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Green Synthesis of Metallic and Carbon Nanostructures

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Abstract

The technological and biomedical applications of low toxicity and eco-friendly organic compounds are nowadays increasingly attracting the attention of researchers in nanoscience, who are aiming for more biocompatible and nanostructured systems for their application in antineoplastic therapies. This study presents the significance of “green components” in the production of graphene, metallic, and semiconductor nanoparticles, due to their antioxidant and antitumor properties. The formation of nanostructures is caused during green synthesis methods by organic molecules or carboxylic acid groups present in some plant extracts; for this reason, we include here a recapitulation and analysis of the role of carboxylic acids in those systems (organic). Furthermore, we propose the use of the extract from *Opuntia ficus-indica* cladodes to obtain metallic and carbon nanostructures, as an alternative biosynthesis method for the development of future nanobiotechnological applications.

Keywords: green synthesis, nanoparticles synthesis, carbon nanostructures, carboxylic acid

1. Introduction

Several nanoparticle synthesis methods are applied nowadays in different scientific fields; furthermore, based on the type of process (physical, chemical, or biological) and the conditions the synthesis is undertaken, they allow a control of the shape of the material, thus managing their application more accurately [1, 2]. With the objective of adopting eco-friendly methods that help to reduce the pollution caused by some toxic compounds and to exploit the local natural resources, the biosynthesis of nanostructured materials (green methods)

has been undertaken through antioxidant microorganisms and agents obtained from local plant extracts [3–5]. Thus, the use of green synthesis in nanotechnology is fundamental in scientific research in nanoscience, mainly, in order to find medical applications of the nanostructures that reduce toxicity risks while being biocompatible [6–8]. There is evidence of nanoparticles obtained through size-tunable biosynthesis [9, 10] and different technological and biocompatible applications. For instance, Ag nanoparticles show antibacterial and anti-tumor properties and have potential use in antineoplastic treatments [11–14]; furthermore, they are applicable in SERS (surface-enhanced Raman spectroscopy) [15]. Gold nanoparticles between 20 and 25 nm present catalytic activity [16], and ZnO nanoparticles with a range between 9.6 and 25.5 nm present antibacterial and photocatalytic applications [17]. Pooja et al. synthesized biocompatible gold nanoparticles using karaya gum, which can be used in the elaboration of antineoplastic medications [18]. Biocompatible silver nanoparticles were obtained from the extract of *Rosa damascen* petals, which have anticarcinogenic properties against pulmonary adenocarcinoma [19]. Patra et al. synthesized gold and silver nanoparticles with *Butea monosperma* leaves; this nanoparticle system inhibits the growth of cancer cells, and these authors consider that the synthesis of these nanoparticles is important in biomedicine for the development of cancer treatments [20]. The biosynthesis of nanostructured systems thus appears to be a valuable tool for nano-biotechnological applications in nanoscience around the world.

Similarly, the green synthesis is used in the graphene and bimetallic nanoalloys obtained. Coconut water and pomegranate juice were reported as reducing and capping agents of graphite oxide (OG) to obtain graphene [21, 22]. Other authors have obtained Au-Ag bimetallic nanoparticles with pomegranate juice [23] and extract from leaf of mahogany [24], as well as the bioreduction synthesis in bimetallic nanostructure-type core/shell of Ti/Ni between 1 and 4 nm employing *Medicago sativa* [25]. Shen and collaborators used plant extract of *Anacardium occidentale* for the formation of bimetallic nanoparticles of Au-Ag, considering that polyols play an important role in the reduction of metal ions [26].

Table 1 lists a variety of plants that have been recently used for the synthesis of metallic, bimetallic, and semiconductor nanoparticles.

Nanoparticle	Plant extract	Size	Reference
Ag	<i>Atrocarpus attilis</i>	34 nm; 38 nm	[27]
	<i>Artocarpus heterophyllus</i> Lam.	10.78 nm	[28]
	<i>Vigna</i> sp. L	24.35 nm	[29]
	<i>Hydrangea paniculata</i>	36–75 nm	[30]
	<i>Andrographis paniculata</i>	13–27 nm	[31]
	<i>Ficus religiosa</i>	5–35 nm	[32]
	<i>Alternanthera sessilis</i> Linn	20–30 nm	[33]
	<i>Lycium barbarum</i>	3–15 nm	[34]
	<i>Osmanthus fragrans</i>	2–30 nm	[35]
	<i>Sambucus nigra</i>	26 nm	[36]

Nanoparticle	Plant extract	Size	Reference
Au	<i>Citrus limon</i>	32.2 nm	[37]
	<i>Morinda citrifolia</i>	12.1–38.2 nm	[38]
	<i>Terminalia arjuna</i>	20–50 nm	[39]
	<i>Zingiber officinale</i>	5–15 nm	[40]
	<i>Dillenia indica</i>	5–50 nm	[41]
	<i>Plumeria alba flower</i>	15.6 ± 3.4 nm	[42]
	<i>Citrus maxima</i>	25.7 ± 10 nm	[43]
	<i>Gloriosa superba</i>	20 nm	[44]
	<i>Cinnamomum zeylanicum</i>	25 nm	[45]
	<i>Cassia auriculata</i>	15–25 nm	[46]
Cu	<i>Ginkgo biloba</i>	15–20 nm	[47]
	<i>Tamarind and lemon juice</i>	20–50 nm	[48]
Pt	<i>Azadirachta indica</i>	5–50 nm	[49]
Pd	<i>Chlorella vulgaris</i>	5–20 nm	[50]
	<i>Catharanthus roseus</i>	38 nm	[51]
Fe	<i>Citrus maxima</i>	10–100 nm	[52]
	<i>Eucalyptus</i>	20–80 nm	[53]
Ni	<i>Ocimum sanctum</i>	12–36 nm	[54]
Au-Ag	<i>Antigonon leptopus</i>	10–60 nm	[55]
	<i>Gloriosa superba</i>	10 nm	[44]
	<i>Guazuma ulmifolia</i>	10–25 nm	[56]
	<i>Ocimum basilicum</i>	3–25 nm	[57]
	<i>Commelina nudiflora</i>	20–80 nm	[58]
Au-Pd	<i>Cacumen platycladi</i>	~7 nm	[59]
CuO	<i>Calotropis gigantea</i>	20–30 nm	[60]
	<i>Carica papaya</i>	140 nm	[61]
ZnO	<i>Punica granatum</i>	10–100 nm	[62]
	<i>Solanum nigrum</i>	20–30 nm	[63]
	<i>Ocimum basilicum L.</i>	50 nm	[64]
	<i>Agathosma betulina</i>	15.8 nm	[65]
	<i>Aspalathus linearis</i>	4.08 nm	[66]
TiO ₂	<i>Jatropha curcas L.</i>	25–50 nm	[67]
	<i>Eclipta prostrata</i>	49.5 nm	[68]
	<i>Cicer arietinum L.</i>	14 nm	[69]
SnO ₂	<i>Aspalathus linearis</i>	2.1–19.3 nm	[70]
NiO	<i>Agathosma betulina</i>	15–55 nm	[71]

Table 1. Plant extracts used in the synthesis of metallic, bimetallic, and semiconductor nanoparticles.

2. The role of carboxylic acids in nanoparticles

Nano-biosynthesis is classified as a chemical method that promotes the growth of a system by the aggregation of the metallic atoms reduced from the atoms in precursor solutions. Literature reports show that certain organic compounds are responsible for oxidation-reduction (redox) reactions, which trigger the formation and stabilization of nanoparticles. For instance, in the cases of the biometallic alloys Au, Ag, and Au/Ag, it is observed that polyphenols and polyols that carry antioxidant properties present in plants have an important role in the formation of nanostructures [24, 72–74]. Quercetin (a flavonol with high antioxidant activity [75]) also appears in the reports as a main component in the formation of metallic nanostructures [76]. It is thus important to highlight the role that the antioxidant activity of the substances used in biosynthesis has on the fabrication of nanoparticles. Similarly, literature reports that carboxylic acids are commonly used in biological methods as reducing and sometimes stabilizing agents in the production and application of these materials. Yoosaf et al. show that it is possible to stabilize nanoparticles through electrostatic interactions with carboxylic groups (using gallic acid), which adhere to the surface of the nanoparticles [77]. This argument is supported by Amornkitbamrung et al. who attribute the reduction of $\text{Pd}^{+2} \rightarrow \text{Pd}^0$ to the functionality of the carboxylate ion (R-COO^-) [78]. On the other hand, Hosseini-M et al. address that carboxylic acids are crucial in the morphology, size, and distribution of Fe_3O_4 nanoparticles; furthermore, they present a co-catalyst effect [79]. Au nanoparticles were synthesized with dicarboxylic acids (oxalic, malonic, succinic, glutaric, and adipic) as reducing agents of HAuCl_4 , without the presence of any other surfactant agents, the synthesis resulted in different morphologies and SERS applications [80]. Similarly, other reports reiterate the importance of the carboxylic groups in the formation of nanoparticles [81, 82]. On nonmetals, Dwivedi et al. obtained selenium nanoparticles of 40–100 nm using carboxylic acids (acetic, oxalic, and gallic acids) for the synthesis method [83]. Propionic acid is used as a stabilizing agent in the fabrication of ZnO quantum dots (3.6–5.2 nm) [84]; similarly, carboxylic acids were used in manganese oxide nanoparticles, which work as catalysts in the conversion of CO to CO_2 [85]; additionally, pimelic dicarboxylic acid is used as a nucleating agent for the synthesis of TiO_2 nanoparticles [86]. Thus, the carboxylic acid groups stick to nanoparticles transferring stability (**Figure 1**), as reported by Zhi-Mei Qi et al. who synthesized gold nanoparticles through infrared (IR) spectroscopy [81].

Carboxylic acids are the most common type of organic acids in the carboxylic group (made by the fusion of one hydroxyl and carboxyl group) at the extreme end of the carbon chain. Under certain conditions, proton donors transfer H^+ hydrons through heterolysis. The general formula of the carboxylic acid group is R-COOH , where R is a monovalent functional group (one hydrogen or carbon chain), when the carbon structure is replaced by two functional carboxylic groups, the acid is dicarboxylic acid (HOOC-R-COOH). When the proton H^+ is transferred to the remaining ion, the formula changes into R-COO^- carboxylate [87]. These acids are used in the food and pharmaceutical industries and in the manufacture of detergent and surfactant agents, among other applications [88]. Recent reports have demonstrated that when COOH groups are applied to certain biological complexes, they present excellent antitumor and antioxidant activity [89]; furthermore, other reports indicate that the carboxylic acids in *Rhinacanthus nasutus* show antiviral activity [90].

Figure 1. Representation of the electrostatic interaction of the carboxylic acid group on the nanoparticles.

The use of these compounds in the synthesis processes of metallic and nonmetallic nanoparticles is increasing due to the biocompatible and antioxidant properties of carboxylic acids.

Table 2 shows scientific reports on carboxylic acids used in biosynthesis for the production of nanomaterials; the table focuses on the different applications of the acids. In regard to the reduction-oxidation process of metallic ions, Zoya Zaheer and Rafiuddin [91] propose a reduction

Carboxylic acid	NPs	Size (nm)	Function report. used as:	Reference
Formic acid	Ag Pd	13–25 4.1–5.7	Formic acid—used as a solvent and reducing agent of Ag precursor. Formic acid as a reducing agent in the presence of polyvinylpyrrolidone (PVP) for the synthesis of size-tunable Pd NCs.	[92] [93]
Propionic acid	Au	12–41	Functionalization of gold nanoparticles synthesized on reaction of propionic acid with aqueous H ₂ AuCl ₄ .	[94]
Caprylic acid	Au	5–15	Gold NPs—synthesized by reduction technique-based redox-active amphiphiles (e.g., caproic acid, caprylic acid, and capric acid).	[95]
Nonanoic acid	Ag	7.6	Silver nanoparticles—stabilized in nonanoic acid. Capping agent.	[96]
Oxalic acid	Ag	3.5–9	Colloidal silver nanoparticles were prepared with oxalic acid in the presence of CTAB.	[97]

Carboxylic acid	NPs	Size (nm)	Function report. used as:	Reference
Malic acid	Ag	~10	Citric acid present in <i>S. lycopersicums</i> fruit extract is used as reducing agent and malic acid is used as capping agent of the bioreduced silver nanoparticles.	[98]
Gallic acid	Au@Pt	~50 nm	Gallic acid (GA) as both a reducing and a protecting agent.	[99]
Acetic acid	CuS CuInSe ₂	5 400	CuS nanoparticles using carboxylic acid (acetic, propionic) as a solvent have been developed [100] The CuInSe ₂ nanoparticles for thin-film solar cells were synthesized using acetic acid as a mineralizer. [101]	[100] [101]
Decanoic acid	ZnO	100	Zinc oxide (ZnO) nanoparticles were examined using surface modifiers (oleic acid and decanoic acid) in supercritical methanol. [102]	[102]
Lauric acid	Fe ₃ O ₄ Ag	9.4 ± 2.3 8	The nanostructured material was coated with lauric acid. [103] Capping agents. [104]	[103] [104]
Trifluoroacetic acid	TiO ₂	5	Trifluoroacetic acid—used as an electron scavenger and a morphological control agent. [105]	[105]
Benzoic acid	ZnO	5–50	ZnO precursors—obtained by the intimate mixing of zinc acetate dihydrate and carboxylic acids as capping agents. [106]	[106]
Glutaric acid	Ag NiO-Ni	30–50 22–41	The morphologies of silver nanoparticles are impacted by glutaric acid. [107] Nanocomposite has been fabricated via the thermal decomposition of nickel salts by using glutaric acid as a spacer agent. [108]	[107] [108]

Table 2. Influence of some carboxylic and dicarboxylic acids on the synthesis of nanoparticles.

mechanism of Ag⁺ by oxalic acid (HOOC-COO⁻) with CTAB as the stabilizing agent; the reduction mechanism takes place in an aqueous solution with a pH control of pK = 1.2 and pK₂ = 4.2.

Since the organic compounds of carboxylic acids can be found in nature (for instance, in plants such as fungi) and they are not harmful for human consumption or the environment,

they are used in the food and pharmaceutical industries. Studies on the synthesis of metallic and semiconductor nanoparticles are beginning to be used in these fields in order to improve processes that are beneficial to the environment and human beings. It is important to mention that some carboxylic acids functionalized with nanoparticles are also used in technological applications (**Scheme 1**).

A recent study shows a simpler unsaturated carboxylic acid (acrylic acid) that works with silver nanoparticles in the process of membrane filtration that avoids nanoparticles to adhere to the surface of the modified membranes, which at the same time show antibacterial/bacteriostatic properties [109]. The main reaction of acrylic acid is polymerization; thus, it is commonly used in the production of plastics, paints, and adhesives. Due to these characteristics, Ag nanoparticles modified with polyacrylic acid was produced by the redox method showing excellent water solubility, stability, and biocompatibility, as well as antibacterial properties against *Escherichia coli*, *Staphylococcus aureus*, and *Pseudomonas aeruginosa* [110]. Nanoparticles and formic acid have a similar role, since the electrochemical oxidation process of formic acid is an efficient energy supplier in direct formic acid fuel cells (DFAFCs) for mobile and portable applications [111–113]. The biodegradability and low cost of formic acid makes it a valuable resource in energy storage, in spite of its toxicity [114–117]. Thus, metallic and bimetallic nanoparticles Pt [118], Pt-Cu [119], Pt-Au [120, 121], Pd-Ag [122], and so on are used as catalysts in the electro-oxidation of formic acid.

Reports also show oxalic acid functionalized with biocompatible magnetite nanobars (oxalic acid- Fe_3O_4) prepared through the co-precipitation method for applications in electrochemical

Scheme 1. Some nanobiotechnological applications of carboxylic acids functionalized with nanoparticles.

biosensors [123]. Additionally, oxalic acid and malic acid play an important role in the synthesis of tungstate nanoplates and nanoflowers (hydrated tungsten oxide: $\text{WO}_3 \cdot \text{H}_2\text{O}$) which show photocatalytic properties [124, 125]. Sedira et al. show that Ag nanoparticles oxidize easily in aqueous solutions, which in combination with acetic acid cause the liberation of Ag^+ and improve the bactericidal effect in a higher range than with zinc oxide quantum dots [126]. Similarly, benzoic acid in the surface of TiO_2 nanorods increases the power conversion efficiency of dye-sensitized solar cells (DSSCs), becoming at the same time an alternative and efficient method for the production of electrodes based on TiO_2 nanorods [127]. It has been shown recently that the synthesis of Se nanoparticles induced by carboxylic acids (acetic acid, pyruvic acid, and benzoic acid) has antitumor properties with good potential in the treatment of Dalton's lymphoma (DLA) cancer cells [128]. On the other hand, caffeic acid (containing the functional groups phenolic and acrylic) is used as a reducing and stabilizing agent in the preparation of silver nanoparticles, which show antitumor properties and works as an alternative agent in human hepatoma therapies [129]. Reports show that green synthesis of gold nanoparticles obtained with chlorogenic acid presents anti-inflammatory properties; additionally, it has promising applications in nanomedicine [130]. Maleic acid (dicarboxylic) functionalized with gold nanoparticles is used in the colorimetric detection of high efficiency of lead [131]; correspondingly, copper nanoparticles functionalized with carboxylic acid act as catalysts, when reducing 2-nitrophenol to 2-aminophenol in a few minutes [132]. Hence, it can be concluded that the different applications of metallic and nonmetallic nanoparticles in combination with organic agents such as carboxylic groups are of great importance in future medical applications for the development of antineoplastic therapies.

3. Biosynthesis of nanoparticles with *Opuntia ficus-indica*

The cladodes from *O. ficus-indica* are characterized by their antioxidant properties, vitamin content, and by the presence of flavonoids and gallic acids [133–137], in addition to their content of uronic acid, a type of sugar acid with carbonyl and carboxylic functional groups [138]. In recent studies, gallic acid is used as a reducing and stabilizing agent in the mass production of silver nanoparticles with antioxidant properties and low cytotoxicity for normal cells [139, 140]. Similarly, biocompatible gold nanoparticles are synthesized at environment temperature through the reduction of HAuCl_4 with gallic acid and poly-(N-vinyl-2-pyrrolidone) (PVP) [141]. Thus, carboxylic organic agents (gallic and uronic acids) in the cladode extract are responsible for the reduction and stabilization of the nanoparticles (**Figure 2**).

O. ficus-indica is well known for its anti-diarrheal, anti-inflammatory, antiviral, and anticarcinogen properties [142, 143], as well as for being used in treatments for diabetes and indigestion. The plant is commonly used as a nutritional complement, and its fruits and cladodes can be consumed in salads [144–146]. In general, this plant contains vitamins, minerals, and sugars, indispensable for human health. A recent study by E. Ramirez M et al. reports that *O. ficus-indica* cladodes improve the physicochemical properties of corn tortillas [147]; additionally, it increases the antioxidant activity in the blood and plasma of humans [148]. Furthermore, the extract has better anti-inflammatory potential than the drug indometacin [149]. Similarly, metallic and nonmetallic nanoparticles obtained with ecological methods are pioneering in the same fields as the extract *O. ficus-indica* (**Scheme 2**).

Figure 2. Carboxylic acids in *O. ficus-indica* play an important role in the formation of nanoparticles.

Scheme 2. Nanoparticles and cladodes from *O. ficus-indica* have similar range of technological applications.

For instance, silver nanoparticles obtained from the extracts of *R. indica* and *European black elderberry* show anti-inflammatory properties [150, 151]. Gold nanoparticles from *Inonotus obliquus* show antioxidant activity [152]. Synthesized ZnO nanoparticles from the root of *Polygala tenuifolia* show antioxidant and anti-inflammatory activity [153]. In the same way, Au and Ag nanoparticles obtained by biosynthesis are powerful nanomaterials in the control of diabetes [154–156]. Thus far, literature only reports in vitro studies with antibacterial activity using *O. ficus-indica* extract, applied in the biofabrication of silver nanoparticles, considering the synergic affects against *E. coli* and *S. aureus* [133]. As a consequence, the organic agents such as carboxylic acids, in the cladode extract of *O. ficus-indica*, and the nanoparticles obtained through eco-friendly methods, can improve the nanobiotechnological applications; furthermore, they secure innovative developments of the several application fields and the modern technology. It is still necessary to develop studies in order to validate the hypotheses presented in this study, concerning the nanoparticles obtained from the extracts from the cladodes.

4. Experimental section

4.1. Metallic nanoparticles

In this study, we synthesized metallic nanoparticles Ag, Au, Cd, Cu, Pb, and Ti with cladodes from *O. ficus-indica* in a colloidal medium. The synthesis presented excellent stability during long periods of time. The following were used as precursors during the synthesis processes: Nitrates AgNO_3 ; $\text{Cu}(\text{NO}_3)_2$; $\text{Pb}(\text{NO}_3)_2$; $\text{Cd}(\text{NO}_3)_2$; Chlorides: HAuCl_4 . Small fragments of metal underwent a thermal treatment in nitric acid for the synthesis of Ti nanoparticles (**Figure 2**).

The method used in this study was made in collaboration with other authors [157]: 25 g of the cladode was mixed in 50 ml of deionized water; subsequently, the solution underwent thermal treatment at a constant temperature of 60°C, and magnetic agitation for 1 h. The resulting solution is then filtered obtaining the *O. ficus-indica* extract. Three milliliters of the extract is mixed with 25 ml of the precursor solutions (nitrate and chlorides) for the reduction of the metallic ions. The solution undergoes the same thermal treatment and magnetic agitation described above. The nanoparticles are formed and stabilized during these processes.

4.2. Carbon nanostructures

The organic molecules containing the *O. ficus-indica* extract may have hydrophilic properties. This represents of the extract of the plant a strong candidate for the obtaining of laminar materials of carbon and small quantum dots both in colloidal means.

To obtain a few graphene sheets from commercial graphite, 5 ml of the extract of *O. ficus-indica* was used as mentioned in the previous section. Subsequently, 2 g of commercial graphite was added to 50 ml of deionized water and mixed with 5-ml extract of *O. ficus-indica*. The mixture was kept in an ultrasonic bath for 30 min. Finally, floating material was collected on the liquid surface with a slightly bright hue, to be analyzed by transmission electron microscopy (TEM), Raman, and X-ray photoelectron spectroscopy (XPS). To obtain carbon quantum dots (CQDs), a mixture with the same components was maintained under magnetic stirring and at 50°C for 30 min and then subjected to an ultrasonic bath for 30 min. In the first minutes of subjecting the sample in the ultrasonic bath, a tone change in the surface of the liquid is observed. In the same way, floating material was collected on the surface of the liquid, finding small CQD.

5. Results and discussions

Nanoparticles of the precursors mentioned in the experimental section were obtained and characterized by transmission electron microscopy. In the case of the silver nanoparticles, these mainly presented particle sizes that oscillate between 2 and 4 nm, and few cases are observed with sizes between 10 and 15 nm (**Figure 3a**). In both cases, morphologies of spherical type are observed. For the case of the precursor HAuCl_4 after performing the synthesis process mentioned in the experimental section, gold nanoparticles with different morphologies such as triangular, pentagonal, hexagonal, and quasi-spherical were obtained. The mentioned macroscopic parameters allowed a diversity of morphologies for this precursor as seen in **Figure 3b**. In the case of cadmium nanoparticles (**Figure 3c**), an irregular shape with sizes located between 2 and 8 nm approximately was obtained.

In some cases, the organic molecules contained in the plant extract are manifested by interacting with the surface of the nanoparticle, possibly as a consequence of molecular affinity. As is the case with copper nanoparticles (**Figure 3d**), in these, a region between 2 and 3 nm in thickness is observed that surrounds a nanoparticle with a diameter of approximately 10 nm. Another similar case was presented when synthesizing titanium nanoparticles; in the TEM image (**Figure 3f**), we observed clusters of nanoparticles were stabilized by an organic

Figure 3. TEM images of metallic nanoparticles and carbon nanostructures synthesized with cladode extract from *O. ficus-indica*. a) Ag Nps, b) Au Nps, c) Cd Nps, d) Cu Nps, e) Pb Nps, f) Ti Nps, g) Graphene, h) Graphene, i) Carbon Quantum dots.

medium. The nanoparticles of titanium have sizes located at approximately 5 nm; we assume that this stabilizing medium may contain ascorbic acid, starches, proteins, and various vitamins naturally contained in the extract of the plant *O. ficus-indica*.

On the other hand, when using PbNO_3 as a precursor of lead nanoparticles by the synthesis method presented, nanoparticles below 10 nm were obtained with well-defined crystalline phase as seen in **Figure 3e**. For the case of the synthesized metallic nanoparticles, we observed that the extract of *O. ficus-indica* facilitates the obtaining for a size smaller than 10 nm. This has several advantages for analyzing biomedical applications such as drug delivery, therapeutic applications, bioimaging, and magnetic energy storage [158–160].

For the laminar carbon nanostructures obtained by green synthesis methods, there are currently published results that start from graphite oxide as a precursor [161, 162]. In the present investigation, we use commercial graphite as a precursor, further reducing the costs of synthesis for the nanostructured laminar final product. **Figure 3g** and **h** show graphene layers made up of less than 10 layers. These were obtained by the simple ultrasonic sonication method shown in the experimental section. We assume that the method presented can be made repeatedly until a smaller number of graphene sheets are obtained because the hydrophilic components in the extract of *O. ficus-indica* favor the exfoliation.

The use of green synthesis to obtain CQD is rarely documented. Few numbers of articles show evidence of the synthesis of CQD using plant extract [163, 164]. By combining the *O. ficus-indica* plant extract with a small amount of commercial graphite and maintaining the mixture at 60° C for 1 h, it was possible to collect the surface liquid from the solution for further analysis by TEM and to find CQD (**Figure 3i**). In the same way as the metallic nanoparticles, the extract allowed to obtain CQD with a size smaller than 5 nm. This favors the applications of chemical sensors, photodetectors, and so on [165, 166].

6. Optical properties in metallic nanoparticles

As is well known, the metallic and semiconductor nanoparticles have new optical properties in relation to the bulk material. These properties can be detected by ultraviolet/visible spectroscopy (UV/Vis) and are associated with the existence of surface plasmon. Surface plasmon resonance (SPR) physically represents the oscillation of free electrons on the surface of the nanoparticles, constituting a characteristic fingerprint of each nanostructured material. The nanoparticles obtained using the extract of *O. ficus-indica* were analyzed experimentally by UV/Vis spectroscopy. All spectra were considered from 200 to 800 nm.

In the case of silver nanoparticles, these showed an absorption band centered on 390-nm characteristic of the SPR due to quantum confinement in silver, as seen in **Figure 4a**. The dependence of the location of the SPR is associated with the morphology of the nanostructures as well as the size. Silver nanostructures can be found in the literature with an SPR located at 408, 430, 440, and so on [167–169], associated with different sizes of silver nanoparticles.

The gold nanoparticles probably represent the most studied metal nanostructured in terms of behavior and shifts of SPR. The gold nanoparticles have absorption bands located at 500, 550, 800, and so on, for nanoparticles with different morphologies. This indicates the dependence and sensitivity of the location of the SPR with the morphology of the gold nanostructures [170–172]. The gold nanoparticles obtained in this work show a large amplitude absorption band associated with the presence of the SPR centered at 55 nm. We assume that this band implicitly considers the contribution of several SPRs associated with the different morphologies obtained, as shown in **Figure 4b**. This can be seen in the large amplitude of the absorption band, with a range from 500 to 670 nm. For cadmium nanoparticles, an absorption band centered at 232 nm is shown in **Figure 4c**. For lead, there are reports of nanocubes with absorption bands located at approximately 320 and 400 nm [173]. A band detected at 300 nm was associated with SPR due to the confinement in these lead nanoparticles (**Figure 4e**).

The obtained copper nanoparticles had a well-defined absorption band centered at 580 nm approximately as shown in **Figure 4d**. The synthesis of copper nanoparticles it faces to copper oxidation easily in a colloidal medium, the extract of *O. ficus-indica* facilitates the stabilization of these nanoparticles. Prabsash et al. obtained nanoparticles of copper with a size of 10 nm, using chemical reduction by the reducing agent sodium borohydride [174].

On the other hand, titanium (metal) nanoparticles are difficult to find in the literature. There are reports from Mohammadi and Halali who used the electromagnetic levitation melting gas

Figure 4. Optical absorbance of metallic nanoparticles synthesized by *O. ficus-indica* extract.

method to evaporate titanium particles [175]; the nanoparticles obtained by them have sizes between 28 and 40 nm. Although the method presented is effective, it represents a requirement of special equipment to carry out the synthesis of titanium nanoparticles. The titanium nanoparticles obtained in the present work were based on the modified method presented by R. Britto et al. [176], varying slightly the amount of extract of the plant *O. ficus-indica*. The absorption band obtained for titanium nanoparticles (**Figure 4f**) was located at 350 nm, associated with the SPR of this metal.

7. Conclusions

In conclusion, the current importance of organic agents functionalized with nanoparticles in the nanotechnological and biomedical fields has been exposed in this study. The properties of carboxylic acids make the fabrication of biocompatible nanostructured systems attractive for future attention. The biosynthesis process used in the fabrication of graphene layers and nanoparticles initiates an ecological and low-cost alternative in biocompatible applications for the treatment of diseases, mainly for antineoplastic therapies. The cladode extract from *O. ficus-indica* is highly efficient in the formation of nanoparticles, which can play an important role in the biocompatibility for the benefit of health and nutrition. Metallic and nonmetallic nanoparticles with nanobiotechnological applications synthesized with ecological methods (carboxylic groups) will be a fundamental tool for biocompatible applications in nanoscience and nanotechnology.

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References

- [1] Sahayaraj K, Rajesh S, A. Méndez-Vilas. Bionanoparticles synthesis and antimicrobial applications. In: Science against Microbial Pathogens: Communicating Current Research and Technological Advances. Formatex Research Center. 2011. pp. 228-244
- [2] Kaushik NT, Snehit SM, Rasesh YP. Biological synthesis of metallic nanoparticles. Nanomedicine: Nanotechnology, Biology and Medicine. 2010;**6**(2):257-262
- [3] Prashant M, Nisha KR, Sudesh KY. Biosynthesis of nanoparticles: Technological concepts and future applications. Journal of Nanoparticle Research. 2008;**10**:507-517
- [4] Xiangqian L, Huizhong X, Chen Z-S, Chen G. Biosynthesis of nanoparticles by microorganisms and their applications. Journal of Nanomaterials. 2011;**2011**, Article ID 270974:16
- [5] Amit KM, Yusuf C, Uttam CB. Synthesis of metallic nanoparticles using plant extracts. Biotechnology Advances. March–April 2013;**31**(2):346-356

- [6] Cristina B-A, Le Duc T, Nguyen TKT. Synthesis of nanoparticles for biomedical applications. Annual Reports on the Progress of Chemistry, Section A: Inorganic Chemistry. 2010;**106**:553-568
- [7] Adam S, Gabriela K, Ivo Š, Mirka Š, Ivan R, Leslie MS. Applications of biosynthesized metallic nanoparticles – A review. Acta Biomaterialia. October 2014;**10**(10):4023-4042
- [8] Khabat V, Sedigheh KD. Chapter 29 – Biosynthesis of silver nano-particles by trichoderma and its medical applications. Biotechnology and Biology of Trichoderma. Elsevier B. V. 2014;**1**:393-404
- [9] Mingxia G, Wei L, Feng Y, Huihong L. Controllable biosynthesis of gold nanoparticles from a *Eucommia ulmoides* bark aqueous extract. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy. 5 May 2015;**142**:73-79
- [10] Salman K, Syed MDR, Mohd A, Mohd A, Pramdeep B, Mohd SK. A novel process for size controlled biosynthesis of gold nanoparticles using bromelain. Materials Letters. 15 November 2015;**159**:373-376
- [11] Amit KM, Debabrata T, Alka C, Pavan KA, Anupam C, Inder PS, Uttam CB. Bio-synthesis of silver nanoparticles using *Potentilla fulgens* Wall. ex Hook. and its therapeutic evaluation as anticancer and antimicrobial agent. Materials Science and Engineering: C. 1 August 2015;**53**:120-127
- [12] Arthanari S, Mani G, Jayabalan J, Hyun TJ. Biosynthesis of silver nanoparticles using *Cassia tora* leaf extract and its antioxidant and antibacterial activities. Journal of Industrial and Engineering Chemistry. 25 August 2015;**28**:277-281
- [13] Debasis N, Sonali P, Sarbani A, Pradipta RR, Bismita N. Biologically synthesised silver nanoparticles from three diverse family of plant extracts and their anticancer activity against epidermoid A431 carcinoma. Journal of Colloid and Interface Science. 1 November 2015;**457**:329-338
- [14] Ramachandran R, Krishnaraj C, Stacey LH, Yun S-Il, Thangavel Kalaichelvan P. Plant extract synthesized silver nanoparticles: An ongoing source of novel biocompatible materials. Industrial Crops and Products. August 2015;**70**:356-373
- [15] Monica P, Manisha B, Timea S, Swapnil G, Emilia L, Avinash I, Manuela B, Adriana V, Simion A, Mahendra R. Biosynthesized silver nanoparticles performing as biogenic SERS-nanotags for investigation of C26 colon carcinoma cells. Colloids and Surfaces B: Biointerfaces. 1 September 2015;**133**:296-303
- [16] Srinath BS, Ravishankar Rai V. Rapid biosynthesis of gold nanoparticles by *Staphylococcus epidermidis*: Its characterisation and catalytic activity. Materials Letters. 1 May 2015;**146**:23-25
- [17] Tamanna B, Kavita M, Manika K, Ram P, Ajit V. Biosynthesis of zinc oxide nanoparticles from *Azadirachta indica* for antibacterial and photocatalytic applications. Materials Science in Semiconductor Processing. April 2015;**32**:55-61
- [18] Deep Pooja D, Sravani P, Hitesh K, Bharathi R, Shyam SR, Ramakrishna S. Natural polysaccharide functionalized gold nanoparticles as biocompatible drug delivery carrier. International Journal of Biological Macromolecules. September 2015;**80**:48-56

- [19] Balaji V, Vimala S, Anusha T, Elangovan V. Rapid synthesis of biocompatible silver nanoparticles using aqueous extract of *Rosa damascena* petals and evaluation of their anticancer activity. *Asian Pacific Journal of Tropical Medicine*. September 2014; **7**(Suppl 1):S294-S300
- [20] Sujata P, Sudip M, Ayan KB, Anirban G, Bojja S, Chitta RP. Green synthesis, characterization of gold and silver nanoparticles and their potential application for cancer therapeutics. *Materials Science and Engineering: C*. 1 August 2015; **53**:298-309
- [21] Kartick B, Srivastava SK, Srivastava I. Green synthesis of graphene. *Journal of Nanoscience and Nanotechnology*. 2013; **13**:4320-4324
- [22] Farnosh T, Masoud S-N, Alireza B, Fatemeh M. Green synthesis and characterization of graphene nanosheets. *Materials Research Bulletin*. 2015; **63**:51-57
- [23] Meena Kumari M, John J, Daizy P. Green synthesis and applications of Au–Ag bimetallic nanoparticles. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*. 2015; **137**:185-192
- [24] Samiran M, Nayan R, Rajibul AL, Ismail SK, Saswati B, Debabrata M, Naznin AB. Biogenic synthesis of Ag, Au and bimetallic Au/Ag alloy nanoparticles using aqueous extract of mahogany (*Swietenia mahogani* JACQ.) leaves. *Colloids and Surfaces B: Biointerfaces*. 2011; **82**:497-504
- [25] Schabes-Retchkiman PS, Canizal G, Herrera-Becerra R, Zorrilla C, Liu HB, Ascencio JA. Biosynthesis and characterization of Ti/Ni bimetallic nanoparticles. *Optical Materials*. 2006; **29**:95-99
- [26] Sheny DS, Joseph M, Daizy P. Phytosynthesis of Au, Ag and Au–Ag bimetallic nanoparticles using aqueous extract and dried leaf of *Anacardium occidentale*. *Spectrochimica Acta Part A*. 2011; **79**:254-262
- [27] Veerasamy R, Sethu V, Sivadasan S, Syed AAS, Rajak H. Green synthesis of silver nanoparticles using *Atrocarpus altilis* leaf extract and the study of their antimicrobial and antioxidant activity. *Materials Letters*. 2016; **180**:264-267
- [28] Umesh BJ, Vishwas AB. Green synthesis of silver nanoparticles using *Artocarpus heterophyllus* Lam. seed extract and its antibacterial activity. *Industrial Crops and Products*. 2013; **46**:132-137
- [29] Soheila M, Shahram P, Abbas A. Green synthesis of silver nanoparticles with a long lasting stability using colloidal solution of cowpea seeds (*Vigna sp. L*). *Journal of Environmental Chemical Engineering*. 2016; **4**:2023-2032
- [30] Gopalu K, Matheswaran J, Manickam V, Govindan SK, Evgeny K, Arkhipov D, Alexander G, Denis K. *Hydrangea paniculata* flower extract-mediated green synthesis of MgNPs and AgNPs for health care applications. *Powder Technology*. 2017; **305**:488-494
- [31] Udhayaraj S, Jacob JA, Subramanian S, Durairaj S, Raman S, Soundarrajan K, Tirupathi Pichiah PB, Shanmugam A. Hepatocurative activity of biosynthesized silver nanoparticles fabricated using *Andrographis paniculata*. *Colloids and Surfaces B: Biointerfaces*. 2013; **102**:189-194

- [32] Jacob JA, Mohamed AAS, Thomas AJ, Udhayaraj S, Arunachalam S, Durairaj S, Seenivasan K, Shanmugam A. In vivo antitumor activity of biosynthesized silver nanoparticles using *Ficus religiosa* as a nanofactory in DAL induced mice model. *Colloids and Surfaces B: Biointerfaces*. 2013;**108**:185-190
- [33] Niraimathi KL, Sudha V, Lavanya R, Brindha P. Biosynthesis of silver nanoparticles using *Alternanthera sessilis* (Linn.) extract and their antimicrobial, antioxidant activities. *Colloids and Surfaces B: Biointerfaces*. 2013;**102**:288-291
- [34] Chunfa D, Chuanliang C, Xianglin Z, Yanlong Z, Xiangjie W, Xiuzhi Y, Kui Z, Xinhua X, Bin Y. Wolfberry fruit (*Lycium barbarum*) extract mediated novel route for the green synthesis of silver nanoparticles. *Optik - International Journal for Light and Electron Optics*. 2017;**130**:162-170
- [35] Chunfa D, Xianglin Z, Hao C, Chuanliang C. Green synthesis of biocompatible silver nanoparticles mediated by *Osmanthus fragrans* extract in aqueous solution. *Optik - International Journal for Light and Electron Optics*. 2016;**127**:10378-10388
- [36] Bianca M, Luminița D, Marcela A, Simona C, Gabriela AF. A green approach to phyto-mediated synthesis of silver nanoparticles using *Sambucus nigra* L. fruits extract and their antioxidant activity. *Journal of Molecular Liquids*. 2016;**221**:271-278
- [37] Mohanan VS, Soundarapandian K. Green synthesis of gold nanoparticles using Citrus fruits (*Citrus limon*, *Citrus reticulata* and *Citrus sinensis*) aqueous extract and its characterization. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*. 2013;**102**:15-23
- [38] Suman TY, Radhika Rajasree SR, Ramkumar R, Rajthilak C, Perumal P. The green synthesis of gold nanoparticles using an aqueous root extract of *Morinda citrifolia* L. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*. 2014;**118**:11-16
- [39] Gopinath K, Venkatesh KS, Ilangoan R, Sankaranarayanan K, Arumugam A. Green synthesis of gold nanoparticles from leaf extract of *Terminalia arjuna*, for the enhanced mitotic cell division and pollen germination activity. *Industrial Crops and Products*. 2013;**50**:737-742
- [40] Praveen Kumar K, Willi P, Chandra PS. Green synthesis of gold nanoparticles with *Zingiber officinale* extract: Characterization and blood compatibility. *Process Biochemistry*. 2011;**46**:2007-2013
- [41] Arghya S, Manoj G, Pragya S, Manab D, Utpal B. Green synthesis of gold nanoparticles using aqueous extract of *Dillenia indica*. *Advances in Natural Sciences: Nanoscience and Nanotechnology*. 2016;**7**:025005 (8pp)
- [42] Rani M, Aswathy B, Sudha RS. Green-synthesized gold nanoparticles from *Plumeria alba* flower extract to augment catalytic degradation of organic dyes and inhibit bacterial growth. *Particuology*. 2016;**24**:78-86
- [43] Jia Y, Di X, Hua NG, Chao W, Li KH, De FC. Facile one-step green synthesis of gold nanoparticles using *Citrus maxima* aqueous extracts and its catalytic activity. *Materials Letters*. 2016;**166**:110-112

- [44] Kasi G, Shanmugasundaram K, Kasi B, Subramanian M, Kunga SV, Masanam E, Periyannan K, Naiyf SA, Shine K, Marimuthu G, Giovanni B, Ayyakannu A. Green synthesis of silver, gold and silver/gold bimetallic nanoparticles using the *Gloriosa superba* leaf extract and their antibacterial and antibiofilm activities. *Microbial Pathogenesis*. 2016;**101**:1-11
- [45] Smitha SL, Daizy P, Gopchandran KG. Green synthesis of gold nanoparticles using *Cinnamomum zeylanicum* leaf broth. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*. 2009;**74**:735-739
- [46] Ganesh Kumar V, Dinesh Gokavarapu S, Rajeswari A, Stalin Dhas T, Karthick V, Kapadia Z, Tripti Shrestha IAB, Anindita R, Sweta S. Facile green synthesis of gold nanoparticles using leaf extract of antidiabetic potent *Cassia auriculata*. *Colloids and Surfaces B: Biointerfaces*. 2011;**87**:159-163
- [47] Mahmoud N, Mohammad Sajadi S. Green synthesis of copper nanoparticles using *Ginkgo biloba* L. leaf extract and their catalytic activity for the Huisgen [3 + 2] cycloaddition of azides and alkynes at room temperature. *Journal of Colloid and Interface Science*. 2015;**457**:141-147
- [48] Sastry ABS, Karthik AamanchiCh RB, Sree Rama Linga Prasad BSM. Large-scale green synthesis of Cu nanoparticles. *Environmental Chemistry Letters*. 2013;**11**:183-187
- [49] Thirumurugan A, Aswitha P, Kiruthika C, Nagarajan S, Nancy Christy A. Green synthesis of platinum nanoparticles using *Azadirachta indica* – An eco-friendly approach. *Materials Letters*. 2016;**170**:175-178
- [50] Farzaneh A, Mohammad HS, Sara S. Green synthesis of palladium nanoparticles using *Chlorella vulgaris*. *Materials Letters*. 2017;**186**:113-115
- [51] Aasaithambi K, Selvaraj MR, Gunabalan M, Ramalingam C, Ganesh E. Synthesis and characterization of palladium nanoparticles using *Catharanthus roseus* leaf extract and its application in the photo-catalytic degradation. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*. 2015;**135**:116-119
- [52] Yufen W, Zhanqiang F, Liuchun Z, Lei T, Eric PT. Green synthesis of Fe nanoparticles using *Citrus maxima* peels aqueous extracts. *Materials Letters*. 2016;**185**:384-386
- [53] Ting W, Xiaoying J, Zuliang C, Mallavarapu M, Ravendra N. Green synthesis of Fe nanoparticles using eucalyptus leaf extracts for treatment of eutrophic wastewater. *Science of the Total Environment*. 2014;**466–467**:210-213
- [54] Chitra JP, Rameshthangam P, Solairaj D. Green synthesis of nickel nanoparticles using *Ocimum sanctum* and their application in dye and pollutant adsorption. *Chinese Journal of Chemical Engineering*. 2015;**23**:1307-1315
- [55] Ganaie SU, Abbasi T, Abbasi SA. Rapid and green synthesis of bimetallic Au–Ag nanoparticles using an otherwise worthless weed *Antigonon leptopus*. *Journal of Experimental Nanoscience*. 2015;**11**:6, 395-417

- [56] Viswanathan K, Ayyakannu A, Kasi G, Periyannan K, Marimuthu G, Naiyf SA, Shine K, Jamal MK, Giovanni B. Guazuma ulmifolia bark-synthesized Ag, Au and Ag/Au alloy nanoparticles: Photocatalytic potential, DNA/protein interactions, anticancer activity and toxicity against 14 species of microbial pathogens. *Journal of Photochemistry and Photobiology B: Biology*. 2017;**167**:189-199
- [57] Malapermal V, Mbatha JN, Gengan RM, Anand K. Biosynthesis of bimetallic Au-Ag nanoparticles using *Ocimum basilicum* (L.) with antidiabetic and antimicrobial properties. *Advanced Materials Letters*. 2015;**6**(12):1050-1057
- [58] Palaniselvam K, Soundharajan I, Srisesharam S, Da HK, Natanamurugaraj G, Gaanty P, Maniam MM, Yusoff Ki CC. Synthesis of bimetallic nanoparticles (Au-Ag alloy) using *Commelina nudiflora* L. plant extract and study its on oral pathogenic bacteria. *Journal of inorganic and Organometallic Polymers and Materials*. 2017;**27**:562-568. DOI:10.1007/s10904-017-0498-8
- [59] Guowu Z, Jiale H, Mingming D, Ibrahim A-R, Yao M, Qingbiao L. Green synthesis of Au-Pd bimetallic nanoparticles: Single-step bioreduction method with plant extract. *Materials Letters*. 2011;**65**:2989-2991
- [60] Jitendra KS, Shaheer Akhtar M, Ameen S, Pratibha S, Gurdip S. Green synthesis of CuO nanoparticles with leaf extract of *Calotropis gigantea* and its dye-sensitized solar cells applications. *Journal of Alloys and Compounds*. 2015;**632**:321-325
- [61] Renu S, Perumal M, Viswanathan M, Tajudeennasrin F, Kanchi SS, Vilwanathan R. Green synthesis of colloidal copper oxide nanoparticles using *Carica papaya* and its application in photocatalytic dye degradation. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*. 2014;**121**:746-750
- [62] Alaa YG, Tawfiq Al-Antary M, Akl MA. Green synthesis of copper oxide nanoparticles using *Punica granatum* peels extract: Effect on green peach Aphid. *Environmental Nanotechnology, Monitoring & Management*. 2016;**6**:95-98
- [63] Ramesh M, Anbuvarannan M, Viruthagiri G. Green synthesis of ZnO nanoparticles using *Solanum nigrum* leaf extract and their antibacterial activity. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*. 2015;**136**:864-870
- [64] Hasna AS, Rajeshwari S, Venckatesh R. Green synthesis and characterization of zinc oxide nanoparticles from *Ocimum basilicum* L. var. *purpurascens* Benth.-Lamiaceae leaf extract. *Materials Letters*. 2014;**131**:16-18
- [65] Thema FT, Manikandan E, Dhlamini MS, Maaza M. Green synthesis of ZnO nanoparticles via *Agathosma betulina* natural extract. *Materials Letters*. 2015;**161**:124-127
- [66] Diallo A, Ngom BD, Park E, Maaza M. Green synthesis of ZnO nanoparticles by *Aspalathus linearis*: Structural & optical properties. *Journal of Alloys and Compounds*. 2015;**646**:425-430

- [67] Manish H, Shreeram J, Mayur D, Kisan K. Green synthesis of TiO₂ nanoparticles by using aqueous extract of *Jatropha curcas* L. latex. *Materials Letters*. 2012;**75**:196-199
- [68] Rajakumar G, Abdul Rahuman A, Priyamvada B, Gopiesh Khanna V, Kishore Kumar D, Sujin PJ. *Eclipta prostrata* leaf aqueous extract mediated synthesis of titanium dioxide nanoparticles. *Materials Letters*. 2012;**68**:115-117
- [69] Anil AK, Ketan PG, Kalyani G, Vijay HI, Swapnali D, Ramphal S, Chang J-Y, Anil VG. Biomediated green synthesis of TiO₂ nanoparticles for lithium ion battery application. *Composites Part B: Engineering*. 2016;**99**:297-304
- [70] Diallo A, Manikandan E, Rajendran V, Maaza M. Physical & enhanced photocatalytic properties of green synthesized SnO₂ nanoparticles via *Aspalathus linearis*. *Journal of Alloys and Compounds*. 2016;**681**:561-570
- [71] Thema FT, Manikandan E, Gurib-Fakim A, Maaza M. Single phase Bunsenite NiO nanoparticles green synthesis by *Agathosma betulina* natural extract. *Journal of Alloys and Compounds*. 2016;**657**:655-661
- [72] Shiv Shankar S, Akhilesh R, Absar A, Murali S. Rapid synthesis of Au, Ag, and bimetallic Au core–Ag shell nanoparticles using Neem (*Azadirachta indica*) leaf broth. *Journal of Colloid and Interface Science*. 2004;**275**:496-502
- [73] Huang J, Li Q, Sun D, Lu Y, Su Y, Yang X, Wang H, Wang Y, Shao W, He N, Hong J, Chen C. Biosynthesis of silver and gold nanoparticles by novel sundried *Cinnamomum camphora* leaf. *Nanotechnology*. 2007;**18**:105104-105114
- [74] Sheny DS, Joseph M, Daizy P. Phytosynthesis of Au, Ag and Au–Ag bimetallic nanoparticles using aqueous extract and dried leaf of *Anacardium occidentale*. *Spectrochimica Acta, Part A*. 2011;**79**
- [75] Wieslaw W, Dorota S-N, Joanna T, Katarzyna O, Henryk Z, Mariusz KP. Metabolites of dietary quercetin: Profile, isolation, identification, and antioxidant capacity. *Journal of Functional Foods*. November 2014;**11**:121-129
- [76] Egorova EM, Revina AA. Synthesis of metallic nanoparticles in reverse micelles in the presence of quercetin. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. 31 July 2000;**168**(1):87-96
- [77] Karuvath Y, Binil II, Cherumuttathu HS, George Thomas K. In situ synthesis of metal nanoparticles and selective naked-eye detection of lead ions from aqueous media. *Journal of Physics and Chemistry C*. 2007;**111**:12839-12847
- [78] Lunjakorn A, Prompong P, Chuchaat T, Sanong E. Palladium nanoparticles synthesized by reducing species generated during a successive acidic/alkaline treatment of sucrose. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*. 2014;**122**:186-192
- [79] Hassan H-M, Fatemeh P, Sohaila A. Carboxylic acid effects on the size and catalytic activity of magnetite nanoparticles. *Journal of Colloid and Interface Science*. 1 January 2015;**437**:1-9

- [80] Ravi Kumar DV, Kumavat SR, Chamundeswari VN, Partha PP, Kulkarni A, Prasad BLV. Surfactant-free synthesis of anisotropic gold nanostructures: Can dicarboxylic acids alone act as shape directing agents? *RSC Advances*. 2013;**3**:21641
- [81] Qi Z-M, Zhou H-S, Naoki M, Itaru H, Kayori S, Akiko T, Kenji K. Characterization of gold nanoparticles synthesized using sucrose by seeding formation in the solid phase and seeding growth in aqueous solution. *Journal of Physics and Chemistry B*. 2004;**108**
- [82] Naheed A, Seema S, Radheshyam R. Rapid green synthesis of silver and gold nanoparticles using peels of *Punica granatum*. *Advanced Materials Letters*. 2012;**3**(5):376-380
- [83] Charu D, Chetan PS, Krishankant S, Manmohan K, Parma NB. An organic acid-induced synthesis and characterization of selenium nanoparticles. *Journal of Nanotechnology*. 2011;**2011**, Article ID 651971, p. 6
- [84] Aleksandra S, Mathieu F, Commenge J-M, Lavinia B, Laurent F, Raphaël S. Size-controlled synthesis of ZnO quantum dots in microreactors. *Nanotechnology*. 2014;**25**:145606 (9pp) 1-9
- [85] Stanton C, David AK, Kurt ML, Eric CN, Steven LS. Self-assembly of manganese oxide nanoparticles and hollow spheres. Catalytic activity in carbon monoxide oxidation. *Chemical Communications*. 2011;**47**:8286-8288
- [86] Amir G, Elías P, Armando A, Antonio V, Javier V-M. Calcium pimelate supported on TiO₂ nanoparticles as isotactic polypropylene prodegradant. *Polymer Bulletin*. 2015;**1**:13
- [87] Keyshawn C. Chemistry of carboxylic acid. In: Research World. 2012 [Otra ref. por si acaso: Saul Patai. *The Chemistry of Carboxylic Acids and Esters*. Ansari Road, Darya Ganj, Delhi: Interscience Publisher, Chichester; 1969]
- [88] Ashton Acton Q. *Carboxylic Acids—Advances in Research and Application*. Atlanta, GA: Scholarly Editions; 2013.
- [89] Kamatchi TS, Chitrapriya N, Kim SK, Fronczek FR, Natarajan K. Influence of carboxylic acid functionalities in ruthenium (II) polypyridyl complexes on DNA binding, cytotoxicity and antioxidant activity: Synthesis, structure and in vitro anticancer activity. *European Journal of Medicinal Chemistry*. January 2013;**59**:253-264
- [90] Thongchuai B, Tragoolpua Y, Sangthong P, Trisuwan K. Antiviral carboxylic acids and naphthoquinones from the stems of *Rhinacanthus nasutus*. *Tetrahedron Letters*. 9 September 2015;**56**(37):5161-5163
- [91] Rafiuddin Zoya Zaheer. Silver nanoparticles to self-assembled films: Green synthesis and characterization. *Colloids and Surfaces B: Biointerfaces*. 2012;**90**:48-52
- [92] Jeong L, Park WH. Preparation and characterization of gelatin nanofibers containing silver nanoparticles. *International Journal of Molecular Science*. 2014;**15**:6857-6879
- [93] Wang Q, Wang Y, Guo P, Li Q, Ding R, Wang B, Li H, Liu J, Zhao XS. Formic acid-assisted synthesis of palladium nanocrystals and their electrocatalytic properties. *Langmuir*. 2014;**30**:440-446

- [94] Venkatachalam M, Govindaraju K, Mohamed Sadiq A, Tamilselvan S, Ganesh Kumar V, Singaravelu G. Functionalization of gold nanoparticles as antidiabetic nanomaterial. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*. 2013;**116**:331-338
- [95] Dinda E, Harunar Rashid MD, Mandal TK. Amino acid-based redox active amphiphiles to in situ synthesize gold nanostructures: From sphere to multipod. *Crystal Growth and Design*. 2010;**10**(5):2421-2433
- [96] Henneke DE, Malyavanatham G, Kovar D, O'Brien DT, Becker MF, Nichols WT, Keto JW. Stabilization of silver nanoparticles in nonanoic acid: A temperature activated conformation reaction observed with surface enhanced Raman spectroscopy. *The Journal of Chemical Physics*. 2003;**119**:6802
- [97] Khan Z, Hussain JI, Kumar S, Hashmi AA, Malik MA. Silver nanoparticles: Green route, stability and effect of additives. *Journal of Biomaterials and Nanobiotechnology*. 2011;**2**:390-399
- [98] Umadevi M, Bindhu MR, Sathe V. A novel synthesis of malic acid capped silver nanoparticles using solanum lycopersicums fruit extract. *Journal of Materials Science & Technology*. April 2013;**29**(4):317-322
- [99] Zhang G, Zheng H, Shen M, Wang L, Wang X. Green synthesis and characterization of Au@Pt core-shell bimetallic nanoparticles using gallic acid. *Journal of Physics and Chemistry of Solids*. 2015;**81**:79-87
- [100] Armelao L, Camozzo D, Gross S, Tondello E. Synthesis of copper sulphide nanoparticles in carboxylic acids as solvent. *Journal of Nanoscience and Nanotechnology*. 2006 Feb;**6**(2):401-408
- [101] Shim JB, Kim CG, Jeon DJ, Chung T-M, An K-S, Lee SS, Lim JS, Jeong SJ, Park BK, Lee YK. Hydrothermal synthesis of CuInSe₂ nanoparticles in acetic acid. *Journal of Physics and Chemistry of Solids*. June 2013;**74**(6):867-871
- [102] Veriansyah B, Kim J-D, Min BK, Shin YH, Lee Y-W, Kim J. Continuous synthesis of surface-modified zinc oxide nanoparticles in supercritical methanol. *The Journal of Supercritical Fluids*. February 2010;**52**(1):76-83
- [103] Mamani JB, Costa-Filho AJ, Cornejo DR, Vieira ED, Gamarra LF. Synthesis and characterization of magnetite nanoparticles coated with lauric acid. *Materials Characterization*. July 2013;**81**:28-36
- [104] Dong CF, Zhang XL, Cao CL, Cai H. Synthesis of monodispersed lauric acid capped silver nanoparticles by wet-chemical reduction method. *Applied Mechanics and Materials*. December 2013;**477-478**:1246-1252
- [105] Calatayud DG, Jardiel T, Peiteado M, Rodríguez CF, Rocio Espino Estévez M, Doña Rodríguez JM, Palomares FJ, Rubio F, Fernández-Hevia D, Caballero AC. Highly photoactive anatase nanoparticles obtained using trifluoroacetic acid as an electron scavenger and morphological control agent. *Journal of Material Chemistry A*. 2013;**1**:14358-14367
- [106] Estruga M, Domingo C, Ayllón JA. Solution-processable ZnO nanoparticles obtained by low-temperature solventless synthesis. *Journal of Material Chemistry*. 2011;**21**:4408-4415

- [107] Xiong N, Wang M, Zhang H, Xie H, Zhao Y, Wang Y, Li J. Sintering behavior and effect of silver nanoparticles on the resistivity of electrically conductive adhesives composed of silver flakes. *Journal of Adhesion Science and Technology*. 2014;**28**(24):2402-2415
- [108] Rahimpour HR, Hosseini A. Preparation of NiO-Ni nanocomposite by using of glutaric acid in neutral condition. *Advanced Materials Research*. November 2013;**829**:554-558
- [109] Bojarska M, Piatkiewicz W. Antibacterial properties of membranes modified by acrylic acid with silver nanoparticles. *Desalination and Water Treatment*. 2014;1-7
- [110] Ni Z, Wang Z, Sun L, Li B, Zhao Y. Synthesis of poly acrylic acid modified silver nanoparticles and their antimicrobial activities. *Materials Science and Engineering: C*. 1 August 2014;**41**:249-254
- [111] Rejal SZ, Masdara MS, Kamarudin SK. A parametric study of the direct formic acid fuel cell (DFAFC) performance and fuel crossover. *International Journal of Hydrogen Energy*. 24 June 2014;**39**(19):10267-10274
- [112] Yu X, Pickup PG. Recent advances in direct formic acid fuel cells (DFAFC). *Journal of Power Sources*. 15 July 2008;**182**(1):124-132
- [113] Baik SM, Kim J, Han J, Kwon Y. Performance improvement in direct formic acid fuel cells (DFAFCs) using metal catalyst prepared by dual mode spraying. *International Journal of Hydrogen Energy*. September 2011;**36**(19):12583-12590
- [114] Liu X, Li S, Liu Y, Cao Y. Formic acid: A versatile renewable reagent for green and sustainable chemical synthesis. *Chinese Journal of Catalysis*. September 2015;**36**(9):1461-1475
- [115] Chen D, Cui P, He H, Liu H, Yang J. Highly catalytic hollow palladium nanoparticles derived from silver@silver-palladium core-shell nanostructures for the oxidation of formic acid. *Journal of Power Sources*. 25 December 2014;**272**:152-159
- [116] Zhong X, Wang Z, Huang Y, Yu Y, Feng Q, Li Q. Fabrication of Pt nanoparticles on ethylene diamine functionalized graphene for formic acid electrooxidation. *International Journal of Hydrogen Energy*. 23 September 2014;**39**(28):15920-15927
- [117] Sáez A, Expósito E, Solla-Gullón J, Montiel V, Aldaz A. Bismuth-modified carbon supported Pt nanoparticles as electrocatalysts for direct formic acid fuel cells. *Electrochimica Acta*. 29 February 2012;**63**:105-111
- [118] Moghaddam RB, Pickup PG. Oxidation of formic acid at polycarbazole-supported Pt nanoparticles. *Electrochimica Acta*. 1 May 2013;**97**:326-332
- [119] Hosseini SR, Hosseinzadeh R, Ghasemi S, Farzaneh N. Synthesis of poly (2-Methoxyaniline)/sodium dodecyl sulfate film including bimetallic Pt-Cu nanoparticles and its application for formic acid oxidation. *International Journal of Hydrogen Energy*. 9 February 2015;**40**(5):2182-2192
- [120] Oko DN, Zhang J, Garbarino S, Chaker M, Ma D, Tavares AC, Guay D. Formic acid electro-oxidation at PtAu alloyed nanoparticles synthesized by pulsed laser ablation in liquids. *Journal of Power Sources*. 15 February 2014;**248**:273-282

- [121] Liaoa M, Xiong J, Fan M, Shi J, Luo C, Zhong C-J, Chen BH. Phase properties of carbon-supported platinum–gold nanoparticles for formic acid electro-oxidation. *Journal of Power Sources*. 30 October 2015;**294**:201-207
- [122] Mandal K, Bhattacharjee D, Dasgupta S. Synthesis of nanoporous PdAg nanoalloy for hydrogen generation from formic acid at room temperature. *International Journal of Hydrogen Energy*. 20 April 2015;**40**(14):4786-4793
- [123] Sharma A, Baral D, Bohidara HB, Solanki PR. Oxalic acid capped iron oxide nanorods as a sensing platform. *Chemico-Biological Interactions*. 5 August 2015;**238**:129-137
- [124] Li L, Zhao J, Wang Y, Li Y, Ma D, Zhao Y, Hou S, Hao X. Oxalic acid mediated synthesis of $\text{WO}_3 \cdot \text{H}_2\text{O}$ nanoplates and self-assembled nanoflowers under mild conditions. *Journal of Solid State Chemistry*. July 2011;**184**(7):1661-1665
- [125] Miao B, Zenga W, Xu S, Zeng S, Chen Y, Wu S. Synthesis and controlled growth of monodisperse $\text{WO}_3 \cdot \text{H}_2\text{O}$ square nanoplates with the assistance of malic acid. *Materials Letters*. 15 December 2013;**113**:13-16
- [126] Sedira S, Ayachi AA, Lakehal S, Fateh M, Achour S. Silver nanoparticles in combination with acetic acid and zinc oxide quantum dots for antibacterial activities improvement—A comparative study. *Applied Surface Science*. 30 August 2014;**311**:659-665
- [127] Liu J, Wang Y, Sun D. Enhancing the performance of dye-sensitized solar cells by benzoic acid modified TiO_2 nanorod electrode. *Renewable Energy*. 2012;**38**(1):214-218
- [128] Kumar S, Tomar MS, Acharya A. Carboxylic group-induced synthesis and characterization of selenium nanoparticles and its anti-tumor potential on Dalton's lymphoma cells. *Colloids and Surfaces B: Biointerfaces*. 1 February 2015;**126**:546-552
- [129] Guo D, Dou D, Ge L, Huang Z, Wanga L, Gu N. A caffeic acid mediated facile synthesis of silver nanoparticles with powerful anti-cancer activity. *Colloids and Surfaces B: Biointerfaces*. 1 October 2015;**134**:229-234
- [130] Hwang SJ, Jun SH, Park Y, Cha S-H, Yoon M, Cho S, Lee H-J, Park Y. Green synthesis of gold nanoparticles using chlorogenic acid and their enhanced performance for inflammation. *Nanomedicine: Nanotechnology, Biology and Medicine*. October 2015;**11**(7):1677-1688
- [131] Ratnarathorn N, Chailapakul O, Dungchai W. Highly sensitive colorimetric detection of lead using maleic acid functionalized gold nanoparticles. *Talanta*. 15 January 2015;**132**:613-618
- [132] Poupart R, Droumaguet BL, Guerrouache M, Carbonnier B. Copper nanoparticles supported on permeable monolith with carboxylic acid surface functionality: Stability and catalytic properties under reductive conditions. *Materials Chemistry and Physics*. 1 August 2015;**163**:446-452
- [133] Gade A, Gaikwad S, Tiwari V, Yadav A, Ingle A, Rai M. Biofabrication of silver nanoparticles by *Opuntia ficus-indica*: In vitro antibacterial activity and study of the mechanism involved in the synthesis. *Current Nanoscience*. 2010;**6**(4):370-375

- [134] Chougui N, Djerroud N, Naraoui F, Hadjal S, Aliane K, Zeroual B, Larbat R. Physicochemical properties and storage stability of margarine containing *Opuntia ficus-indica* peel extract as antioxidant. *Food Chemistry*. 15 April 2015;**173**:382-390
- [135] El-Mostafa K, El Kharrassi Y, Badreddine A, Andreoletti P, Vamecq J, El Kebbaj MHS, Latruffe N, Lizard G, Nasser B, Cherkaoui-Malki M. Nopal cactus (*Opuntia ficus-indica*) as a source of bioactive compounds for nutrition, health and disease. *Molecules*. 2014;**19**:14879-14901
- [136] Zhong X-K, Jin X, Lai F-Y, Lin Q-S, Jiang J-G. Chemical analysis and antioxidant activities in vitro of polysaccharide extracted from *Opuntia ficus indica* Mill. cultivated in China. *Carbohydrate Polymers*. 15 October 2010;**82**(3):722-727
- [137] Habibi Y, Heyraud A, Mahrouz M, Vignon MR. Structural features of pectic polysaccharides from the skin of *Opuntia ficus-indica* prickly pear fruits. *Carbohydrate Research*. 28 April 2004;**339**(6):1119-1127
- [138] Cárdenas A, Goycoolea FM, Rinaudo M. On the gelling behaviour of 'nopal' (*Opuntia ficus indica*) low methoxyl pectin. *Carbohydrate Polymers*. 2008;**73**:212-222
- [139] Kim D-Y, Sung JS, Kim M, Ghodake G. Rapid production of silver nanoparticles at large-scale using gallic acid and their antibacterial assessment. *Materials Letters*. 15 September 2015;**155**:62-64
- [140] Li D, Liu Z, Yuan Y, Liu Y, Niu F. Green synthesis of gallic acid-coated silver nanoparticles with high antimicrobial activity and low cytotoxicity to normal cells. *Process Biochemistry*. March 2015;**50**(3):357-366
- [141] Wang W, Chen Q, Jiang C, Yang D, Liu X, Xu S. One-step synthesis of biocompatible gold nanoparticles using gallic acid in the presence of poly-(N-vinyl-2-pyrrolidone). *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. 5 July 2007;**301**(1-3):73-79
- [142] Morales P, Ramírez-Moreno E, de Cortes Sanchez-Mata M, Carvalho AM, Ferreira ICFR. Nutritional and antioxidant properties of pulp and seeds of two xoconostle cultivars (*Opuntia joconostle* F.A.C. Weber ex Diguët and *Opuntia matudae* Scheinvar) of high consumption in Mexico. *Food Research International*. 2012;**46**:279-285
- [143] López-Romero P, Pichardo-Ontiveros E, Avila-Nava A, Vázquez-Manjarrez N, Tovar AR, Pedraza-Chaverri J, Torres N. The effect of nopal (*Opuntia Ficus Indica*) on post-prandial blood glucose, incretins, and antioxidant activity in Mexican patients with type 2 diabetes after consumption of two different composition breakfasts. *Journal of the Academy of Nutrition and Dietetics*. November 2014;**114**(11):1811-1818
- [144] Kaur M, Kaur A, Sharma R. Pharmacological actions of *Opuntia ficus indica*: A review. *Journal of Applied Pharmaceutical Science*. 2012;**02**(07):15-18
- [145] Ahmad A, Davies J, Randall S, Skinner GR. Antiviral properties of extract of *Opuntia streptacantha*. *Antiviral Research*. May 1996;**30**(2-3):75-85

- [146] Sreekanth D, Arunasree MK, Roy KR, Reddy TC, Reddy GV, Reddanna P. Betanin a betacyanin pigment purified from fruits of *Opuntia ficus-indica* induces apoptosis in human chronic myeloid leukemia cell line-K562. *Phytomedicine*. 2007;**14**:739-746
- [147] Ramírez-Moreno E, Cordoba-Díaz M, de Cortes Sánchez-Mata M, Díez Marqués C, Goñi I. The addition of cladodes (*Opuntia ficus indica* L. Miller) to instant maize flour improves physicochemical and nutritional properties of maize tortillas. *LWT - Food Science and Technology*. June 2015;**62**(1), Part 2:675-681
- [148] Avila-Nava A, Calderón-Oliver M, Medina-Campos ON, Zou T, Gu L, Torres N, Tovar AR, Pedraza-Chaverri J. Extract of cactus (*Opuntia ficus indica*) cladodes scavenges reactive oxygen species in vitro and enhances plasma antioxidant capacity in humans. *Journal of Functional Foods*. 2014;**10**:13-24
- [149] Antunes-Ricardo M, Gutiérrez-Uribe JA, López-Pacheco F, Alvarez MM, Serna-Saldívar SO. In vivo anti-inflammatory effects of isorhamnetin glycosides isolated from *Opuntia ficus-indica* (L.) Mill cladodes. *Industrial Crops and Products*. 2015;**76**:803-808
- [150] Manikandan R, Manikandan B, Raman T, Arunagirinathan K, Marimuthu Prabhu N, Jothi Basu M, Perumal M, Palanisamy S, Munusamy A. Biosynthesis of silver nanoparticles using ethanolic petals extract of *Rosa indica* and characterization of its antibacterial, anticancer and anti-inflammatory activities. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*. 5 March 2015;**138**:120-129
- [151] David L, Moldovan B, Vulcu A, Olenic L, Perde-Schrepler M, Fischer-Fodor E, Florea A, Crisan M, Chiorean I, Clichici S, Adriana Filip G. Green synthesis, characterization and anti-inflammatory activity of silver nanoparticles using European black elderberry fruits extract. *Colloids and Surfaces B: Biointerfaces*. 1 October 2014;**122**:767-777
- [152] Lee KD, Nagajyothi PC, Sreekanth TVM, Park S. Eco-friendly synthesis of gold nanoparticles (AuNPs) using *Inonotus obliquus* and their antibacterial, antioxidant and cytotoxic activities. *Journal of Industrial and Engineering Chemistry*. 25 June 2015;**26**:67-72
- [153] Nagajyothi PC, Cha SJ, Yang IJ, Sreekanth TVM, Kim KJ, Shin HM. Antioxidant and anti-inflammatory activities of zinc oxide nanoparticles synthesized using *Polygala tenuifolia* root extract. *Journal of Photochemistry and Photobiology B: Biology*. May 2015;**146**:10-17
- [154] Ganesh Kumar V, Dinesh Gokavarapu S, Rajeswari A, Stalin Dhas T, Karthick V, Kapadia Z, Shrestha T, Barathy IA, Roy A, Sinha S. Facile green synthesis of gold nanoparticles using leaf extract of antidiabetic potent *Cassia auriculata*. *Colloids and Surfaces B: Biointerfaces*. 1 October 2011;**87**(1):159-163
- [155] Venkatachalam M, Govindaraju K, Mohamed Sadiq A, Tamilselvan S, Ganesh Kumar V, Singaravelu G. Functionalization of gold nanoparticles as antidiabetic nanomaterial. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*. December 2013;**116**:331-338

- [156] Rajaram K, Aiswarya DC, Sureshkumar P. Green synthesis of silver nanoparticle using *Tephrosia tinctoria* and its antidiabetic activity. *Materials Letters*. 1 January 2015;138:251-254
- [157] Álvarez RAB, Cortez-Valadeza M, Britto-Hurtado R, Oscar Neira Bueno L, Flores-Lopez NS, Hernández-Martínez AR, Gámez-Corrales R, Vargas-Ortiz R, Bocarando-Chacon J-G, Arizpe-Chavez H, Flores-Acosta M. Raman scattering and optical properties of lithium nanoparticles obtained by green synthesis. *Vibrational Spectroscopy*. March 2015;77:5-9
- [158] Ghosh P, Han G, De M, Kim CK, Rotello VM. Gold nanoparticles in delivery applications. *Advanced Drug Delivery Reviews*. 2008;60(11):1307-1315
- [159] Zhang L, Gu FX, Chan JM, Wang AZ, Langer RS, Farokhzad OC. Nanoparticles in medicine: Therapeutic applications and developments. *Clinical Pharmacology & Therapeutics*. 2008;83:761-769
- [160] Frey NA, Peng S, Cheng K, Sun S. Magnetic nanoparticles: Synthesis, functionalization, and applications in bioimaging and magnetic energy storage. *Chemical Society Reviews*. 2009;38:2532-2542
- [161] Zhu C, Guo S, Fang Y, Dong S. Reducing sugar: New functional molecules for the green synthesis of graphene nanosheets. *ACS Nano*. 2010;4(4):2429-2437
- [162] Wang Y, Shi ZX, Yin J. Facile synthesis of soluble graphene via a green reduction of graphene oxide in tea solution and its biocomposites. *ACS Applied Materials & Interfaces*. 2011;3(4):1127-1133
- [163] Mewada A, Pandey S, Shinde S, Mishra N, Oza G, Thakur M, Sharon M, Sharon M. Green synthesis of biocompatible carbon dots using aqueous extract of *Trapa bispinosa* peel. *Materials Science and Engineering: C*. 2013;33(5):2914-2917
- [164] Mehta VN, Jha S, Kailasa SK. One-pot green synthesis of carbon dots by using *Saccharum officinarum* juice for fluorescent imaging of bacteria (*Escherichia coli*) and yeast (*Saccharomyces cerevisiae*) cells. *Materials Science and Engineering: C*. 2014;38:20-27
- [165] Dong Y, Wang R, Li H, Shao J, Chi Y, Lin X, Chen G. Polyamine-functionalized carbon quantum dots for chemical sensing. *Carbon*. 2012;50(8):2810-2815
- [166] Keuleyan S, Lhuillier E, Brajuskovic V, Guyot-Sionnest P. Mid-infrared HgTe colloidal quantum dot photodetectors. *Nature Photonics*. 2011;5:489-493
- [167] Qin Y, Ji X, Jing J, Liu H, Wu H, Yang W. Size control over spherical silver nanoparticles by ascorbic acid reduction. *Colloids and Surfaces A: Physicochemical Engineering Aspects*. 2010;372:172-176
- [168] Vijayaraghavana K, Kamala Nalini SP, Udaya Prakash N, Madhankumar D. One step green synthesis of silver nano/microparticles using extracts of *Trachyspermum ammi* and *Papaver somniferum*. *Colloids and Surfaces B: Biointerfaces*. 2012;94:114-117

- [169] Bindhu MR, Umadevi M. Antibacterial and catalytic activities of green synthesized silver nanoparticles. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*. 2015;**135**:373-378
- [170] Jain PK, El-Sayed IH, El-Sayed MA. Au nanoparticles target cancer. *Nano Today*. 2007;**2**:18-29
- [171] Zheng YB, Juluri BK, Mao X, Walker TR, Huang TJ. Systematic investigation of localized surface plasmon resonance of long-range ordered Au nanodisk arrays. *Journal of Applied Physics*. 2008;**103**:014308
- [172] Prathap Chandran S, Chaudhary M, Pasricha R, Ahmad A, Sastry M. Synthesis of gold nanotriangles and silver nanoparticles using aloe vera plant extract. *Biotechnology Progress*. 2006;**22**(2):577-583
- [173] Xiong Y, Chen J, Wiley B, Xia Y, Yin Y, Li Z-Y. Size-dependence of surface plasmon resonance and oxidation for Pd nanocubes synthesized via a seed etching process. *Nano Letters*. 2005;**5**(7):1237-1242
- [174] Prabhasha PG, Haritha VS, Nair SS, Pilankatta R. Localized surface plasmon resonance based highly sensitive room temperature pH sensor for detection and quantification of ammonia. *Sensors and Actuators B: Chemical*. 2017;**240**:580-585
- [175] Vahid Mohammadi A, Halali M. Synthesis and characterization of pure metallic titanium nanoparticles by an electromagnetic levitation melting gas condensation method. *RSC Advances*. 2014;**4**:7104-7108
- [176] Britto-Hurtado R, Cortez-Valadez M, Álvarez-Bayona R, Horta-Fraijo P, Bocarando-Chacon J-G, Gámez-Corrales R, Pérez-Rodríguez A, Martínez-Suárez F, Arizpe-Chávez H, Flores-Acosta M. Green synthesis and optical properties of Ti nanoparticles. *NANO*. 2015;**10**, 1550069:1-7