

We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

4,800

Open access books available

122,000

International authors and editors

135M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com



Exploring the Effect of Operational Factors and Characterization Imperative to the Synthesis of Silver Nanoparticles

Adewumi O. Dada, Folahan A. Adekola,
Oluyomi S. Adeyemi, Oluwasesan M. Bello,
Adetunji C. Oluwaseun, Oluwakemi J. Awakan and
Femi-Adepoju A. Grace

Additional information is available at the end of the chapter

<http://dx.doi.org/10.5772/intechopen.76947>

Abstract

The synthesis and application of silver nanoparticles are increasingly becoming attractive. Hence, a critical examination of the various factors needed for the synthesis of silver nanoparticles as well as the characterization is imperative. In light of this, we addressed in this chapter, the nitty-gritty on the operational parameters (factors) and characterization relevant to synthesis of silver nanoparticle. The following characterization protocols were discussed in the context of silver nanoparticle synthesis. These protocols include spectroscopic techniques such as ultraviolet visible spectroscopy (UV-Vis), Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), transmission electron microscopy (TEM), energy-dispersive X-ray spectroscopy (EDX), X-ray fluorescence (XRF), X-ray diffraction (XRD), thermogravimetric analysis (TGA) and X-ray photoelectron spectroscopy (XPS).

Keywords: silver nanoparticles, characterization, morphology, operational factors

1. Introduction

The field of nanotechnology is gaining more attention daily from different researchers based on the vast applications and its efficacy. Silver nanoparticle is a metallic nanoparticle with the size of 1–100 nm existing either as zerovalent silver (Ag^0) or silver oxide due to their large ratio

of surface-to-bulk silver atoms. Of all the metallic nanoparticles, silver nanoparticles is exceptional and it is the most explored by researchers globally because of its various versatility, simplicity of synthesis, adaptability, morphology and its extreme surface area that paves way for the coordination of a vast number of ligands [1–9]. The following methods have been identified for synthesis of silver nanoparticles: Wet chemistry, Ion implantation, Biological synthesis and product functionalization. Wet chemistry involves nucleation of the nanoparticles within the solution by the action of a reducing agent on the silver ion complex forming colloidal silver. A number of wet chemistry methods, including the use of reducing sugars, citrate reduction, reduction via sodium borohydride, the silver mirror reaction, the polyol process seed-mediated growth and light-mediated growth have been identified [10–14]. However, reduction by borohydride is gradually facing out because of its toxicity thus the major reason why biological method of synthesis has been more preferable. Biological method of synthesizing silver nanoparticles may involve the use of bacteria, fungi and plant extract using green synthesis route. This method is ecofriendly, low cost and silver nanoparticles formed are stable and well dispersed with limited aggregation and good size control [15, 16]. There are different applications of silver nanoparticles ranging from its function as catalyst [5, 17], water treatment [6], antimicrobial properties [8], chemotherapeutic agent and drug delivery [18], Optical sensor [19], food packaging [20], and adsorption [21]. Although, there have been reports on the synthetic routes and applications of silver nanoparticle, however, nitty-gritty on the operational parameters imperative to the synthesis have not been so reported and the cogent considerable factors in characterization have not been majorly explored by researchers. Therefore, this book chapter aimed at taking a review survey of the operational parameters (factors) and the characterization imperative to synthesis of silver nanoparticles.

2. Operational parameters for synthesis of silver nanoparticles

The synthesis of silver nanoparticles depends on some important operational parameters. Irrespective of the technique used for the synthesis of silver nanoparticles, certain operational factors such as the concentration and volume ratio of reacting substances, reaction time, temperature and pH influence the synthesis rate, size and shape of the nanoparticles. These parameters could be varied to control its size, shape and general morphology, efficiency and applicability. A survey of these operational parameters are examined in this section.

2.1. Effects of concentration

The silver ion concentration majorly affects the synthesis of silver nanoparticles. This parameter was investigated to identify the amount of silver ion most suitable for the generation of silver nanostructure. To investigate the effect of initial silver ion concentration, range of concentrations were prepared while other parameters was kept constant. The common practice is to vary the concentration of Ag^+ ion from 10^{-3} to 10^{-2} M. Report from the literature have established and approved 10^{-3} M as the most appropriate and suitable concentration where better surface plasmon resonance was obtained. In most wet chemistry and biological synthetic

methods, increase in silver ion intensity increases the rate at which the surface plasmon resonance will be attained. Silver nanoparticle is formed within the wavelength range of 400–490 nm with the formation of the ideal bell shape which is characteristic for the formation of Ag^0 nanoparticles [19].

Studies have shown that a variation in the concentration of metal salt used in the synthesis of nanoparticles influences the product of synthesis. Ibrahim [21] synthesized silver nanoparticle using silver nitrate as metallic salt and banana peel extract as reductant and capping agent, and reported a variation in color tending from yellowish brown to light reddish brown and darker shades of reddish brown with increasing silver nitrate concentration. Surface plasmon resonance (SPR) also attained distinctiveness with increasing concentrations of silver nitrate. These findings were also corroborated by reports from literature [22, 23]. Typical result of effect of concentration is shown in **Figure 1A**.

2.2. Effect of volume ratio

The volume ratio of silver ion solution to the extract which is serving as the reducing and stabilizing or sodium borohydride plays a substantive in the synthesis of silver nanoparticles. Report from different literature showed that in biological method/green synthesis route, excess silver ion is needed for better formation of the silver nanoparticles. In some instances, ratio 9:1 (Silver ion solution: plant extract/broth) were used while in some other reports, ratio of 4:1 was

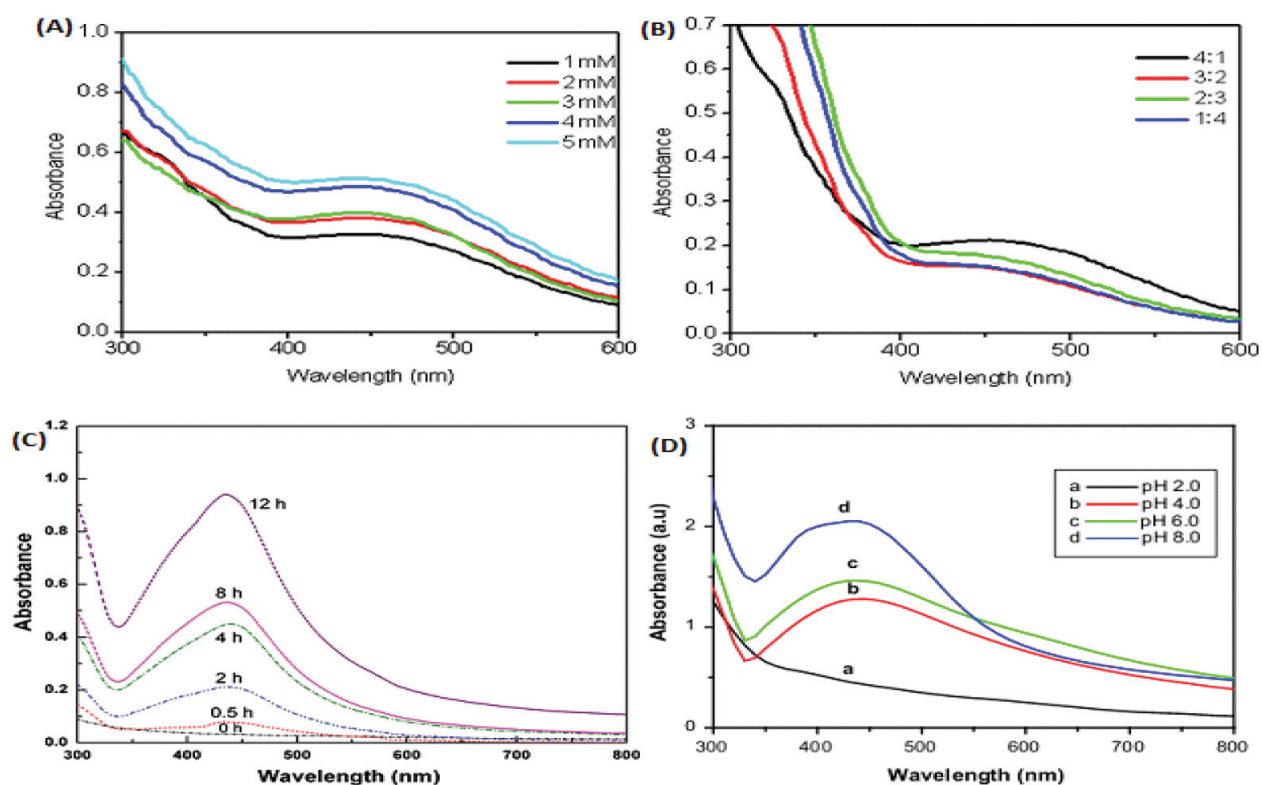


Figure 1. (A-D): (A) effect of variation of concentrations of Ag^+ solution (B) effect of volume ratio (C) effect of contact time (D) effect of change in pH carried out by different researchers [22–24].

used. Typical instances is seen in the synthesis of silver nanoparticle using *T. peruviana* (**Figure 1B**). Oluwaniyi et al., (2016) [22] investigated the influence of change in volume of silver nitrate to *T. peruviana* aqueous leaf extract other parameters were kept constant. Different volume ratios ranging from 4:1, 3:2, 2:3 and 1:4 of 1 mM silver nitrate to *T. peruviana* aqueous leaf extract, respectively, were used. Excellent surface plasmon resonance (SPR) was recorded on the UV–Vis at ratio 4:1. At 4 parts of 1 mM silver nitrate solution to 1 part of *T. peruviana* aqueous leaf extract (4,1), the leaf extract bio-reduced and stabilized the nanoparticles with the plasmon resonance at 460 nm. Other volume ratios, 3:2, 2:3 and 1:4 of 1 mM silver nitrate to *T. peruviana* aqueous leaf extract did not give distinct characteristics SPR for silver nanoparticles at the visible region of the UV–Vis. However, in the case of wet chemistry method using sodium borohydride (NaBH_4) as the reducing agent, excess volume of borohydride is needed for better formation of silver nanoparticle for better dispersion and low agglomeration. Typical, the ratio of NaBH_4 to silver ion solution is 4:1 or 5:1 [25, 26].

2.3. Effect of contact time and temperature

Another important factor influencing the growth of silver nanoparticles is the contact time which is also known as reaction time (**Figure 1C**). This was done by varying the time taken for the formation of silver nanoparticle. Generally, the change in color to yellow or brown is an evidence of the growth of silver nanoparticle. This is monitored with use of UV–Vis spectrophotometer until the maximum absorption wavelength is reached with excellent surface plasmon resonance (SPR). The intensity of the peak is function of the contact time therefore it increases with increase in time. Contact time is one of the parameters that controls the size of silver nanoparticles because of the blue shift of the adsorption peaks. It can be inferred that at between 0 and 20 minutes (at the early stage), the SPR band is broadened because of the slow conversion of silver ion (Ag^+) to zerovalent silver (Ag^0) nanoparticles. Increasing the contact time enhances excellent plasmon band formation because large amount of Ag^+ has been converted to Ag^0 . However, further increase in the contact time leads to noticeable decrease in the absorption intensity and wavelength which is an indication of some aggregation of silver nanoparticles leading to decrease in particle size [17, 19–23, 25, 26].

Temperature is another essential factor that should be considered in the synthesis of silver nanoparticles because it controls the reaction kinetics of the synthetic process. Increase in temperature is known to increase the rate of reaction because there will be an increase in the effective collision and the frequency factor of the reacting species. From the literature reports, studies showed that increase in temperature leads to increase in the intensity of the plasmon band as a result of bathochromic shift resulting in a decrease in the mean diameter of silver nanoparticle. At the beginning of the reaction, the synthesis of AgNPs may be rapid but this does not connote optimum temperature of the system because low temperature readily underscores the ability of reducing and stabilizing agent [27, 28].

2.4. Effect of pH

There are so many factors that influence the reduction of silver ion to AgNP. Effect of pH as one of the operational parameters plays a major role because it influences the chemistry of the

silver nanoparticle synthesis (**Figure 1D**). This is carried out by pH adjustment using phosphoric acid or hydrochloric acid and sodium hydroxide. In practice, during green synthesis, the extract pH is adjusted from pH 2 to 11 and its reduction process monitored by UV–Vis spectrophotometer. This change in the chemical nature of the extract affects its performance as well as the rate of reduction. In the study carried out by Heydari and Rashidipour on the green synthesis of silver nanoparticles using extract of Oak fruit hull, the result showed that the rate of AgNPs synthesis increases with increasing pH up to pH = 9 and then decrease [29]. More so, investigation carried out by Kokila et al., on biosynthesis of silver nanoparticles from Cavendish banana peel extract and its antibacterial and free radical scavenging assay showed that formation of AgNPs depends mostly on the pH of the reaction medium. The result confirmed that formation of silver nanoparticles is favorable in the basic medium than in acidic medium because the absorbance values increase with increase in pH. This could be accredited to the ionization of the functional groups at higher pH and the slow rate of reduction observed in the acidic medium could be attributed to electrostatic repulsion of anions present in the reaction mixture. This was in accordance with the findings in the literature [30–34].

3. Characterization

One of the main problems confronting scientists is understanding the properties a novel material displayed. This can only be achieved by knowing and determining the structure of this new material by characterization. Presently, there is an established and well accepted concept that structures are driven by properties. This is acknowledged in chemistry and in all fields where chemistry plays a primary character such as biochemistry, biology, environmental science, engineering, medicine, polymer science and nutrition. The make-up or property of a nano/biomaterial is placed into three groups i.e. chemical (e.g., equilibrium position, reaction rates, etc.), physical (e.g., melting/boiling points, solubility, spectra, symmetry, etc.) and biological (e.g., color, drug action, odor, taste, toxicity, etc.). This property gives rise to structural features which affect intensely the macroscopic character of the material. Since this is a structure driven properties concept, the structure of the novel material mostly signifies its composition at each level of complexity. However, this varies from the simple molecule formula (giving the ratio that the elements present bears to each other) and the exact positions and locations of all atoms in the molecules of this novel material referring to the three (3) dimensional electronic density distribution [35]. This section of book chapter therefore, excellently and succinctly state the relevant of various characterization techniques relevant to the synthesis of silver nanoparticles.

3.1. UV: Vis spectroscopy

Ultraviolet visible spectroscopy (UV–Vis Spec) remains the most useful characterization relevant to the synthesis of silver nanoparticles [2–23, 25–28]. In principle, the absorption of light occurs in the visible region of the electromagnetic spectrum where atoms and molecules undergo electronic transition of π - π^* , n - π^* , σ - σ^* , and n - σ^* . Absorption of energy in the form

of ultraviolet or visible light is by molecules containing π -electrons or non-bonding electrons (n-electrons) to excite these electrons to higher anti-bonding molecular orbitals. The length of wave depends on the excitation of the electrons, the more easily excited the electrons the longer the wavelength of light it can absorb. The absorption in the visible range directly affects the perceived color of the chemicals involved. UV-Vis in silver nanoparticle synthesis provides vivid information on the surface plasmon resonance (SPR) at the absorption maximum wavelength. The surface plasmon resonance comes from the free electron arising from the conduction and valence bands lying close to each other in metal nanoparticles. It is as a result of the collective oscillation of free electron of silver nanoparticles in resonance with the light wave in silver nanoparticle synthesis [36, 37]. All the experimental operational parameters vis-à-vis effect of initial concentration, contact time, temperature, pH, and volume ratio are monitored using the UV-Vis spectrophotometric technique. Information obtained from the absorption spectrum as a result of SPR surface, gives a clue on the type of shape of the silver nanoparticles. It is important that the interpretation from the UV-Vis measurement corroborates with TEM measurement [38]. **Figures 1(A-D)** portray different UV-Vis spectra at various operational factors influencing the synthesis in the studies carried by researchers.

3.2. Fourier transform infrared spectroscopy (FTIR)

The nature, structure and physicochemical properties of silver nanoparticles (AgNPs) are imperative to their activity, behavior, bio-distribution and safety. Therefore, characterization of AgNPs is essential and important for the assessment of the functional features and characteristics of the synthesized nanoparticles.

FTIR measurements is usually carried out to identify the possible biomolecules which are involved in the synthesis of nanoparticles and to find out their functions in reduction and stabilizing the nanoparticles. This spectroscopy method is employ to detect and distinguish small absorption bands (changes on the order of 10^{-3}) of functional group covalently grafted onto silver or functionally active points that is characteristics to AgNPs. This method has the ability to give precision, it is easily reproducible and also a favorable signal-to-noise ratio [39–41]. One of the major advantage of FTIR spectrometers to other methods of characterization of AgNPs is that, it is a non-invasive technique, data are collected rapidly data, signals are strong and bold, large signal-to-noise ratio, and very little sample is heat-up [42].

Lately, attenuated total reflection (ATR)-FTIR spectroscopy which is more advance in measurement than the conventional FTIR method has been discovered [43]. Using ATR-FTIR, we can easily know and establish the chemical properties on the polymer surface, nanoparticle surfaces and nature, its sample preparation is very simple when compared to conventional FTIR [44]. Therefore, FTIR as a method is appropriate, indispensable, non-invasive, affordable, easy and hands-on technique to know the function of biological molecules in the reduction of silver nitrate to silver.

Identification of the functional groups or biomolecules which are responsible for the reduction of silver ions in silver nanoparticles could be achieved by the Fourier transform infrared (FTIR) spectroscopy. This is achieved by comparing the intense bands with standard values. The

proportionate shift in band revealed after treatment with silver nitrate is a likely indication of participation of the functional groups in the process of nanoparticle synthesis [45].

3.3. Scanning electron microscopy (SEM) and transmission electron microscopy (TEM)

The significance attributes of synthesized silver nanoparticles have been documented to have a greater consequence on their behavior and toxicity encompasses of particle size, shape, surface properties, aggregation state, solubility, structure and chemical make-up. The characterization of silver nanoparticle is necessary for proper insight into the formation, synthesis and their utilization in various fields including agriculture, medical, industries, and environment [46, 47]. The validation and confirmation of synthesized nanoparticle have been carried out using various techniques however transmission electron microscopy (TEM) and scanning electron microscopy (SEM) is important methods for the cases. The significant of Microscopic techniques in the characterization of silver nanoparticles cannot be overemphasized because they give a more clear insight from the obtained data on the size, size distribution, and other quantifiable properties. The significant of electron microscopy in the analysis the synthesized silver premised on their ability to show the real structure of the particle between some ranges of nanometers (nm) conventional bright field images and the intermediate resolution darkfield techniques, to the high-resolution atomic images [48].

3.3.1. Scanning electron microscopy (SEM)

The SEM works by producing images whenever the electron beams scanning probe the peripheral surface of the given sample in order to confirm its structure as well as the topographical and elemental composition present in the materials [48]. During SEM analysis the electrons possess large amount of kinetic energy that is distributed and eventually leads to the generation numerous signals during the analysis of samples during whenever they interacts with the surface of the atom in the sample. The generated signal are secondary electrons, backscattered electrons, characteristics X rays, cathodoluminescence, specimen current and transmitted electrons which can generate a high-resolution magnified descriptions of a synthesized silver nanoparticle, illuminating facts with sizes that varies from 1 to 5 nm in size. Appropriate signals are collected depending upon the mode of operation of the instrument. The numerous field observed in SEM could be linked to the facts that it produced a large depth of field. Many researchers have utilized SEM for the determination of various synthesized silver nanoparticles including, polyhedral [49], flake flower [50], hexagonal [51], isotropic [52], irregular [53], triangular [54], anisotropic [55] and rod like structures [56], pentagonal [57].

3.3.2. Transmission electron microscopy (TEM)

The TEM works based on the application of a very high resolution microscopy method to generate an image as well as a diffraction patterns of the atomic size as well as shape of material by focusing the electron beam that can penetrate through the given material as well as interact with the sample of microstructure of materials. The major difference between TEM and SEM is that TEM can detect the following in the synthesized silver nanoparticles in a microstructure: crystallographic defects, line defects and planar defects. Another major difference

is that TEM could determine the available elemental composition at nano level [58, 59]. There are different forms of TEM including high-resolution transmission electron microscopy (HRTEM), scanning transmission electron microscopy (STEM) and analytical transmission electron microscopy (ATEM). TEM also shows a better image, diffraction properties, and the chemical analysis competences when compared to SEM. TEM can also detect a small size up to 0.2 nm when compared to SEM. Also, TEM produced a better resolution image because it utilized a low wavelength electron when compared to SEM. Finally, TEM can shift from diffraction to imaging by shifting the excitation of the lenses following the objective lens. TEM can be utilized to capture silver synthesized particle image in the plane of the fluorescent screen as well as the diffraction pattern from the particles. The nanoparticle size and particle size distribution of the synthesized nanoparticle could be determined and evaluated by transmission electron microscopy (TEM) and high-resolution microscopy. Moreover, the application of image J software for the plotting of histogram by measuring the size of different nanoparticles could be explored. Some of the demerits of using TEM entails required high vacuum, thin sample section, time consuming for the sample preparation [60]. Further insight and details about the morphology of AgNPs are provided by TEM. The most common size of the silver nanoparticles from various TEM image is spherical [61].

3.4. Energy-dispersive X-ray spectroscopy (EDX) and X-ray fluorescence (XRF)

The elemental constituents and composition of nano-materials could be determined by EDX and XRF. This section explores the principle and relevance of these analytical techniques in nano-research and most especially, silver nanoparticles studies.

3.4.1. Energy-dispersive X-ray spectroscopy (EDX)

Energy-dispersive X-ray spectroscopy (EDX) is an analytical technique that gives information on the surface atomic distribution and the chemical elemental composition [62–65]. In most cases, the EDX is always coupled with SEM. The EDX is used in the elemental determination of composition of the silver nanoparticles.

In Practice, it relies on an interaction of some source of X-ray excitation and a sample. Its characterization capabilities are due in large part to the fundamental principle that each element has a unique atomic structure allowing a unique set of peaks on its electromagnetic emission spectrum. In order to determine the peak of an element, a high energy beam of electron or beam of X-ray is targeted toward the sample to analyze. Excitation of electrons in the inner shell (lower energy level) occurs via the incident beam creating an electron holes which electron from the outer shell (higher energy level) fills. The difference between the higher and lower energy levels is released in form of an X-ray. The number and energy of the X-rays emitted from the silver nanoparticle can be measured by an energy-dispersive spectrometer. Electron beam excitation is used in electron microscopes, scanning electron microscopes (SEM) and scanning transmission electron microscopes (STEM). X-ray beam excitation is used in X-ray fluorescence (XRF) spectrometers. A detector is used to convert X-ray energy into voltage signals; this information is sent to a pulse processor, which measures the signals and passes them onto an analyzer for data display and analysis [66, 67]. Most researchers

utilize EDX for characterization of silver nanoparticles than XRF. Report from the literature vividly revealed that AgNPs signal is detected at 3.0 keV [19, 22, 23, 61, 68–70].

3.4.2. X-ray fluorescence (XRF)

This is the emission of characteristic “secondary” (or fluorescent) X-rays from a material that has been excited by bombarding with high energy x-rays or gamma rays. XRF technology provides one of the simplest, most accurate and most economic analytical methods for the determination of the chemical composition of many types of materials, particularly in the investigation of metals, glass, ceramics and building materials, and for research in geochemistry, forensic science and archeology. It is non-destructive and reliable, requires no, or very little, sample preparation and is suitable for solid, liquid and powdered samples. It can be used for wide range of elements and provide detection limits at the sub-ppm level; it can also measure concentrations of up to 100% easily and simultaneously [71].

In principle, an inner shell electron is excited by an incident photon in the X-ray region. During the de-excitation process, an electron is moving from a higher energy level to fill the vacancy. The energy difference between the two shells appears as an X-ray, emitted by the atom. The X-ray spectrum acquired during the above process reveals a number of characteristic peaks. The energy of the peaks leads to the identification of the elements present in the sample (qualitative analysis), while the peak intensity provides the relevant or absolute elemental concentration (semi-quantitative or quantitative analysis) [72]. A typical XRF spectroscopy arrangement includes a source of primary radiation (usually a radioisotope or an X-ray tube) and equipment for detecting the secondary X-rays. When materials are exposed to short wavelength x-rays or to gamma rays, ionization of their component atoms may take place. If an X-ray beam is used to excite atoms in a sample, electrons near the nucleus emit secondary fluorescent x-rays on reversion to their original states [73].

In silver nanoparticle studies, XRF could be employed for elemental determination of the composition of nanoparticles although this is not frequently used compared to EDX. The X-ray fluorescence technique is of special interest for the analysis of silver nanoparticles because the technique is not only fast, sensitive and capable of simultaneous multi-element analysis, but also ensures that the sample can be quantitatively analyzed without damage. Therefore, it is mostly used to identify determining the presence of silver and other element in the compound. Specifically, silver nanoparticle is detected at 3.0 keV which is the characteristic peak reported by different researchers [74].

3.5. X-ray diffraction (XRD)

X-ray diffraction (XRD) (among others, such as FT-IR, UV, TEM, SEM, EDX) is a widely used technique for structural characterization which participate (a main part) in identifying the structure of a (nano/bio)-material or particle. Hence, XRD is a widely held analytical technique, which has been employed in the analysis of both molecular and crystal structures, qualitative detection of elements and their compounds, quantitative resolution of chemical species, quantifying the degree/measure of crystallinity, isomorphous substitutions, stacking faults, polymorphisms, particle sizes, *in situ* studies at process temperatures and in reactive atmospheres, phase identification and quantification etc. [75, 76].

XRD technique is a handy popular technique for characterizing silver nanoparticles and has grown into a common characterization method for evaluating these nanoparticles. Some of the main structural uniqueness are related with these i.e., measuring degree of crystallinity, phase identification, super-lattice generation, impurities detection, material's vacancy characterization and also novel materials development [77]. The crystalline structure or nature of bio-synthesized silver nanoparticles is determined by XRD analysis and patterns; this also use to confirm the structural information. Many authors reported a similar diffraction profile for most Ag-NPs with XRD peaks at 2θ of 38.18° , 44.25° , 64.72° , and 77.40° which are indexed to the 111, 200, 220, and 311 crystallographic planes of Bragg's reflections of the face-centered cubic structure of silver crystals, which suitably matched the standard diffraction data with those reported for silver by joint committee on powder diffraction standards. The average crystalline size of the silver nanoparticles was estimated using (Eq. 1), the Debye-Scherrer's equation [45, 78]:

$$D = 0.9\lambda / \beta \cos \theta \quad (1)$$

where d is the particle size, λ is the wavelength of X-ray radiation (1.5406 \AA), β is the full-width at half-maximum (FWHM) of the height (in radians) and 2θ is the Bragg angle. The precision, significance, sensitivity and easy use of XRD increases its importance in AgNPs. However, there are some limitations that one might face using this analysis. It can only analyze and identify an unknown material that is homogeneous and single phase. There should be a standard reference file for compounds especially inorganic ones (d -spacings, hkl s), peaks overlay mostly happened in XRD and worsen for high angle' reflections, to determine unit cell using XRD, indexing of patterns for non-isometric crystal systems is complicated.

3.6. Thermogravimetric analysis (TGA) and X-ray photoelectron spectroscopy (XPS)

The advancement of nanotechnology is rapidly evolving and holds potential to completely redefine applications of material science in the nearest future. In order to maximize the prospects of nanotechnology for diverse applications, the characterization of nanomaterials and/or nanoparticles have become imperative. Among the several techniques available for the characterization of nanomaterials are thermogravimetric analysis (TGA) and X-ray photoelectron spectroscopy (XPS).

3.6.1. Thermogravimetric analysis

Thermogravimetric analysis (TGA) is an analytical technique for measuring changes in the mass of a material that occur in response to programmed temperature changes [79]. TGA represents a branch of thermal analysis examining the mass changes of a sample as a function off temperature (in the scanning mode) or as a function of time (in the isothermal mode). In TGA changes in physical and chemical properties of materials are measured as a function of increasing temperature (with constant heating rate), or as a function of time (with constant temperature and/or constant mass loss). The changes in the mass of a sample due to various thermal events (desorption, absorption, sublimation, vaporization, oxidation, reduction and decomposition) can be studied while the sample is subjected to a program of change in temperature. TGA has found applications in the analysis of volatile products, gaseous

products lost during the reaction in thermoplastics, thermosets, elastomers, composites, films, fibers, coatings, paints among others. Further practical applications, are determining composition and thermal stability of materials, evaluating the kinetics of thermally stimulated processes, predicting lifetimes, and studying reactions of materials with gases. There are different types of TGA ranging from isothermal to dynamic TGA.

3.6.1.1. *Thermal properties of silver nanoparticles*

In a recent investigation, thermal behavior of silver nanoparticles was monitored by TGA Khan et al. [80], authors reported dominant weight loss in silver nanoparticles occurred in temperature region between 200 and 300°C. There was almost no weight loss below 200°C and above 300°C. The weight loss was attributed to the evaporation of water and organic components. Overall, TGA results show a loss of 14.58% up to 300°C. In the same study, the differential thermal analysis (DTA) plot displayed an intense exothermic peak between 200 and 300°C which mainly could be attributed to crystallization of silver nanoparticles. DTA profiles suggest that complete thermal decomposition and crystallization of the sample occur simultaneously. Taken together, the TGA/DTA study shows that the dominant weight loss occurs between 200 and 300°C; and the reaction is of exothermic type [80].

In a separate study, the low-temperature sintering behavior of Ag nanoparticles was investigated. The silver nanoparticles were shown to exhibit obvious sintering behavior at significantly lower temperatures (~150°C) than the T_m (960°C) of silver while coalescence of the silver nanoparticles was observed by sintering the particles at 150, 200, and 250°C. The thermal profile of the nanoparticles was examined by a differential scanning calorimeter (DSC) and a thermogravimetric analyzer (TGA). Shrinkage of the silver nanoparticle compacts during the sintering process was observed by thermomechanical analysis (TMA). Sintering of the nanoparticle pellet led to a significant increase in density and electrical conductivity. The size of the sintered particles and the crystallite size of the particles increased with increasing sintering temperature [81].

3.6.2. *X-ray photoelectron spectroscopy (XPS)*

As the demand for high performance materials increases, so does the importance of surface engineering. Typically, the surface of a material represents the platform of interaction with the external environment and other materials. In the case of nanotechnology, surface chemistry of nanomaterials and/or nanoparticles is key to exploring the prospects of these particles for diverse applications. Surface modification can be used to alter or improve the properties of nanomaterials and/or nanoparticles, and so surface analysis becomes a technique for probing the surface chemistry of these particles. More so, nanotechnology approaches include surface modification of nanomaterials in order to suit specific purposes. Therefore, it becomes expedient to understand the physical and chemical interactions occurring at the surface, or at the interfaces of the nanomaterial's layers.

X-ray photoelectron spectroscopy (XPS) also known as electron spectroscopy for chemical analysis (ESCA) is a widely accepted technique for surface analysis. This probably may be because XPS can be applied to a broad range of materials and provides valuable quantitative and chemical state information from the surface of the material being studied. The average depth of analysis for an XPS measurement is approximately 5 nm. XPS measurement involves

irradiating the surface of sample materials with monochromatic Al-K- α x-rays. This leads to excitation thereby causing photoelectrons to be emitted from the sample surface. Then an electron energy analyzer is used to measure the energy of the emitted photoelectrons. From the binding energy and intensity of a photoelectron peak, the elemental identity, chemical state, and quantity of a detected element can be determined.

3.6.2.1. X-ray photoelectron spectroscopy (XPS) of silver nanoparticles

Several investigations have reported the use XPS technique to characterize the surface chemistry of silver nanoparticles. Larrude et al. [82] characterized silver-multiwalled carbon nanotubes (Ag-MWCNTs) nanocomposite using the XPS technique. Their report showed spectrum revealing the dominance of silver and carbon, with small amounts of sodium and sulfur in the sample. According to the author of the investigation, presence of Na and S was attributable to the use of sodium dodecyl sulfate (SDS) for the MWCNTs dispersion. Also, the study demonstrated increased oxygen content compared to a pure MWCNTs sample. However, there was no evident relationship between the oxygen and the silver contents because the O/Carbon atomic rate did not change significantly between the different silver concentrations. Furthermore, the spectrum of the Ag 3d core level of the Ag-decorated MWCNTs, confirmed the presence of metallic silver because the 3d_{5/2} component occurred at a binding energy of 368.3 eV, which is characteristic of the metallic Ag (0) oxidation state [82].

In a separate study involving a surface chemical characterization of silver nanoparticles thin film using XPS instrument equipped with monochromatic Al-K- α X-ray source [83]; the XPS spectrum and the high-resolution XPS window of the core level atoms comprising the silver nanoparticles capped with carboxylate/1-dodecylamine revealed the presence of Ag, C, O, and N atoms according to their binding energies. The most prominent signal in the XPS spectrum was the Ag 3s consisting of two spin-orbit components at 368.8 (Ag3d_{5/2}) and 374.8 (Ag3d_{3/2}) eV and separated by 6.0 eV. Moreover, the deconvolution of Ag (3d) doublet revealed asymmetric peak shape. These two characteristics indicated the existence of the Ag in metallic form.

Furthermore, another investigation reported consistence of the XPS analysis of silver behenate was with the theoretical C: O: Ag atomic composition. The report noted that brown discoloration of silver behenate powder within a few seconds of exposure to monochromatic X-rays and that this increased significantly with time. Further, noticeable changes to the XPS spectra and the observed surface composition begin to occur after about 30 minutes of X-ray exposure, while prolonged exposure to monochromatic X-rays resulted in significant changes in the C 1s, O 1s, and Ag 3d peak shapes and positions. Changes in the XPS spectra indicated that exposure to Al K α X-rays resulted in the formation of silver metal particles and decomposition of the carboxylic acid portion of the molecule to hydrocarbon species. Thermal reduction of silver behenate powder produced similar changes in the XPS spectra [84].

4. Conclusion

This chapter has examined the operational parameters which are imperative to the synthesis of silver nanoparticles. Effect of concentration, volume ratio, contact time, temperature and pH

affect the synthesis of silver nanoparticles. Conditions attached to each of these have been identified. Chief among these factors is the effect of pH which affect the chemistry of the silver nanoparticle synthesis. However, irrespective of the synthetic route and conditions, characterization Techniques which are germane to the studies of silver nanoparticles have also been critically examined. The UV–Vis spectroscopy helps in determining the surface plasmon resonance absorption band and this is vital in nanoparticle studies. The functional groups are determined by FTIR, morphology and sizes by SEM and TEM, atomic distributions and relative abundances were revealed by EDX and XRF respectively. The crystallinity can be determined by XRD, surface chemical characterization by X-ray photoelectron spectroscopy (XPS) and silver content by thermogravimetric analysis (TGA). It can be concluded that relevant research in nanoparticle studies rely on both the operational conditions and excellent characterization.

Acknowledgements

The authors appreciate the management of Landmark University for providing enabling environment for research.

Conflict of interest

The authors declare that there is no conflict of interest.

Author details

Adewumi O. Dada^{1*}, Folahan A. Adekola², Oluyomi S. Adeyemi³, Oluwasesan M. Bello⁴, Adetunji C. Oluwaseun⁵, Oluwakemi J. Awakan³ and Femi-Adepoju A. Grace⁶

*Address all correspondence to: dada.oluwasogo@lmu.edu.ng

1 Industrial Chemistry Programme, Nanotechnology Laboratory, Department of Physical Chemistry, Landmark University, Omu-Aran, Nigeria

2 Department of Industrial Chemistry, University of Ilorin, Nigeria

3 Medicinal Biochemistry and Toxicology Laboratory, Department of Biological Sciences, Landmark University, Omu-Aran, Nigeria

4 Department of Applied Chemistry, Federal University Dutsin-Ma, Katsina State, Nigeria

5 Department of Biological Sciences, Applied Microbiology, Biotechnology and Nanotechnology Laboratory, Landmark University, Omu Aran, Kwara State, Nigeria

6 Department of Plant and Environmental Biology, Kwara State University, Malete, Kwara State, Nigeria

References

- [1] Christina G, Vossen DLJ, Arnout I, Alfon VB. General method to coat colloidal particles with silica. *Langmuir*. 2013;**19**(17):6693-6700. DOI: 10.1021/la0347859
- [2] Benn TM, Westerhoff P. Nanoparticle silver released into water from commercially available sock fabrics. *Environmental Science & Technology*. 2008;**42**:4133-4139
- [3] Shi J, Xu B, Sun X, Ma C, Yu C, Zhang H. Light induced toxicity reduction of silver nanoparticles to *Tetrahymena pyriformis*: Effect of particle size. *Aquatic Toxicology*. 2010. DOI: 10.1016/j.aquatox.2013.02.001
- [4] Chen E, Su H, Zhang W, Tan T. A novel shape-controlled synthesis of dispersed silver nanoparticles by combined bioaffinity adsorption and TiO₂ photocatalysis. *Powder Technology*. 2011;**212**:166-172
- [5] Edison TJI, Sethuraman MG. Biogenic robust synthesis of silver nanoparticles using *Punica granatum* peel and its application as a green catalyst for the reduction of an anthropogenic pollutant 4-nitrophenol. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*. **104**:262-264
- [6] Dankovich TA, Gray DG. Bactericidal paper Impregnated with silver nanoparticles for point-of-use water treatment. *Environmental Science & Technology*. 2011;**45**:1992-1998
- [7] Hendi A. Silver nanoparticles mediate differential responses in some of liver and kidney functions during skin wound healing. *Journal of King Saud University (Science)*. 2011;**23**:47-52
- [8] An J, Wang D, Luo Q, Yuan X. Antimicrobial active silver nanoparticles and silver/poly-styrene core-shell nanoparticles prepared in room-temperature ionic liquid. *Materials Science and Engineering C*. 2009;**29**:1984-1989
- [9] Mohanty S, Mishra S, Jena P, Jacob B, Sarkar B, Sonawane A. An investigation on the antibacterial, cytotoxic, and antibiofilm efficacy of starch-stabilized silver nanoparticles. *Nanomedicine: Nanotechnology, Biology, and Medicine*. 2012;**8**:916-924
- [10] Dong X, Ji X, Jing J, Li M, Li J, Yang W. Synthesis of triangular silver nanoprisms by stepwise reduction of sodium borohydride and trisodium citrate. *Journal of Physical Chemistry C*. 2010;**114**(5):2070-2074. DOI: 10.1021/jp909964k
- [11] Shan Z, Wu J, Xu F, Huang F-Q, Ding H. Highly effective silver/semiconductor photocatalytic composites prepared by a silver mirror reaction. *Journal of Physical Chemistry C*. 2008;**112**(39):15423-15428. DOI: 10.1021/jp804482k
- [12] Wiley B, Sun Y, Xia Y. Synthesis of silver nanostructures with controlled shapes and properties. *Accounts of Chemical Research*. 2007;**40**:1067-1076
- [13] Pietrobon B, Mceachran M, Kitaev V. Synthesis of size-controlled faceted pentagonal silver nanorods *with* tunable plasmonic properties and self-assembly of these nanorods. *ACS Nano*. 2009;**3**:21-26. DOI: 10.1021/nn800591y

- [14] Tanimoto H, Ohmura S, Maeda Y. Size-selective formation of hexagonal silver nanoprisms in silver citrate solution by monochromatic-visible-light irradiation. *Journal of Physical Chemistry C*. 2012, 2012;**116**(29):15819-15825. DOI: 10.1021/jp304504c
- [15] Yong SJ, Kim SKB. Rapid biological synthesis of silver nanoparticles using plant leaf extracts. *Bioprocess and Biosystems Engineering*. 2008;**32**(1):79-84. DOI: 10.1007/s00449-008-0224-6 PMID 18438688
- [16] Shiv SS, Absar A, Murali S. Geranium leaf assisted biosynthesis of silver nanoparticles. *Biotechnology Progress*. 2003;**19**(6):1627-1631. DOI: 10.1021/bp034070w. PMID 14656132
- [17] Wen C, Shao M, Zhuo S, Lin Z, Kang Z. Silver/graphene nanocomposite: thermal decomposition prep catalytic performance. *Materials Chemistry and Physics*. 2012;**135**:780-785
- [18] Dan P, Jeffrey MP, Seungpyo H, Omid CF, Rimona M, Robert L. Nanocarriers as an emerging platform for cancer therapy. *Nature Nanotechnology*. 2007;**2**(12):751-760. Bibcode:2007NatNa...2..751P. DOI: 10.1038/nnano.2007.387
- [19] Pandey S, Goswami GK, Nanda KK. Green synthesis of biopolymer–silver nanoparticle nanocomposite: An optical sensor for ammonia detection. *International Journal of Biological Macromolecules*. 2012;**51**:583-589
- [20] de MMR, Mattoso LHC, Zucolotto V. Development of cellulose-based bactericidal nanocomposites containing silver nanoparticles and their use as active food packaging. *Journal of Food Engineering*. 2012;**109**:520-524
- [21] Ibrahim HMM. Green synthesis and characterization of silver nanoparticles using banana peel extract and their antimicrobial activity against representative microorganisms. *Journal of Radiation Research and Applied Sciences*. 2015;**8**:265-275
- [22] Oluwaniyi OO, Adegoke HI, Adesuji ET, Alabi AB, Bodede SO, Labulo AH, Oseghale CO. Biosynthesis of silver nanoparticles using aqueous leaf extract of *Thevetia peruviana* Juss and its antimicrobial activities. *Applied Nanoscience*. 2015. DOI: 10.1007/s13204-015-0505-8
- [23] Kokila T, Ramesh PS, Geetha D. Biosynthesis of silver nanoparticles from Cavendish banana peel extract and its antibacterial and free radical scavenging assay: A novel biological approach. *Applied Nanoscience*. 2015;**5**:911-920
- [24] Vinod VTP, Saravanan P, Sreedhar B, Devi KD, Sashidhar RB. A facile synthesis and characterization of Ag, Au and Pt nanoparticles using a natural hydrocolloid gum kondagogu (*Cochlospermum gossypium*). *Colloids and Surfaces B: Biointerfaces*. 2011; **83**:291-298
- [25] Ravindran A, Chandran P, Khan SS. Biofunctionalized silver nanoparticles: Advances and prospects. *Colloids and Surfaces B: Biointerfaces*. 2013;**105**:342-352
- [26] Lü X, Cui S. Wool keratin-stabilized silver nanoparticles. *Bioresource Technology*. 2010; **101**:4703-4707

- [27] Bindhu MR, Umadevi M. Silver and gold nanoparticles sensor and antibacterial applications. *Spectrochim Acta Part A Molecular and Biomolecular Spectroscopy*. 2014;**128**:37-45
- [28] Maidul Islam AKM, Mukherjee M. Effect of temperature in synthesis of silver nanoparticles in triblock copolymer micellar solution. *Journal of Experimental Nanoscience*. 2011;**6**(6):596-611. DOI: 10.1080/17458080.2010.506518
- [29] Heydari R, Rashidipour M: Green synthesis of silver nanoparticles using extract of oak fruit hull (Jaft): Synthesis and in vitro cytotoxic effect on MCF-7 cells. *International Journal of Breast Cancer Volume 2015*, Article ID 846743, 6 pages. <http://dx.doi.org/10.1155/2015/846743>
- [30] Sun L, Wang L, Yonghai S, Guo C, Sun Y, Peng C. Aggregation- based growth of silver nanowires at room temperature. *Applied Surface Science*. 2008;**254**:2581-2587
- [31] Martinez-Castanon GA, Nino-Martinez N, Martinez-Gutierrez F, Martinez- Mendoza JR. Synthesis and antibacterial activity of silver nanoparticles with different sizes. *Journal of Nanoparticle Research*. 2008;**10**:1343-1348
- [32] Velgosová O, Mražíková A, Marcinčáková R. Influence of pH on green synthesis of Ag nanoparticles. *Materials Letters*. <http://dx.doi.org/10.1016/j.matlet.2016.04.045>
- [33] Alqadi MK, Noqtah OAA, Alzoubi FY, Alzoubi J, Aljarrah K. pH effect on the aggregation of silver nanoparticles synthesized by chemical reduction. *Materials Science-Poland*. 2014;**32**(1):107-111
- [34] Baranova OA, Khizhnyak SD, Pakhomov PM. Effect of the pH value on the synthesis of silver nanoparticles in an aqueous cysteine–silver solution. *Journal of Structural Chemistry*. 2016;**57**(6):1203-1208
- [35] Giannini C, Ladisa M, Altamura D, Siliqi D, Sibillano T, De Caro L. X-ray diffraction: A powerful technique for the multiple-length-scale structural analysis of nanomaterials. *Crystals*. 2016;**6**:87. DOI: 10.3390/cryst6080087
- [36] Skoog DA, Holler FJ; Crouch SR: *Principles of Instrumental Analysis* (6th ed.). Belmont, CA: Thomson Brooks/Cole. 2007; pp. 169-173. ISBN: 9780495012016
- [37] Das R, Nath SS, Chakdar D, Gope G, Bhattacharjee R. Preparation of silver nanoparticles and their characterization. *Journal of Materials Science*. 2009:1-9. DOI: 10.2240/azojono0129
- [38] Van Dong P, Ha CH, Binh LT, Kasbohm J. Chemical synthesis and antibacterial activity of novel-shaped silver nanoparticles. *International Nano Letters*. 2012;**2**(9):1-9
- [39] Jung C. Insight into protein structure and protein-ligand recognition by Fourier transform infrared spectroscopy. *Journal of Molecular Recognition*. 2000;**13**:325-351. DOI: 10.1002/1099-1352(200011/12)13:6<325::AID-JMR507>3.0.CO;2-C
- [40] Kim S, Barry BA. Reaction-induced FT-IR spectroscopic studies of biological energy conversion in oxygenic photosynthesis and transport. *The Journal of Physical Chemistry*. B. 2001;**105**:4072-4083. DOI: 10.1021/jp0042516

- [41] Vogel R, Siebert F. Vibrational spectroscopy as a tool for probing protein function. *Current Opinion in Chemical Biology*. 2000;**4**:518-523. DOI: 10.1016/S1367-5931(00)00125-3
- [42] Kumar S, Barth A. Following enzyme activity with infrared spectroscopy. *Sensors*. 2010; **10**:2626-2637. DOI: 10.3390/s100402626
- [43] Hind AR, Bhargava SK, McKinnon A. At the solid/liquid interface: FTIR/ATR—The tool of choice. *Advances in Colloid and Interface Science*. 2001;**93**:91-114. DOI: 10.1016/S0001-8686(00)00079-8
- [44] Liu H, Webster TJ. Nanomedicine for implants: A review of studies and necessary experimental tools. *Biomaterials*. 2007;**28**:354-369. DOI: 10.1016/j.biomaterials.2006.08.049
- [45] Bankar A, Joshi B, Kumar AR, Zinjarde S. Banana peel extract mediated novel route for the synthesis of silver nanoparticles. *Colloids and Surfaces A-Physicochemical and Engineering Aspects*. 2010;**368**:58-63
- [46] Adetunji CO, Sarin NB. Impacts of biogenic nanoparticle on the biological control of plant pathogens. *Advances in Biotechnology & Microbiology*. 2017;**7**(3):555711. DOI: 10.19080/AIBM.2017.07.555711
- [47] Adetunji CO, Phazang P, Sarin NB. Biosensors: A Fast-Growing Technology for Pathogen Detection in Agriculture and Food Sector. *InTechOpen*; 2018
- [48] Wang ZL. Transmission electron microscopy of shape-controlled nanocrystals and their assemblies. *The Journal of Physical Chemistry. B*. 2000;**104**:1153-1175
- [49] Ortega-Arroyo L, Martin-Martinez ES, Aguilar-Mendez MA, Cruz-Orea A, Hernandez-Perez I, Glorieux C. Green synthesis method of silver nanoparticles using starch as capping agent applied the methodology of surface response. *Starch-Starke*. 2013;**65**:814-821. <http://dx.doi.org/10.1002/star.201200255>
- [50] Sreekanth TVM, Nagajyothi PC, Lee KD. *Dioscorea batatas* rhizome-assisted rapid biogenic synthesis of silver and gold nanoparticles. *Synthesis and Reactivity in Inorganic, Metal-Organic, and Nano-Metal Chemistry*. 2012;**42**:567-572. <http://dx.doi.org/10.1080/15533174.2011.613886>
- [51] Vigneswaran N, Ashtaputre NM, Varadarajan PV, Nachane RP, Paralikar KM, Balasubramanya RH. Biological synthesis of silver nanoparticles using the fungus *Aspergillus flavus*. *Materials Letters*. 2007;**61**:1413-1418. <http://dx.doi.org/10.1016/j.matlet.2006.07.042>
- [52] Vigneshwaran N, Kathe AA, Varadarajan PV, Nachane RP, Balasubramanya RH. Biomimetics of silver nanoparticles by white rot fungus. *Colloids and Surfaces B: Biointerfaces*. 2006;**53**:55-59. <http://dx.doi.org/10.1016/j.colsurfb.2006.07.014>
- [53] Jagtap UB, Bapat VA. Green synthesis of silver nanoparticles using *Artocarpus heterophyllus* lam. Seed extract and its antibacterial activity. *Industrial Crops and Products*. 2013;**46**:132-137. <http://dx.doi.org/10.1016/j.indcrop.2013.01.019>

- [54] Vijayaraghavan K, Nalini SPK, Prakash NU, Madhankumar D. One step green synthesis of silver nano/micro particles using extracts of *Trachyspermum ammi* and *Papaver somniferum*. *Colloids and Surfaces B: Biointerfaces*. 2012;**94**:114-117. <http://dx.doi.org/10.1016/j.colsurfb.2012.01.026>
- [55] Sant DG, Gujarathi TR, Harne SR, Ghosh S, Kitture R, Kale S, Chopade BA, Pardesi KR. *Adiantum philippense* L. Frond assisted rapid green synthesis of gold and silver nanoparticles. *Journal of Nanoparticles*. 2013 Article ID: 182320
- [56] Satishkumar G, Gobinath G, Karpagam K, Hemamalini V, Premkumar K, Sivaramakrishna S. Phyto-synthesis of silver nanoscale particles using *Morinda citrifolia* L. and its inhibitory action against human pathogens. *Colloids and Surfaces B: Biointerfaces*. 2012;**95**:235-240. <http://dx.doi.org/10.1016/j.colsurfb.2012.03.001>
- [57] Rajakumar G, Rahuman AA. Larvicidal activity of synthesized silver nanoparticles using *Eclipta prostrata* leaf extract against Filariasis and malaria vectors. *Acta Tropica*. 2011;**118**: 196-203. <http://dx.doi.org/10.1016/j.actatropica.2011.03.003>
- [58] Joshi M, Bhattacharyya A. Characterization techniques for nanotechnology applications in textiles. *Indian Journal of Fiber Textiles Research*. 2008;**33**:304-317
- [59] Williams DB, Carter CB. *The Transmission Electron Microscope*. New York, NY, USA: Springer Verlag; 2009
- [60] Lin PC, Lin S, Wang PC, Sridhar R. Techniques for physicochemical characterization of nanomaterials. *Biotechnology Advances*. 2014;**32**:711-726
- [61] Jyoti K, Baunthiyal M, Singh A. Characterization of silver nanoparticles synthesized using *Urtica dioica* Linn. leaves and their synergistic effects with antibiotics. *Journal of Radiation Research and Applied Sciences*. 2016;**9**:217-227
- [62] Dada AO, Adekola FA, Odebunmi EO. Liquid phase scavenging of Cd (II) and Cu (II) ions onto novel nanoscale zerovalent manganese (nZVMn): Equilibrium, kinetic and thermodynamic studies. *Environmental Nanotechnology, Monitoring & Management*. 2017;**8**:63-72. <http://dx.doi.org/10.1016/j.enmm.2017.05.001>
- [63] Dada AO, Adekola FA, Odebunmi EO (2017). Kinetics, mechanism, isotherm and thermodynamic studies of liquid phase adsorption of Pb²⁺ onto wood activated carbon supported zerovalent iron (WAC-ZVI) nanocomposite. *Cogent Chemistry Journal*. 3: 1351653, pg 1–20. DOI: <http://doi.org/10.1080/23312009.2017.1351653>
- [64] Dada AO, Adekola FA, Odebunmi EO. Novel zerovalent manganese for removal of copper ions: Synthesis, characterization and adsorption studies. *Applied Water Science*. 2017;**7**:1409-1427. DOI: 10.1007/s13201-015-0360-5
- [65] Dada AO, Adekola FA, Odebunmi EO. Kinetics and equilibrium models for sorption of Cu (II) onto a novel manganese nano-adsorbent. *Journal of Dispersion Science and Technology*. 2015;**37**(1):119-133. DOI: 10.1080/01932691.2015.103461

- [66] Corbari L, Cambon-Bonavita MA, Long GJ, Grandjean F, Zbinden M, Gaill F, Compere P. Iron oxide deposits associated with the ectosymbiotic bacteria in the hydrothermal vent shrimp *Rimicaris exoculata*. *Biogeosciences*. 2008;5(5):1295-1310. DOI: 10.5194/bg-5-1295-2008
- [67] Goldstein J. *Scanning Electron Microscopy and X-Ray Microanalysis*. 2003. Springer. ISBN: 978-0-306-47292-3. Retrieved 26 May 2012
- [68] Anandalakshmi K, Venugobal J, Ramasamy V. Characterization of silver nanoparticles by green synthesis method using *Petalium murex* leaf extract and their antibacterial activity. *Applied Nanoscience*. 2016;6:399-408. DOI: 10.1007/s13204-015-0449-z
- [69] Torrent L, Iglesias M, Hidalgo M, Margu E. Determination of silver nanoparticles in complex aqueous matrices by total reflection X-ray fluorescence spectrometry combined with cloud point extraction. *Journal of Analytical Atomic Spectrometry*. 2018. DOI: 10.1039/c7ja00335h
- [70] Sasikala A, Rao ML, Savithramma N, Prasad TNVKV. Synthesis of silver nanoparticles from stem bark of *Cochlospermum religiosum* (L.) Alston: An important medicinal plant and evaluation of their antimicrobial efficacy. *Applied Nanoscience*. 2015;5:827-835. DOI: 10.1007/s13204-014-0380-8
- [71] John A, Alexandra S, Larry A. Approaching a universal sample preparation method for XRF analysis of powder materials. *International center for diffraction data. Advances in X-Ray Analysis*. 2001;44:368-370
- [72] Loupilov A, Sokolov A, Gostilo V. X – Ray Peltier cooled detectors for X – Ray. *Radiation Physics and Chemistry*. 2001;61(3–6):463-464
- [73] De Viguerie L, Sole VA, Walter P. Multilayer quantitative X-ray fluorescence analysis applied to easel paintings. *Analytical and Bioanalytical Chemistry*. 2009 Dec;395(7):2015-2020. DOI: 10.1007/s00216-009-2997-0
- [74] Fierascu RC, Bunghez IR, SOMOGHI R, Fierascu I, Ion RM. Characterization of silver nanoparticles obtained by using *Rosmarinus officinalis* extract and their antioxidant activity. *Revue Roumaine de Chimie*. 2014;59(3–4):213-218
- [75] Ivanisevic I, McClurg RB, Schields PJ. In: *Uses of X-ray powder diffraction in the pharmaceutical industry*, ed. by S.C. Gad, *Pharmaceutical Sciences Encyclopedia: Drug Discovery, Development, and Manufacturing* (John Wiley & Sons, Inc., New Jersey). 2010. p. 1
- [76] Pecharsky V, Zavalij P. *Fundamentals of Powder Diffraction and Structural Characterization of Materials*. 2nd ed. Springer; 2009
- [77] Das R, Ali ME, Abd Hamid nan SB: Current applications of X-ray powder. *Reviews on Advanced Material Science*. 2014;38:95-109
- [78] Ajitha B, Reddy YAK, Reddy PS. Biogenic nano-scale silver particles by *Tephrosia purpurea* leaf extract and their inborn antimicrobial activity. *Spectrochim Acta Part A*. 2014;121:164-172
- [79] Vyazovkin S. *Thermogravimetric analysis. Characterization of Materials*. 2012:1-12

- [80] Khan MAM, Kumar S, Ahamed M, Alrokaya SA, Alsalhi MS. Structural and thermal studies of silver nanoparticles and electrical transport study of their thin films. *Nanoscale Research Letters*. 2011;**6**(434):2011
- [81] Moon KS, Dong H, Maric R, et al. Thermal behavior of silver nanoparticles for low-temperature interconnect applications. *Journal of Electronic Materials*. 2005;**34**(2):168-175. DOI: <https://doi.org/10.1007/s11664-005-0229-8>
- [82] Larrude DG, Maia da Costa MEH, Freire FL Jr. Synthesis and characterization of silver nanoparticle-multiwalled carbon nanotube composites. *Journal of Nanomaterials*. 2014; **2014**:7 Article ID 654068. DOI: 10.1155/2014/654068
- [83] Uznanski P, Zakrzewska J, Favier F, Kazmierski S, Bryszewska E. Synthesis and characterization of silver nanoparticles from (bis)alkylamine silver carboxylate precursors. *Journal of Nanoparticle Research*. 2017;**19**(3):121. DOI: 10.1007/s11051-017-3827-5
- [84] Strohmeier BR, Bunker KL, Lopano CL, Marquis JP, Piasecki JD, Bennethum KE, White RG, Nunney T, Lee RJ. XPS and SEM/STEM characterization of silver nanoparticles formed from the X-ray-induced and thermal reduction of silver behenate. *Microscopy and Microanalysis*. 2009;**15**:1298-1299