Review Article

Reviewing the Tannic Acid Mediated Synthesis of Metal Nanoparticles

Tufail Ahmad

Applied Science and Humanities Section, University Polytechnic, Faculty of Engineering & Technology, Aligarh Muslim University, Aligarh 202002, India

Correspondence should be addressed to Tufail Ahmad; tufailahmadphys@gmail.com

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Metal nanoparticles harbour numerous exceptional physiochemical properties absolutely different from those of bulk metal as a function of their extremely small size and large superficial area to volume. Naked metal nanoparticles are synthesized by various physical and chemical methods. Chemical methods involving metal salt reduction in solution enjoy an extra edge over other protocols owing to their relative facileness and capability of controlling particle size along with the attribute of surface tailoring. Although chemical methods are the easiest, they are marred by the use of hazardous chemicals such as borohydrides. This has led to inclination of scientific community towards eco-friendly agents for the reduction of metal salts to form nanoparticles. Tannic acid, a plant derived polyphenolic compound, is one such agent which embodies characteristics of being harmless and environmentally friendly combined with being a good reducing and stabilizing agent. In this review, first various methods used to prepare metal nanoparticles are highlighted and further tannic acid mediated synthesis of metal nanoparticles is emphasized. This review brings forth the most recent findings on this issue.

1. Introduction

Owing to the nanoscale dimension (in the range of 1–1000 nm), nanoparticles enjoy a leading edge in the fields of nanoscience and nanotechnology. Recent years have witnessed increased interests of scientific community in nanomaterials particularly metal nanoparticles in various areas ranging from material science to nanotechnology [1–3]. Although nanomaterials have begun to be sought after only recently, the notion dates back to the early 20th century [3]. Humans have developed and used nanomaterials since a very long time as evidenced by the ruby red colour of some glass which is due to the entrapment of gold nanoparticles in the glass matrix. Appearance of ruby red colour of the colloidal gold solution results as a formation of small gold nanoparticles [4]. Medieval potteries embellished with glaze or luster display different characteristic colours that result from special optical properties of the glaze which themselves arise due to the random dispersion of metallic spherical nanoparticles within the glaze [3]. The properties of the glaze have been well enumerated in 1857 by Michael Faraday in his revolutionary study “Experimental relations of gold (and other metals) to light” [3, 5].

The nanoscale dimension and high surface area to volume ratio of nanoparticles makes their physicochemical properties quite different from those of the bulk materials [3, 5]. This makes nanomaterials capable of being potentially applied in diverse fields including photonics and electronics, sensing, imaging, information storage, environmental remediation, drug delivery, and biolabelling [3]. It has been well documented that the optical, electronic, and catalytic properties of metal nanoparticles are functions of nanoparticle size, shape, and crystal structure. For instance, differently shaped nanostructures of silver and gold embody unique optical scattering properties [3, 6]. While a single scattering peak is shown by highly symmetric spherical particles; multiple scattering peaks in the UV-vis range are exhibited by anisotropic nanoparticles like rods, triangular prisms, and cubes exhibit as a result of highly localized charge polarizations at corners and edges [3]. This developed increased interest of scientific community in the synthesis of metal nanoparticles of defined morphology. Various procedures have been developed for the
Figure 1: Molecular structure of tannic acid (C_{76}H_{52}O_{46}) carrying numerous phenolic groups.

synthesis of metal nanoparticles and nanomaterials including physical, chemical, and biological methods. Numerous reducing agents have been used to reduce metal salts to form metal nanoparticles; for example, tri-sodium citrate [7–9] and sodium borohydride [10] are being used for the reduction of gold chloride and silver nitrate solutions to form gold and silver nanoparticles, respectively, for decades. Tannic acid, a plant derived polyphenolic compound [11] (Figure 1), has also been exploited as a reductant of metal salt solutions. Ostwald in as early as 1917 reported that chloroauric acid solutions can be reduced to gold nanoparticles employing tannin even when tap water is used to prepare aqueous solutions [12]. Ostwald’s protocol was replicated by Turkevich et al. [13] in 1951 who reported generation of gold particles with size to be 12.0 ± 3.6 nm. Mülfordt in 1982 [14] prepared colloidal gold nanoparticles employing tannic acid as an additional reductant. Moreover, tannic acid has also been an essential component of the extensively used Slot and Geuze protocol proposed in 1985 [15] for synthesizing gold nanoparticles in the size range of 3–17 nm. This gives the historical significance of tannic acid being used as a reductant for metal nanoparticle synthesis. Despite that the first exploitation of tannic acid mediated nanoparticle synthesis possibly dates back to early 20th century [11], its use remained subdued for a finite period of time after that owing to the extra edge enjoyed by citrate as a reducing agent for metal salts. However, scientific community has recently revisited interest in this compound owing to its properties of being a reducing as well as stabilizing agent [16, 17].

Tannic acid has been well studied for its antioxidant, antimutagenic, and anticancer properties [18, 19]. Tannic acid has been reported to harbour inhibitory action against skin, lung, and forestomach tumors caused by polycyclic aromatic hydrocarbon carcinogens and N-methyl-N-nitrosourea in mice [18, 20, 21]. Glucose occupies the central core position in the tannic acid structure whose hydroxyl groups are attached to one or more galloyl residues [16]. At its natural acidic pH, tannic acid behaves as a weak reducing agent which can induce growth of only seeds to nanoparticles at room temperature [16, 22]. Tannic acid owing to the pKa value between seven and eight, as a function of the degree of dissociation, partially gets hydrolysed into glucose and gallic acid moieties under mild acidic/basic conditions [16, 23, 24]. At alkaline pH, gallic acid induces formation of silver nanoparticles from silver nitrate rapidly at room temperature [16, 25], but the poor stabilization potential of gallic acid leads to aggregation of particles in solution. However, glucose harbours the property of being a good stabilizing agent at alkaline pH but concomitantly is a weak reducing agent at room temperature [26]. These facts enumerate the attribute of tannic acid of being an ideal reducing and stabilizing agent under alkaline conditions at room temperature. The aggressive reducing properties of tannic acid owe to the numerous phenolic groups in its structure. These phenols take part in redox reactions by forming quinones and donating electrons. The donated electrons reduce the oxidised metal ions in metal salts to form corresponding metal nanoparticles. The reaction mechanism of phenol (present in tannic acid) based reduction of metal ions is outlined in Figure 2. In this review first we will discuss the various methods used for the synthesis of metal nanoparticles in general. Further, we will specifically review the synthesis procedures for silver, gold, and palladium nanoparticles with special emphasis on tannic acid mediated synthesis of these particles since tannic acid has begun to be used as a universal reductant of gold, silver, and palladium salts for the production of respective nanoparticles. We will discuss the most recent findings on this issue.
2. Synthesis of Metal Nanoparticles

Numerous physical and chemical methods have been used to carry out the synthesis of metal nanoparticles that include laser ablation, ion sputtering, solvothermal synthesis, chemical reduction, and sol-gel method [3, 27–31]. Moreover, biological method is also being used to fabricate metal nanoparticles [3, 32, 33]. Nanoparticle synthesis approaches can be basically divided into two: the top-down approach and the bottom-up approach [3]. The concept of top-down approaches is to create nanoscale objects by using bulky, externally controlled microscopic devices for directing their assembly, while bottom-up approaches adopt molecular components that are built up into more complex assemblies [3]. Microfabrication techniques are often used for top-down approaches, wherein externally controlled equipment are exploited for shaping materials into the required shape and size by cutting or milling. Photolithography and inkjet printing which fall under micropatterning techniques are well-known examples of top-down approach. On the other contrary, bottom-up approaches use the self-assembled properties of single molecules into some useful conformation [3]. Various physical and chemical methods for metal nanoparticle synthesis are described in the following section.

2.1. Laser Ablation. Laser ablation can be used to obtain colloidal nanoparticles solutions in a number of solvents [3, 28]. Plasma plume generated in response to laser ablation of bulk metal plate dipped in liquid solution on condensation forms nanoparticles. This method being conceived as “green technique” is used in place of the chemical reduction method for synthesizing noble metal nanoparticles. Nevertheless, this method suffers a setback owing to high energy required per unit of metal nanoparticles generated and the feeble control over the growth rate of the metal nanoparticles.

2.2. Inert Gas Condensation. The most widely applied method at laboratory scale for metal nanoparticle synthesis is inert gas condensation (IGC) which was introduced by Gleiter in 1984 for iron nanoparticle synthesis [3]. In IGC, the small particles synthesized as a result of condensation of metals evaporated in ultra high vacuum chamber grow by Brownian coagulation and coalescence and ultimately form nanoparticles. This technique has recently been applied for size-controlled synthesis of gold or palladium nanoparticles and varied-sized gold nanoclusters for nonvolatile memory cell applications [34, 35].

2.3. Sol-Gel Method. The sol-gel process is a recently developed wet-chemical technique for the synthesis of nanomaterials. Sol-gel process is used for the generation of inorganic nanostructures by first forming a colloidal suspension (sol) and then gelation of the sol to integrated network in continuous liquid phase (gel). Size and stability of metal and metal oxide nanoparticles have been controlled by inverted micelles, polymer blends, block copolymers, porous glasses, and ex situ particle-capping techniques [3, 36–39]. Despite these features, the aqueous sol-gel chemistry is marred by the complexity of process and amorphous nature of the as-synthesized particles.
2.4. Hydrothermal and Solvothermal Synthesis. Synthesis of inorganic materials by hydrothermal and solvothermal technique is amongst the important methodologies for nanomaterial synthesis [3]. For hydrothermal synthesis, the synthetic process is required to occur in aqueous solution at temperature higher than the boiling point of water, while in solvothermal method the reaction takes place in organic solvents above their boiling points (at temperatures 200–300°C). TiO\textsubscript{2} photocatalysts have been reported to be produced by hydrothermal process [40]. Low cost and lower energy consumption make hydrothermal process suitable for industrial production. Solvothermal process on the other hand increases the synthetic diversity as it enables to choose among numerous solvents or mixture thereof. For instance, highly reactive TiO\textsubscript{2} nanocrystals were produced in hydrogen fluoride and 2-propanol solvent mixture [41].

2.5. Colloidal Methods. Colloidal methods have been used for long to control the nucleation and growth of metal nanoparticles [3, 12, 42–44]. In colloidal method, metal salts are reduced by chemical reducing agents such as borohydride, citrate and hydrazine to produce metal nanoparticles which are further stabilized by capping agents to avoid coalescence of the particles. Varying the concentration of these chemical reductants influences the size, shape, and dispersity of produced nanocrystals. Moreover, concentration of metal salts also affects the size and dispersity of generated nanocrystals when such chemical reducing agents are used to reduce metal salts. Recently, reduction of metal salts by tannic acid has attracted attention of scientific community since it fulfils the requirement of a chemical reductant, but itself is a plant derived compound. Hence, it renders the characteristics of green synthesis. In the succeeding section, we will be discussing synthesis of silver, gold, and palladium nanoparticles employing tannic acid.

3. Silver Nanoparticles Synthesized Using Tannic Acid

The unique size and shape dependent optical, electrical, and chemical properties of silver nanoparticles open avenues for their application in diverse fields. They possess antimicrobial properties and can be incorporated in biosensor materials, composite fibres, cryogenic superconducting materials, cosmetic products, and electronic components [10]. Numerous physical and chemical methods have been exploited for generating and stabilizing silver nanoparticles [45, 46]. Silver nanoparticles have been synthesized using chemical reduction method, electrochemical procedure, physiochemical reduction, or radiolysis. For chemical reduction, various organic and inorganic reducing agents are in use [10]. These chemicals are usually hazardous and sometimes require energy inputs. Therefore, there is increasing interest in producing nanoparticles using environment friendly methods, that is, green methods. In this context, use of environmentally safe “green” reducing agents is entailed. Several recent reports have made significant progress towards this goal by using amino acids, vitamins, polysaccharides, and extracts of bioorganisms. However, very recently, tannic acid being a polyphenolic plant extract has been given attention since it is an aggressive reducing agent and behaves as stabilizer as well.

The study conducted by Cataldo et al. [47] reveals that silver nanoparticles synthesized employing tannin make more stable colloidal solutions than those prepared by reduction of silver salt by NaBH\textsubscript{4}. Sivaraman et al. have demonstrated that silver nanoparticle size can be controlled by molar ratio variation of tannic acid to silver nitrate [16]. They found that tannic acid can be used as a reducing and stabilizing agent for silver nanoparticle synthesis within a few minutes. An increase in particle size with increasing molar ratio of tannic acid/silver nitrate indicated that tannic acid acts as an organizer for facilitating nucleation. Moreover, the synthesis was found to occur at room temperature itself. The silver nanoparticles were synthesized over a wide range of values of the initial molar ratio of tannic acid to silver nitrate. Stable colloidal dispersions were formed in all instances. Therefore, they infer that each tannic acid molecule acts as a five-armed chelator and that atomic reorganization occurs within such complexes facilitating nucleation.

Although tannic acid has been previously utilized as a reducing agent in the presence of additional stabilizers [48] or as both the reducing and stabilizing agent [49, 50] but the reaction times reported lie between half to two and a half hours at 80°C, whereas the particle sizes reported are >15 nm. The crucial difference between the study conducted by Sivaraman et al. [16] and the earlier reports is that the pH of the tannic acid solution was adjusted prior to the addition of metal salt. The alkaline pH environment enhanced the reducing and stabilizing capability of tannic acid allowing room temperature synthesis of silver nanoparticles in seconds, and also enabling variation of the mean size from 3 to 22 nm. The increase in particle size with increasing molar ratio of tannic acid to silver nitrate indicates a third role for tannic acid as an organizer for facilitating nucleation. This concept of using tannic acid at alkaline pH as a reducing, organizing, and stabilizing agent is easily extendable to other elements that are known to chelate with tannic acid [16].

Moreover, Călinescu et al. [51] have demonstrated the synthesis of silver nanoparticles in the presence of tannic acid along with poly-vinyl alcohol. Their study enumerates that by varying the molar ratio between silver nitrate/poly-vinyl alcohol and silver nitrate/tannic acid at different NaOH concentration reaction time, temperature and microwave power level renders to develop a fine control over the nanoparticle size and distribution. Gupta et al. [52] have found that silver nanoparticles synthesized employing tannic acid bear antibacterial activity against multidrug resistant human pathogens. Silver nanoparticles synthesized using tannic acid have also been evaluated for release of silver in natural waters [53]. It has been found that tannic acid functionalized silver nanoparticles are more prone to silver release in comparison to citrate coated silver particles in water reservoirs.

Nanoplates as well as nanoshells of silver have been synthesized using tannic acid. Tannic acid has been reported to induce formation of silver nanoplates at room temperature. The synthesis has been found to be a seedless process where
tannic acid plays the role of a reducing as well as a capping agent [54]. Very recently, tannic acid (along with sodium citrate) mediated controlled synthesis of low polydispersity Ag@SiO₂ core-shell nanoparticles has been reported. These nanoparticles have been found to have applications in plasmonics [55].

4. Gold Nanoparticles Synthesized Using Tannic Acid

The unique optical, electronic, and molecular-recognition properties of gold nanoparticles make them the subject of substantial research embodying applications in a wide variety of areas, including electron microscopy, electronics, nanotechnology, and materials science [18]. Specifically gold nanoparticles in the 1–10 nm size range have size-tunable physicochemical properties that are useful in a wide variety of applications such as cancer diagnostics, catalysis, Raman and fluorescence spectroscopy, selective ionisation of biomolecule, water purification, drug delivery, photothermal therapy, and optoelectronics [18, 56–59]. Colloidal synthetic procedure being versatile and relatively easy is better than other chemical methods in vogue for the synthesis of gold nanoparticles [60]. This method allows control over seed size and seed size distribution since the experimental parameters like reactant concentration, addition of stabilizers, mixing rate, and so forth, can be tuned and manipulated as per the requirement. A variety of chemical reagents being able to reduce gold ions have been exploited for gold nanoparticle synthesis. Preparation of thiol-functionalized gold nanoparticles by chemical reduction of soluble Au(I)-thiolates has been reported by Corbierre and Lennox [61]. Long et al. [62] prepared gold nanoparticles exploiting trisodium citrate as reductant and further studied their optical properties. Gold nanoparticles have also been generated by ethanol assisted reduction of tetrachloroaurate ion in the presence of sodium linoleate [63]. Moon et al. [64] have demonstrated the cetyltrimethylammonium bromide (CTAB) mediated synthesis of gold nanoparticles in sodium dodecyl sulfonate (SDS) aqueous solution.

Synthesis of gold nanoparticles using tannic acid has begun to be investigated recently owing to its attribute of being a "green technique." Influence of tannic acid alone and in combination with citrate has been observed on the size of synthesized gold nanoparticles [65]. It has been reported that when the mixture of tannic acid and citrate is used to reduce gold chloride solution, the gold nanoparticles formed are significantly smaller than those observed when only tannic acid is used as a reductant [65]. Mahl et al. [66] have reported synthesis of gold, silver, and gold–silver bimetallic nanoparticles using a modified citrate reduction method where tannic acid has been used. The use of mixture of citrate and tannic acid led to reduction in size of formed nanoparticles by a factor of 3. Sivaraman et al. [11] studied how pH affects the size distribution of gold nanoparticles produced in response to reduction of gold chloride solution by tannic acid. They report that the pH of precursor solutions, mode of contacting, and the dynamics of stabiliser adsorption
nanoplates towards the oxidation and reduction of \( \text{H}_2\text{O}_2 \) has been enumerated in the study. Moreover, they successfully demonstrate that such gold nanoparticles can be used as building blocks for creating biosensor capable of detecting glucose in buffer as well as human serum. Moreover, Untener et al. [70] have demonstrated a distinctive uptake of tannic acid coated gold nanorods by endosomes and their unique distribution within the cell. Their study reveals that tannic acid functionalized gold nanorods maintain their integrity after being endocytosed by the keratinocyte endosomes which indicates their potential candidacy as nanodelivery agents, nanobioimaging tools, and nanotherapeutics.

5. Palladium Nanoparticles Synthesized Using Tannic Acid

Although in the last few decades, the coinage metals like gold and silver had been the focus of the nanoscientific community leaving the transition metals at the backdrop of the research field. However, recently transition metals have begun to prove their mettle when their properties as metal nanoparticles are being harnessed [71, 72]. Transition metal nanoparticles are majorly being exploited in the area of catalysis as the high surface area to volume ratio of nanomaterials makes them highly efficient as potential catalysts. Palladium nanoparticles are one of the transition metal nanoparticles being widely applied in homogenous and heterogenous catalysis [72–75] although they find applications in sensing, chemoeoptical transducers, and plasmonic wave guiding as well [72, 76–78]. Palladium nanoparticles being capable of adsorbing hydrogen are extensively applied in hydrogen storage [72, 79, 80]. Palladium nanoparticles have been prepared by various methodologies including chemical and electrochemical reduction [81, 82], ion exchange [83], vapor deposition, thermal decomposition [84, 85], and polyol method [86]. As discussed earlier, biological and eco-friendly green technologies are at the leading edge of nanoscience and nanotechnology in the current era [87, 88]. Moreover, wide and unique applications of nanoparticles demand economically viable approaches for their synthesis. Metal nanoparticle synthesis entails the use of a reducing agent and a stabilizer for the reduction of a metal salt and further capping of metal nanoparticles, respectively, to avoid nanoparticle collapse and coalescence [89]. Tannic acid has been used as a reducing and protective agent in gold nanoparticle synthesis since time immemorial and recently it has begun to be widely applied for synthesis of other metal nanoparticles which include silver and palladium.

Very recently, Kumari et al. [72] demonstrated an economically viable and efficient procedure for the preparation of palladium nanoparticles exploiting tannic acid. They enumerate a green method for the reduction of \( \text{Pd}^{2+} \) ions to nanometer size using tannic acid. The procedure demonstrated by them neither necessitates the use of any superfluous stabilizing or capping agent nor involves any extreme operating conditions such as high pressure. They synthesized palladium nanoparticles both at room temperature and boiling conditions and found that the nanoparticles formed at the former environmental cue were more stable than those formed at latter condition. Hence, they conclude that stable palladium nanoparticles can be prepared at room temperature by sheer use of tannic acid as reducing agent for palladium salt and capping agent of formed nanoparticles. FTIR analysis performed in the study demonstrates the role of poly-phenolic groups in reducing \( \text{Pd}^{2+} \) ions. They state the development of that simple method for the synthesis of metal nanoparticles is desirable over other methods because of its facile, environment friendly, quick, and one-step approach. Moreover, Devarajan et al. [90] have reported that simultaneous addition of trisodium citrate and tannin to the gold and palladium salt aqueous solutions leads to formation of 4–7 nm sized bimetallic gold-palladium nanoparticles.

6. Other Metal Nanoparticles Synthesized Using Tannic Acid

There are also other metals which have been reduced to nanoparticles employing tannic acid wholly or as a coreductant. Tannins isolated from the biomass of Medicago sativa (alfalfa) have been found to be capable of reducing gold chloride to gold nanorods and zinc salts to zinc nanoparticles [91]. Moreover, they were also found capable of forming bimetallic nanoparticles, lanthanide clusters, iron oxide, and magnetite nanoclusters [91]. Herrera-Becerra et al. [92] have also demonstrated tannin mediated biosynthesis of iron oxide nanoparticles. In a recent study, magnetic carbon-iron oxide nanoparticles have been synthesized using tannin in combination with a microwave-based thermolytic process [93]. The iron oxide nanoparticles generated employing this process have been found to be embedded within a carbon matrix in small nanoclusters (less than or equal to 100 nm). Recently, Chang et al. [94] have reported preparation of 1,5-diaminoanthraquinone nanofibers (DAAQNfs) decorated with small platinum nanoparticles (PtNPs) synthesized using tannic acid as a reducing agent. They found the resultant PtNP/DAAQNFS composites to exhibit a good catalytic activity toward reduction of 4-nitrophenol to 4-aminophenol by NaBH4. In an earlier study, Huang et al. [95] exploited bayberry tannin as a stabilizer to prepare supported platinum nanocatalysts. Preparation of gold-platinum bimetallic nanoparticles has also been reported employing tannic acid [96]. To a mixture of gold chloride and platinum chloride, addition of tannic acid and citrate led to the formation of bimetallic gold-platinum nanoparticles [96].

Ni/graphene nanocomposites have also been prepared using tannic acid. Very recently, Lu et al. [97] prepared novel Ni(II)-based metal-organic coordination polymer nanoparticle/reduced graphene oxide (NiCPNP/rGO) nanocomposites employing hydrothermal treatment of the mixture of tannic acid functioned graphene oxide and NiCl(2) aqueous solution in N,N-dimethylformamide. They found that the NiCPNP/rGO nanocomposite-modified electrode could exhibit high electrocatalytic activity for glucose oxidation in alkaline medium and hence could be used as a glucose sensor in human blood serum.
7. Reduction Mechanism of Metal Salts by Tannic Acid

Tannic acid mediated reduction of metal salts and synthesis of metal nanoparticles is outlined in Figure 3. Gallic acid molecules and glucose polymerise to form tannic acid. Tannic acid being an antioxidant is rich in electrons and embodies the capability of liberating freely reactive hydrogen atom [18]. Presence of a hydrophobic “core,” a hydrophilic “shell,” and above all the polyphenolic nature of tannic acid make it an effective antioxidant [18] combined with an aggressive reducing agent. Numerous polyphenols bear antioxidant nature owing to the relative facilenes of donating hydroxyl group to a free radical and the potency of the aromatic ring to carry an unpaired electron. Hence, the hydroxyls of the phenolic groups present in the tannic acid may be responsible for reducing chloroauric acid. Carboxylic acid groups (COOH) present in the tannic acid lose their hydrogen atoms to become carboxylate ions (COO$^-$) during the reduction process. The COO$^-$ so formed attaches to the surface of metal nanoparticles along with the remaining part of the polymer to act as surfactant and stabilize metal nanoparticles by electrosteric stabilization [18]. Various factors like pH, temperature, and molar ratio of metal salts to tannic acid have been found to play a decisive role in the generation of nanoparticles of various shapes (Figure 4).

8. Conclusion and Future Perspective

Herein, we first reviewed various methods for metal nanoparticle synthesis and further shifted our focus to tannic acid mediated synthesis of metal nanoparticles since tannic acid being a good reductant and eco-friendly compound is currently in vogue for the reduction of metal salts to form metal nanoparticles. From the findings enumerated in the review, it becomes apparent that tannic acid can act as a universal
reducing agent for silver, gold, palladium, platinum, nickel, zinc, iron, and other metallic salts to form their respective metal nanoparticles. Exploitation of tannic acid provides an opportunity for rapid, facile, economically viable, and eco-friendly synthesis of metal nanoparticles in general without requiring specific chemical reductant for each metal salt. pH, temperature, and molar ratio of the metal salt and tannic acid have been found to influence the synthesis of metal nanoparticles from tannic acid. However, a defined pattern of nanoparticle synthesis for various metals in response to variation in these parameters cannot be worked out from state-of-the-art findings. To obtain a complete picture in this regard, further studies on tannic acid mediated metal nanoparticle synthesis have to be performed. Since the nanoparticles formed employing tannic acid have smaller diameters, this can open avenues in future for them to be exploited in therapeutics, drug delivery, and bioimaging as smaller particles cannot be uptaken by the phagocytic system of the body, remain in circulation for a long time, and therefore can have enhanced targeting potential.

Conflict of Interests

The authors declare that there is no conflict of interests.

References


X. Huang, L. Li, X. Liao, and B. Shi, "Preparation of platinum nanoparticles supported on bayberry tannin grafted silica..."

