compounds that have the intrinsic potential to cap, stabilize, and terminate growth (Hussain et al. 2016). The following is a general outline of how AgNPs are made:

Kingdom Plantae is home to a plethora of medicinal plants with remarkable properties. They play a big role in the green synthesis of AgNPs. The plant extract is a critical substrate for biosynthesis since it contains a number of free radical scavenging chemicals. Plant materials such as flowers, leaves, roots, fruit peels, and other plant parts are used to make plant extract, which can be dried or fresh. The former uses dried powder, whilst the latter uses finely diced plant fragments to ensure thorough extraction. Plant pieces are dried in the sun or in the shade while taking care not to lose their antioxidant value. Extraction is normally done with polar or non-polar solvents (Mohamad et al. 2014).

According to Tiwari et al. (2011), solvent diffuses into plant tissues during extraction, resulting in the solubilization of molecules with the same polarity. When doing extractions, the solvent used has a direct impact on the amount of reducing agents removed. The plant sample is dispersed into the water and constantly agitated throughout extraction. The best organic solvents for extraction are ethanol and methanol, whereas water is the most appropriate due to its clarity. Even the temperature at which the plants are extracted plays a role in achieving the best yield. At 60–90 °C the antioxidant level rises to a certain point, but it is degraded as the temperature rises further (Yu et al. 2012; Michiels et al. 2012). Likewise, other factors such as silver nitrate and extract concentrations, light intensity, pH, temperature, and incubation length all have an impact on the success of AgNP synthesis (Akhtar et al. 2013). Various literature searches reveal a slew of scholarly papers on the involvement of pH in this synthesis. Larger nanoparticles are generated at a pH range of 2 to 4, according to Dubey et al. (2010). Smaller AgNPs are more stable at basic pH because their zeta potential is lower at high acidic pH than at basic pH. Sathishkumar et al. (2009) discovered that the pH had a significant impact on AgNPs biosynthesized from *Cinnamomum zeylanicum* Blume powder and bark extract. At acidic pH, ellipsoidal AgNPs develop, but at basic pH, smaller spherical highly scattered AgNPs form. pH, according to Lade and Shaneware (2020a, b), has a significant impact on nanoparticles because of its potential to affect the electrical loads of biomolecules, which alters their efficacy to stabilize, cap, and control their growth. Khatoon et al. (2017) shown that the charge of phytochemicals in plant extracts changes with pH, allowing silver ions to cluster to these molecules. According to Sajjad et al. (2018), pH changes modify the potency to chelate and decrease metal ions, which affects the yield and structure of biosynthesized nanoparticles. Temperature, like pH, has a unique effect in AgNP synthesis, with higher heat boosting yield (Kim et al. 2010).

Apart from demonstrating the effect of pH on AgNPs, Sathishkumar et al. (2009) also showed that surface plasmon resonance exhibits high absorption peaks in response to a rise in temperature and is connected to nanoparticle size and synthesis speed indirectly. According to Verma and Mehata (2016) uniform AgNPs are generated only when temperature rises in tandem with increased silver ion consumption by high kinetic energy molecules. The time spent on completing the full process of phytosynthesis is known as the incubation or reaction phase. It could be anything from a few minutes to several hours. Secondary metabolites found in the extract are mostly responsible. Lade and Shaneware (2020a, b) later justified this by claiming that the number of secondary metabolites and the time it takes to reduce silver salt have an inverse relationship. *Psidium guajava* L. took only 90 s to produce AgNPs with a life span of 18–20 weeks (Raghunandan et al. 2011). After reacting for four hours, AgNPs o*f Azadirachta indica* A. Juss. were created with a four-week life span (Shankar et al. 2004). However, *Syzygium aromaticum* (L.) Merr. & L.M.Perry used a longer time period of 24 h to synthesize silver nanoparticles. Nanoparticle production is influenced by light conditions, whether dark or sunlight. Stable nanoparticles are only created, according to Lade and Patil (2017), when a kinetic reaction between silver salt and functional groups of phytochemicals in the plant extract is triggered by electromagnetic waves of sunlight.

Darkness is chosen as an aid during AgNPs synthesis by *Acalypha indica* L. leaf extract because light causes photooxidation of silver nitrate. The amount of leaf extract used for synthesis has an impact on the availability of phytochemicals as well as the reduction in silver ions to their stable state, which affects the incubation duration (Lade and Shanware 2020a, b). Similarly, because silver nitrate concentration has a direct link with nanoparticle size, it has a significant impact on nanoparticle creation (Dubey et al. 2010; Dwivedi and Gopal 2010). More exactly, the peak sharpness varies with a rise in absorbance value when the concentration of silver nitrate (0.25–1 mM) is changed (Park 2014).

Biological synthesis is generally carried out in vitro, which is similar to the fundamental green synthesis process. Despite the fact that the reaction takes place at room temperature, the crucial steps are distinguished by the purification of the bio-reducing agent, its mixing with an aqueous metal salt solution, and occasionally by extra heating or stirring (Rajakumar et al. 2012; Sankar et al. 2015). After the nanoparticles have been created, characterization procedures must be used to screen them further. This reveals further information about its distinct characteristics, such as size, shape, crystalline nature, toxicity, and so on. The hue of the mixed solution changes from yellow to dark brown, indicating that AgNPs have been synthesized. Recent research works pinpoint that bioreduction silver to AgNPs is disguised by its respective color change which fluctuates for plants and the synthesis method employed (Uzunuigbe et al. 2020).

According to Abdelmigid et al. (2021), AgNPs formation in pomegranate peel and coffee ground extract was depicted by its respective color variation from pale yellow and brown shades to dark brown. Likewise, in *Annona muricata* peel extract, the color change observed was from deep yellow to dark brown (Jabir et al. 2021). In other words, it can be stated that whenever a plant extract gets exposed to silver salt solution, AgNPs synthesis initiates along with visible color change. Further, this observation is confirmed by performing a UV–VIS spectroscopy of the colored solution. The resultant solution's Surface Plasmon Resonance (SPR) peaks were later confirmed using UV–VIS spectral analysis. It illustrates the bio-reduction in silver nitrate to silver by interacting with plant extracts and is regarded as the most widely used preliminary characterization approach for AgNPs due to its optical features (Mittal et al. 2012). Peaks in the wavelength range of 200–800 nm, which corresponds to a size range of 2–100 nm, are observed in silver nanoparticles, indicating SPR (Safaepour et al. 2009; Ibrahim 2015). This implies that phytochemicals prevalent in plant extract control the conversion of monovalent silver in silver nitrate to zerovalent AgNPs (Varadavenkatesan et al. 2016). FTIR analysis is also used to learn more about the chemical composition of AgNPs' surface as well as the capping agents involved in their creation. It illustrates the biomolecules that have played a role in the entire synthesis process, including bioreduction and stabilization (Narayanan and Sakthivel 2011a, b, c; Kaviya et al. 2011). Recent studies proclaim that numerous functional groups take part in AgNPs fabrication but out of them the most common ones are found to be amide (–CO–NH_2), carbonyl (–CO), and hydroxyl (–OH), respectively (Dawadi et al. 2021). AgNPs exhibit a wide array of shapes with its size either less than or greater than 100 nm. In *Odontosoria Chinensis*, the spherical AgNPs of diameters 22.3–48.2 nm were found to be fabricated due to the involvements of carboxylic acid and hydroxyl functional groups of terpenoids, tannins, polyphenols and steroids present in it (Johnson et al. 2020). While for *Parthenium hysterophorus*, spherical AgNPs of size 10.3 ± 1.7 nm were formed due to the bio-reduction silver ion by polypeptides, amine, germinal methyl and hydroxy groups (Sivakumar et al. 2020). Silver nanoparticles synthesized from aqueous bark extract of *Picea abies* were found to be remarkably large (100–500 nm) and was due to the participation of aldehydic, carbonyl, and hydroxyl groups of phenols and carboxylic acids in the respective reduction and stabilization, as per the FTIR analysis (Tanase et al. 2020). FTIR spectral analysis of AgNPs biosynthesized from *Acacia senegal* leaf extract revealed the action of hydroxyl, aromatic and amine groups on its reduction and capping (Uzunuigbe et al. 2020). XRD analysis is also used to reveal the crystalline nature of AgNPs. It displays information on translational symmetry, size, purity, and shape of nanoparticles, as well as phase identification (Sun et al. 2003). Advanced imaging techniques such as SEM-EDAX and TEM are frequently used to gather data on the morphological characteristics of AgNPs as well as their elemental characterization. Zeta potential and Thermal gravimetric analysis (TGA) are used to measure the stability and thermal characteristics of biosynthesized AgNPs. Aside from this, there are a number of approaches for decoding AgNPs in greater depth, but they are frequently underutilized.

Medicinal herbs: an immense ocean for AgNPs synthesis

Plants are preferred over microbes as the most dependable and promising alternatives for AgNPs production since the latter requires the maintenance of certain conditions for optimal synthesis. Plants that are known to be medicinal are found in almost every family. When we go deeper into our everyday routines, we may discover that our lives are entwined with a diverse range of plants, each with its own set of capabilities. It is at ease due to an old habit of incorporating folk herbal treatment into daily life. The 10 sacred flowers, also known as "Dasapushpam," are one such well-known example. It includes *Aerva lanata, Biophytum sensitivum, Curculigo orchioides, Cyanthillium cinereum, Eclipta alba, Evolvulus alsinoides, Ipomea sepiaria, Emilia sonchifolia, Cardiospermum halicacabums, and Eclipta alba, Evolvulus alsinoides, Eclipta alba, Evolvulus alsinoides.* The therapeutic powers of these miracle herbs have been noted in medicinal biology. Dasapushpam is said to depict the cultural and artistic components of Kerala's tradition, according to Varghese et al. (2010). Kerala's Western Ghats have embraced their tenacity for centuries.

Instilling a practice of manufacturing silver nanoparticles from their medicinally useful part would bring a new insight to pharmacology in terms of improving medication delivery efficacy. As a result, scientists are working hard to biosynthesize AgNPs from plants in an environmentally acceptable and sustainable manner. Our current literature collection includes a number of reports on such synthesis, as shown below. Silver nanoparticles made from *Aerva lanata* flower extract were discovered to have cytotoxicity against HeLa cells as well as antibacterial efficacy against *Klebsiella planticola.* These AgNPs predicted an SPR peak at 460 nm and were found to be polydispersed with a nanoscale size of 95 nm after TEM and SEM investigation. Its FTIR research demonstrated that carboxylic acids and secondary amines operate as bio-reducing agents in the flower extract (Kanniah et al. 2020). Its leaves, like flowers, were used to synthesize AgNPs via microwave irradiation and were discovered to be predominantly spherical with an average size of 18.62 nm (Joseph and Mathew 2015). Despite this, a complete extract of the plant was used to make spherical AgNPs with antibacterial activity that were 50 nm in size. It has an absorbance peak at 430 nm, according to its UV–VIS spectral analysis (Appapalam and Panchamoorthy 2017). The AgNPs discovered from leaf extract of *Biophytum sensitivum* were found to be well dispersed spherical ones with a diameter of 8 nm, and their SPR peak was detected at 460 nm (Kavitha et al. 2021). Joseph et al. attempted to manufacture AgNPs from *B.sensitivum* by microwave-assisted green synthesis in 2015, and were able to get nanoparticles with a diameter of 19.06 nm, as observed by TEM. AgNPs are synthesized in *Curculigo orchioides* using the leaf, root, and rhizome. Venkatachalam et al. (2017) used two types of extracts, namely boiling and grinding, to carry out the green synthesis of AgNPs. Using UV–VIS spectral analysis, silver nanoparticles from the former extract had a peak at 433 nm, whereas those from the latter had a peak at 443 nm. AgNPs were found to be spherical with a size of 5–17 nm using FESEM and HRTEM imaging. OH group-containing chemicals are used as both capping and stabilizing agents in this nanosynthesis. Due to its larvicidal, antibacterial, and anticancer properties, silver nanoparticles of size 15–18 nm were also generated from its rhizome by boiled extract, which might be molded into a potential medication (Kayalvizhi et al. 2016). Similarly, Saha et al. (2016) conducted an experiment in 2016 to optimize parameters for successful AgNP synthesis.

She demonstrated that mono-dispersed spherical AgNPs may be produced easily using 2 mM $AgNO_3$, 20% rhizome extract, pH 8, and 60^0C. The size of the AgNPs obtained ranged from 5 to 28 nm, with an SPR peak at 430 nm. Recently, in 2018, the dried roots of *C. orchioides* were used to produce crystalline spherical AgNPs with an average size of 50–70 nm and an SPR band at 440 nm after a 40-min incubation period (Dave 2018). According to recent sources, *Vernonia cinerea* has undergone taxonomic renaming and is now known as *Cyanthillium cinereum.* This plant's use in the biosynthesis of AgNPs dates back much before this revision. Sahayaraj et al. (2015) produced polydisperse crystalline AgNPs in the size range of 5–50 nm, which they discovered using SEM and XRD investigation in 2014. The role of gallic acid and glucose in the decrease and stability of AgNPs at basic pH was also revealed using FTIR research (Sivaraman et al. 2009). Not only that, but these AgNPs were found to be an effective antimicrobial agent against the bacteria *Xanthomonas campestris pv. malvacearum,* which causes bacterial blight in cotton plants. Ramaswamy et al. (2015) employed the whole plant extract for green synthesis later in 2015. By treating 5% plant extract with 1 mM $AgNO_3$ at pH 6 for 1 h at 50 °C, they were able to get the highest yield. Based on the concentrations of extract and silver nitrate at pH 6, the SPR band varied between 400 and 450 nm. Within the size range of 40–75 nm, the nanoparticles produced were predominantly spherical, polydispersed, and slightly aggregated. Zani et al. (2016) demonstrated that AgNPs biosynthesized from its leaf extract are the most effective anticancer drug for treating a cell line with acute myeloid leukemia. These nanoparticles were made by combining plant extract with salt solution in three different ratios (1:5, 1:10, and 1:20), and they were discovered to be spherical and 15.92 nm in size. AgNPs synthesis was mediated by leaf extract in the grass *Cynodon dactylon.* In 2011, Lokina and Stephen (2011) conducted an attempt, which resulted in the creation of spherical and face-centered cubic AgNPs with particle sizes ranging from 5 to 25 nm. Later that year, Sahu et al. (2013) used sunlight as a catalyst to synthesis AgNPs from leaf extract with an average size of 8–10 nm. Supraja et al. (2013) also synthesized AgNPs in 2013 by conducting optimization tests with extracts generated using various procedures. The highest yield was found in homogenized plant extract exposed to sunshine irradiation (Rastogi and Arunachalam 2011), which was supported by the presence of a prominent SPR peak at 450 nm. The size range of the AgNPs that resulted was within the range.

Eclipta alba silver nanoparticles were made by combining its leaf extract with a 1 mM $AgNO_3$ solution in a 1:9 ratio over the course of 30 min. SEM investigation revealed that the resulting AgNPs had a face-centered cubic shape with particles in the 310–400 nm size range (Premasudha et al. 2015). Suma and Navyashree (2018) succeeded in creating spherical AgNPs endowed with excellent antibacterial activity at a size of 5.8 mm by allowing *Emilia sonchifolia* leaf extract to react with 1 mM silver nitrate solution at 30^0C for 48 h. *Ipomea sepiaria* is an untapped prospective candidate in the field of green nanotechnology since it has the ability to fight cancer. Several additional related species in the Ipomea genus are widely used to biosynthesize AgNPs using green synthesis. The interaction of *Evolvulus alsinoides l*eaf extract with 1 mM $AgNO_3$ was used to attempt green synthesis of AgNPs. The produced AgNPs were spherical and ranged in size from 50 to 75 nm, exhibiting a monocrystalline phase with a face-centered cubic structure (Anbarasu et al. 2016). Previously, polydispersed spherical AgNPs with a diameter of 37–47 nm were attempted to be made by combining aqueous leaf extract and silver nitrate solution (1 mM) in a 1:9 ratio, then incubating at 37^0C for 24 h with continuous stirring at 1000 rpm (Arun Kumar et al. 2014). Shekhawat et al. (2013) began working on AgNP biogenesis from *Cardiospermum halicacabum* in 2013 by modifying the leaf extract and silver nitrate solution to react in 1:9 proportions. The visible color associated with the creation of AgNPs was visible after 25 min of shaking, and its intensity increased over the course of the 12 h incubation period. Sundararajan et al. (2016), on the other hand, found that AgNPs were generated after 30 min of mixing followed by 16 h of incubation, and that their production was maximized. These bio-AgNPs had an average crystal size of 23 nm, with a spherical shape and face-centered cubic crystal structure.

A collection of publications on nanoparticle creation by green synthesis has just been published in nanoscience. Their AgNPs production by green approach appears to be a potential arena of research due to their nutraceutical, pharmacological, and ethnobotanical relevance. The synthesis of AgNPs is aided by the use of several ayurvedic plants and their formulations. "Triphala," a well-known ayurveda compound, is utilized as a multifunctional cure for a variety of human illnesses. It's made up of *Phyllanthus emblica, Terminalia bellirica* and *Terminalia chebula* fruits, all of which have medicinal properties. Each of these fruits is used to make silver nanoparticles using a biological technique.

The fruit of *Phyllanthus emblica i*s used to produce an aqueous extract for the synthesis. Renuka et al. (2020) generated hexagonal AgNPs with an average crystal size of 30 nm and a face-centered cubic lattice in 2020. These nanoparticles were also found to be efficient against *Klebsiella pneumoniae* and

Table 1 Biosynthesis of AgNPs from different plants parts with its respective size and shape

S. no	Name of plant	Plant part used	Shape	Size (nm)	Reference
1	*Aegle marmelos*	Leaves Fruit	Spherical	60 159–181	Rao and Paria (2013) Devi et al. (2020)
2	*Acorus calamus*	Rhizome	Spherical	31.83	Nakkala et al. (2014)
3	*Asparagus racemosus*	Roots Leaves	Spherical	30–50 5–15	Khanra et al. (2016) Satyanarayana et al. (2020)
4	*Boerhaavia diffusa*	Whole plant	Spherical	25	Kumar et al. (2014)
5	*Aristolochia indica*	Leaves	Spherical/cubical	30—55	Murugan et al. (2015)
6	*Moringa oleifera*	Leaves	Rectangle	11	Nayak et al. (2015)
7	*Justicia adhathoda*	Leaves	Spherical	5–50	Bose and Chatterjee (2015)
8	*Abutilon indicum*	Leaves	Crystalline	106	Prathap et al. (2014)
9	*Hemidesmus indicus*	Leaves	Spherical	25.24	Latha et al. (2015)
10	*Calotropis gigantea*	Latex	Spherical	5–30	Rajkuberan et al. (2015)
11	*Centella asiatica*	Leaves	Spherical	30–50	Rout et al. (2013)
12	*Tribulus terrestris*	Fruit	Spherical	16–28	Gopinath et al. (2012)
13	*Aloe vera*	Leaves	Spherical, triangular	50–350	Chandran et al. (2006)
14	*Ocimum tenuiflorum*	Leaves	Cuboidal	50	Banerjee et al. (2014)
15	*Eucalyptus hybrida*	Leaves	Crystalline, spherical	50–150	Dubey et al. (2009)
16	*Euphorbia hirta*	Leaves	Spherical	40–50	Elumalai et al. (2010)
17	*Catharanthus rosesus*	Leaves	Spherical	27–30	Kotakadi et al. (2013)
18	*Gloriosa superba*	Leaves	Triangular	20	Gopinath et al.(2016)
19	*Piper logum*	Fruits	Spherical	17.6–41	Jacob et al. (2012)
20	*Piper nigrum*	Fruits	Spherical	32–100	Mohapatra et al. (2015)
21	*Plectranthus amboinicus*	Leaves	Spherical	18	Ajitha et al. (2014)
22	*Pistacia atlantica*	Seeds	Spherical	10–50	Sadeghi et al. (2015)
23	*Lansiumdomesticum*	Fruit peel	Spherical	10–30	Shankar et al. (2014)
24	*Solanum xanthocarpum*	Fruit	Spherical	10	Amin et al. (2012)
25	*Zingiber officinale*	Rhizomes	Spherical	10	Singh et al. (2011)
26	*Alstonia scholaris*	Bark	Spherical	50	Shetty et al. (2014)
27	*Tinospora cordifolia*	Leaves	Spherical	30	Selvam et al. (2017)
28	*Morinda citrifolia*	Roots	Spherical	30–55	Suman et al. (2013)
29	*Tephrosia tinctoria*	Stem	Spherical	73	Rajaram et al. (2015)
30	*Allium sativum*	Leaves	Spherical	4–22	Ahamed et al. (2011)

Staphylococcus aureus bacterium strains. *Terminalia chebula* leaf and fruit extracts are used to make silver nanoparticles. Edison and Sethuraman (2012) made AgNPs from its fruit extract in 2012 by combining 1 ml of it with 25 ml of 0.01 M silver nitrate at room temperature. They were able to observe the stability of nanoparticles as they were elevated to a pH of neutral. AgNPs were discovered to be crystalline with a size of roughly 25 nm and to have catalytic activity toward dye degradation via the electron relay effect during characterization. Espenti et al. (2016) used *T. chebula* leaf extract for a study. They made the synthesis by combining leaf extract with 0.01 M $AgNO_3$ and shaking it for half an hour at 100 rpm at room temperature. The resulting nanoparticles were uniformly scattered spherical nanoparticles with an average diameter of 60 nm. AgNPs are biosynthesized by *Terminalia bellirica* using its fruit and kernel extract. Patil et al. (2017) produced biogenic AgNPs in 2017 by combining its aqueous fruit extract with 3 mM $AgNO_3$ and microwave irradiating the mixture. The AgNPs generated were practically sphere-shaped with a size of 20.6 nm and were examined for antibacterial and antibiofilm efficacy, ensuring its use as a nanocatalyst in the nanomedical industry. Sharma (2021) stated in 2021 that AgNPs may also be made from an ethanolic extract of its fruits. In addition to these reports, the well-known formulation "Triphala" is also employed for green manufacture of silver nanocolloids. These were designed with the goal of enhancing the synergistic effect of silver and extract when used together to treat human illnesses. Triphala extract was mixed in 1:2 with 1 mM silver nitrate solution, then microwave irradiated for 2–5 min to form nanocolloids. UV–VIS spectrum studies supported its development. It has an average size of 242.2 nm, according to characterization (Ranjani et al. 2019). In addition to these publications, green synthesis of silver nanoparticles was carried out in a variety of other plants under ideal conditions, using plant parts such as seed, fruit and its peel, stem, bark, and latex.

The oil-producing plant *Jatropha curcas*, which has natural therapeutic properties, synthesizes AgNPs via the green method by employing its latex and seed extract. Silver nanoparticles generated from its aqueous seed extract had a diameter of 15–50 nm and a radius of 10–20 nm, whereas those synthesized from its latex had a radius of 10–20 nm (Bar et al. 2009a,b).

The manufacturing of nanoparticles is a never-ending process. This is backed up by the valuable medicinal plant treasure trove found in our forest land. Due to the amazing potentialities, these plants continue to add reports relevant to AgNPs synthesis (Table 1) they promise connected sectors of nanoscience such as nanomedicine and nanopharmacology. The biosynthesis of green silver nanoparticles from diverse plant sources is therefore listed and depicted below (Table 1).

In a word, humans would never have been able to establish a nascent technology for manufacturing nanoparticles without the presence of plants in the biosphere. In other terms, it can be defined as a healthy partnership in which plant sources and nanosynthesis are intertwined, allowing nanotechnology to be empowered for sustainable growth.

Conclusions

Scientists can establish the notion of "green nano" by combining sustainability into nanosynthesis, which has paved the way for green route nanoparticle synthesis. In a nutshell, this new approach is dubbed "green nanotechnology," because it is based on green chemistry. It promotes an environmentally benign and cost-effective method of producing nanomaterials, ensuring a future world with a much safer ecosystem. Furthermore, scientists' efforts to create silver nanoparticles in order to protect people's lives will prove to be a blessing in disguise in the coming years. Plants are the main element in sustainable nanosynthesis, which ensures the earth's well-being. Plants are frequently regarded as the center of gravity in our existence, as they are solemnized as the elixir of life by pioneering green synthesis of silver nanoparticles. Since the last era, plant extracts' powerful decreasing and capping abilities have broadened the scope and literature efforts in this area. Our planet is endowed with a vast array of mystical plants that can both flourish and nourish our life. However, because of our inborn need for a lavish lifestyle, we frequently overlook them, making survival in the biosphere the most difficult. We willfully forget our commitment to nature in our desire to instill an affluent lifestyle. Scientists have been driven to carve out a safer form of nanotechnology based on the traditional concept of sustainable development as a result of this mindset. Such efforts have not only made life easier, but they have also sparked greater research in this area, allowing the creation of compounds that aid in functionalization.

Abbreviations

AgNPs: Silver nanoparticles; SPR: Surface plasmon resonance; UV–VIS: Ultraviolet–visible; FTIR: Fourier-transform infrared spectroscopy; XRD: X-ray diffraction; TEM: Transmission electron microscopy; SEM: Scanning electron microscopy; EDAX: Energy-dispersive X-ray analysis; TGA: Thermogravimetric analysis; $AgNO_3$: Silver nitrate.

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