A Review on Metallic Gold and Silver Nanoparticles

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ABSTRACT:

Recent developments in material synthesis involve avariety of physical and chemical approaches which has substantially influenced the field of nanotechnology. These strategies play a significant role in many prospects such as synthesis of nanoparticles of variable shapes and uniform particle size distribution. Toxic chemicals in these strategies for the synthesis of metal nanoparticles create hazardous concerns for the environment. In contrary, the biological approach includes the use of bioactive components which are highly biodegradable in nature. Hence biological approach is considered as a promising method for the eco-friendly synthesis of noble metal nanoparticles.Although these noble metal nanoparticles can be synthesised in various forms such as nano-sols, nano-colloids, nano-crystallines, nanorods, nanotubes and nanowires using a variety of physical as well as chemical approaches. Besides their shape and morphology, the size of noble metal nanoparticles should be efficiently tailored to achieve the desired medical application. The increase in surface area increases the possibility of causing the aggregation of nanoparticles which limit their functionalities. The surface functionalization of noble metal nanoparticles was done using chemical dispersants such as surfactants or polyelectrolytes to avoid the aggregation.This functionalisation improves the stability of the noble metal nanoparticles but at the same time it alters the surface chemistry of the nanoparticles. It is crucial for producing the nanoparticles in such a way that they could be size controlled, inexpensive and eco- friendly. The objective of this review is, therefore, to reveal the past and present scenarios, specifically the possibilities of noble metal nanoparticles in applications. Furthermore, it also documents the detailed information about the strategies involved in the use of plant extracts as reducing agents in the synthesis of metal nanoparticles and the incorporation of metal nanoparticles into polymeric materials for environmental applications. This review paper mainly summarizes the various synthesis methods of gold and silver nanoparticles and their applications in biomedicine.

KEYWORDS: Noble metals, Synthesis, Nanoparticles, Biomedicine.

1. INTRODUCTION:

In recent decades, nanotechnology has drawn increasing impact on the modern scientific research. It deals with the manipulation of individual atoms and molecules with sizes in 1–100 nm range in at least one dimension. The advancements and progress in the development of observation tools have spawned a new form of nanoparticles. Thenanoparticles possess unique properties when compared to their bulk counterparts due to their surface to volume ratio and quantum size effects. More over, so the fabrication of nanoparticles persistently improves due to its unique physical and chemical properties and its utilization in the broad range of applications. A plenty of novel nanoparticles using polymers, ceramics and metals open a way for its exploitation in the market from small scale to large scale industries. Among them, the nanoparticles using noble metals have gained interest because of their unique photonic, electronic and catalytic properties. Additionally, these noble metals with magnetic properties are attracting attention towards biomedical applications.

From the ancient times, noble metals have been used in colloidal forms for the treatment of different dreadful diseases. Gold, Silver, Iridium, Ruthenium, Rhodium and platinum have been proposed as safe drug carriers to combat many diseases caused by the foreign materials. noble metal-based therapeutics had laid its first application in the production of cisplatin and its analogs for the treatment of many types of cancers especially ovarian, testicular, bladder, neck, and small cell lung cancer[1]. Researchers paid more attention to this compound and its variants such as carboplatin, oxaliplatin, satraplatin, picoplatin, nedaplatin, lobaplatin, and eptaplatin whichwere commercially usedplatinum-based drugs. The application of first non-platinum based metal complex employed in clinical trials was colloidal gold in the year 1929. It was utilised for the treatment of tuberculosis and rheumatoid arthritis[2]. Since then, the discovery of metal-based therapeutics has developed progressively as anticancer agents as well as anti-microbial and anti-inflammatory agents. Silver was used as novel anti-bacterial against the treatment of burns and wounds. Ruthenium-based metal complexes were also extensively used as antibacterial as well as anti-parasitic agents. Ruthenium complexes with thiosemicarbazones which exhibit good anti-cancer activity against human cancer cell lines have also been reported. Initially, the Copper-based metal complex was used as a potential antimicrobial drug in the treatment of microbial infections[3]. Lately, it has been used to treat cardiovascular disorders, neuron disorders and also in the treatment of diabetic disorders. This chapter will summarise and discussthe overview of gold and silver nanoparticles, their synthesis methods, properties and its applications.

2. NOBLE METAL NANOPARTICLES:

Since ancient times, Gold and Silver have been exploitedas analternative form of drugs. Additionally, these noble metal nanoparticles offer an important place in simultaneous diagnostics and therapeutics due to their small size. These nanoparticles are also employed as potential agents as they provide versatile features and applications. These metals own superior properties over synthetic drugs due to their catalytic efficiency and excellent biocompatibility. The advancements in the nanotechnology field improve the physical and chemical properties of these noble metals by changing their size to nano-level, which leads to different applications[4].

2.1 Gold Nanoparticles:

Gold nanoparticles have gained major attention in scientific research due to its chemical stability and non-cytotoxicity nature. It also possesses high tunable physical and chemical properties due to their large surface area. Hence it can be functionalised with any organic compounds. The properties and applications of gold nanoparticles differ based on their assembly and interparticle interactions[5]. The gold nanoparticles exhibit less than 100 nm in size when they are in colloidal form and it also can be synthesised in different shapes such as nanorods, nanotriangles, nano prism, and hexagonal platelets. Because of it's nanosize, the gold nanoparticles can be easily transported to the tissues and proved to be efficient drug carrier[6]. The gold nanoparticles have the ability to conjugate with the biomarkers which occupied a significant place in targeted drug delivery applications[7]. Gold nanoparticles have been employed for i*n vivo* imaging of the tumor tissues[8]. The gold nanoparticles also possess unique optical properties and hence they are used as sensing probes in various analytical applications.

2.2 Silver Nanoparticles:

Silver nanoparticles are of greater interest due to their flexible properties which endorse them for a wide variety of applications. According to the project on EmergingTechnologies record, over 313 nano silver based consumer products has reached the market. Silver nanoparticles can be incorporated into any medium and it can be applied

inliquid form, colloidal shapes and also in solid forms. The silver nanoparticles exhibit different colors based on their size and morphology. The size of the silver nanoparticles varies upon fabrication procedures and its size ranges from 2 nm to several 100 nm. Silver nanoparticles possess unique physical properties such as high thermal conductivity, chemical stability, nonlinear optical behavior and high catalytic activity than any other noble metals [9,10]. Besides these properties, silver nanoparticles also possess advantages on the large surface area which allows the functionalisation of any number of ligands. However, silver nanoparticles have significant applications in all areas and it is important to study their toxic nature to understand the risk of using these particles in various applications.

3. SYNTHESIS METHODS:

Currently, different approaches are reported for the synthesis of metal nanoparticles such as physical reduction, chemical reduction, photochemical reduction, electrochemical reduction, radiolysis and biological routes. Almost all these methods are in the development stage and each has its demerits towards the stability, control of morphology, the cost of production and scaling up procedures. Additionally, most of these methods are facing difficulties in the downstream processing. Because of this, produced nanoparticles cannot proceed furtherwithapplications. The prime synthesis methods are discussed in this chapter.

3.1 Physical Methods:

The physical approach utilizes the physical energies and radiations for the production of large quantities of metal nanoparticles. It offers an easy way to synthesise metal nanoparticles in the single step reduction procedure. This method requires very less time when compared to other techniques. Evaporation - condensation technique has been mostly used for the production of metal nanoparticles. Thin films with uniform size distribution were synthesised by using this technique with a tube furnace operated at atmospheric pressure. In this case, stable nanoparticles were produced without adding any surfactants in the solution so that no chemical contamination occurs. However, the procedure involves some drawbacks as it requires large space for the furnace and it requires a larger amount of energy for achieving the thermal stability[11].Thermal decomposition involves the synthesis of stable metal nanoparticles with high surface temperature using the ceramic heater. It was revealed that synthesised nanoparticles were stably dispersed even at higher concentrations and there was no formation of aggregates even at high surface temperatures. The obtained nanoparticles are of spherical shapes and there was no change in size distribution with an increase in time. This technique was used to fabricate the nanoparticles of narrow size distribution at a temperature range of 290°C. The nanoparticles produced were in powdered form with the average size around 9.5 nm[12]. The fabrication of metal nanoparticles without using any surfactants was achieved by using the arc discharge method. By this technique, silver nanoparticles were produced without any aggregation with the average size of 10 nm using spark discharge bombardment[13].This method was adapted for large-scale production, but it is highly expensive and dangerous to the environment.Direct sputtering involves the sputtering of metals in the liquid medium is employed for the synthesis of gold and silver nanoparticles. This method includes the physical deposition of metal ions into propane-1, 2, 3-triol (glycerol) which resulted in nanoparticles of narrow particle dispersion. Round shaped nanoparticles with an average diameter of 4 nm were obtained with this technique. It was found that these nanoparticles possess resistance to aggregation even in the dilute aqueous solutions[14]. Laser ablation involves the production of nanoparticles by ablation of bulk materials and by using pulses of the laser beam of high power in the medium. The efficiency of nanoparticle production depends on the wavelength of laser impinging the metal ion, duration of the laser pulse, the time required for ablation, type of medium used and the presence or absence of surfactants. The silver nanoparticles synthesised in femtoseconds by using the laser pulse stroked on the silver ion. The size of the nanoparticles also increased with the increasing power of radiation with the decreasing the concentration of the surfactant [15]. Gold and silver nanoparticles can also be synthesised using a range of irradiation techniques such as γ-irradiation[16], microwave radiation[17] and laser radiation[18]. This irradiation technique involves three steps for the synthesis: (i) nucleation, (ii) accumulation and (iii) growth. These methods permit the production of stable nanoparticles with narrow size distribution.

3.2 Chemical Methods:

The synthetic approach involves the synthesis of metal nanoparticles in the solution by employing three major components: (1) metal precursors, (2) reducing agents and (3) stabilizing agents or capping agents. The most commonly used reducing agents in these methods are sodium citrate, sodium borohydride (NaBH4), ethylene glycol and glucose. These reducing agents are responsible for the reduction of metal ions followed by the

nucleation and finally lead to the formation of metal nanoparticles. The stabilising agents were added during the preparation, which aids the growth of nanoparticles and it also protects the nanoparticles from forming agglomeration.Seed-mediated growth method involves the addition of seeds into the growth medium to obtain size controlled metal nanoparticles. This was achieved by controlling the rate of heterogeneous deposition and rate of crystal growth. A typical process involves the gold nanoparticles encapsulated inside polyethylene glycol served as seeds to the bulk medium. This wet chemical based method implies that the reduction of gold ions occurs due to formaldehyde in bulk medium and polyethylene glycol dendrimers which acts as surface modifiers. This approach yields nanoparticles of various morphologies. These morphological changes occur based on the type of capping agent used[19]. Using bifunctional ligand hexadecyltrimethylammonium bromide (CTAB) as a linker, partially functionalised between the solid substrate and gold nanoparticles[20]. Single phase system technique was used for the synthesis of gold nanoparticles of 3.7 nm by using peptide-biphenyl hybrids (PBHs) as a stabilizer as well as capping agents[21]. In the same way, the silver nanoparticles were synthesised by stepwise multi-electron reduction of silver ions using polyoxometalates as a reducing agent[22]. Monodispersed samples of spherical nanoparticles with controlled size were synthesised using polyol process and precursor mediated Injection technique. This technique offers rapid nucleation in a shorter time, which resulted in the production of uniform-sized nanoparticles. It was also reported that both the injection rate and the reaction temperature played important roles in determining the size of the nanoparticles. Polyol process with the modified precursor injection technique was employed for the synthesis of spherical shaped silver nanoparticle with the size of 17nm at an injection rate of 2.5 ml/s with a reaction temperature of 100°C[23]. The above approaches utilize high energy, toxic chemicals and costlier as well was evident from the above discussions. Hence, it was important for the researchers to develop efficient, eco-friendly alternative techniques. This lead to the identification of natural reducing agents with the aim of producing nontoxic metal nanoparticles. In this direction, biosynthesis approach became inevitable and vital rather than other methods and it deserved extensive research.

3.3 Biological Methods:

Recently, researchers have found that the biological approaches have more advantages over other conventional methods due to its easy availability, safe and sustainable procedures. The natural sources such as plants, microorganisms, algae, fungi, diatoms and waste materials act as a precursor for the synthesis of metal nanoparticles has been demonstrated[24]. Usually, these bio-resources have the ability to accumulate the metals from the surrounding environment[25,26]. Apart from that, it also possesses biochemical processing capabilities which facilitate the formation of metal nanoparticles with different morphologies[27,28]. The biological sources, especially plants have high ability in the formation of metal nanoparticles and it has been exploited in a variety of medications[29,30] as well as environmental applications[31].

Biosynthesis using Microorganisms:

Many reports have shown that the ability of microbes on the synthesis of metal nanoparticles mainly depends on the culturing conditions. The optimization of the reaction parameters such as temperature, pH, nutrient concentrations and stirring rate largely influences the production of enzyme activity of microbes. Each microorganism possesses unique biochemical pathways and so the interaction with the metal ions and the formation of nanoparticles can vary on their reduction mechanisms[32]. The ability of the bacterial strains to synthesize metal nanoparticles was first confirmed by the isolation of *Pseudomonas stutzeri* AG259 strain from silver mines which accumulate silver nanoparticles in their periplasmic cell walls [33]. These microorganisms grow at low concentrations of silver, which secrete NADPH enzymes and undergo nitrate reductase activity. This enzymatic reduction causes the conversion of silver ions to silver nanoparticles. Similarly, the gold nanoparticles have been synthesised using *Pseudomonas aeruginosa*through NADH- dependent reductase enzyme mechanism was observed by Husseiny et al. 2007. The extracellular synthesis of silver nanoparticles using *Bacillus cereus* species was found to be spherical in shape, and in the range of 10-30 nm in size. These nanoparticles also possess efficient antibacterial activity, even at a lower concentration of 50 ppm[34]. Moreover, the production of gold and silver nanoparticles by non-enzymatic mechanisms was seen in by *Bacillus megaterium* and *Corynebacterium species* respectively[35, 36]. Similar results were observed for the synthesis of gold and silver nanoparticles at standard temperature conditions were achieved using *Lactobacillus species*[37]. However, the most notable downside of using bacterial species decreased in the rate of reduction and restricted morphologies when compared to other biological sources.Algal species contain a lot of proteins which play a main role in the biological synthesis of metal nanoparticles of various shapes. Synthesis of gold nanoparticles of tetrahedral,

octahedral and icosahedral shapes using the dried cell suspension of *Chlorella vulgaris* species was also reported[38]. Similarly, the size-controlled synthesis of gold nanoparticles was produced by *plectonemaboryanum* and *cyanobacterium species* was reported[39]. *Nannochloropsis oculata*and Chlorella Vulgaris have the ability to produce silver nanoparticle in the size range of 15 nm within 24 h hasbeen reported[40]. The studies also confirmed that marine algae *Sargassumwightii* species have the ability to produce an extracellular synthesis of stable monometallic as well as bimetallic nanoparticles[41]. Lately, Green algae *Spirogyra insignis* and red algae *Chondrus crispus* species also having the ability to synthesize gold as well as silver nanoparticles has been reported[42]. The gold nanoparticles produced by using *Stoechospermum marginatum* and *Galaxaura elongata* exhibited antibacterial activity has been reported[43,44]. Fungal species possess the production of a significant amount of extracellular enzymes, which mediate the excellent reduction of metal ions was observed. This activity was seen in the *Fusariumoxysporum* species which contains naphthoquinones and anthraquinones which facilitate reduction mechanisms[45]. Moreover, studies revealed that the fungal species was reported for their ability to uptake metals and synthesis of metal nanoparticles of smaller size range[46,47]. The sequence of different reduction mechanisms such as chelation ability, biosorption capacity, bio- precipitation and intracellular uptake have been of attention in the biological production of metal nanoparticles. The mechanism of nanoparticle production was contrary to that of bacterial species because the reduction occurs only on the surface of the fungal species. This mechanism was due to the electrostatic interaction between the anionic groups present on the surface of fungal cell walls with the cationic groups present on the metal ions. This extracellular extraction simplifies the recovery of the biomass in the downstream procedures. This method was more advantageous than bacterial mediated synthesis. It was observed that the rapid reduction and the extracellular formation of metal nanoparticles occur within 10 min was observed in *Aspergillus species*[48].

Biosynthesis using Waste materials:

Waste materials such as the biodegradable wastes from the food and agriculture industries were successfully employed for the synthesis of metal nanoparticles[49]. These materials are not only economical but also reduce the use of hazardous chemicals for the synthesis. The waste materials, especially the fruit peels, contain plenty of bioactive molecules such as polyphenols, flavonoids, carotenoids and vitamins which act as reducing agents for the synthesis of metal nanoparticles. The Mango peel extract contains organic compounds, which has been used successfully to synthesize gold nanoparticles of size around 6 nm. These nanoparticles were tested on African monkey's kidney cell line (CV-1) and human fetal lung fibroblasts (WI -38) and it was found to be less cytotoxic[50,51]. The peels of custard apple contain water-soluble ketone and hydroxyl groups which were responsible for the formation of silver nanoparticles. The synthesised nanoparticles exhibited antimicrobial as well as anticancer properties[52,53] Microwave assisted synthesis of the silver nanoparticles was done using Orange peel extract. The particles obtained were spherical in shape with 8 nm in size[54]. Chicken eggshell which was considered as waste from the baking and food processing industries has been used for the synthesis of gold nanoparticles under ambient conditions. Eggshell contains glycoproteins, collagen, amino acids and uronic acids havebeen acted as a template for the reduction of metal ions [55].

Biosynthesis using Plants:

Studies have been observed that plants can synthesize metal nanoparticles by both extracellular as well as intracellular methods. Plants have the capability to interact with metal ions through oxidation-reduction mechanisms. It plays a major role in the synthesis of metal nanoparticles due to the presence of different bioactive molecules such as proteins, sugars, amino acids and enzymes[56]. It has been found that whole plant can be used for the synthesis of metal nanoparticles of various sizes and shapes. The stem of *Cissus quadrangularis* contains phenolic, amine, and carboxylic groups which involved in the reduction of silver ions to metallic silver nanoparticles[57]. Flavonoids are a large class of polyphenolic compound present in the fruits of *Vitis vinifera* acts as reducing as well as a stabilizing agent for the synthesis of palladium nanoparticles[58]. Moreover, the Diosgenin and ascorbic acid extracted from the tubers of *Dioscorea bulbifera* was used for the synthesis of silver nanoparticles[59]. The flowers of *Mirabilis Jalapa* contain polysaccharides used for the reduction of gold ions[60]. Among the plant parts, leaves act as an excellent mediator for the synthesis of a wide range of metal nanoparticles. Gold nanoparticles synthesised using leaf extract of *Cymbopogon citratus* was effective against malaria vector species *Anopheles stephensi*[61]. The *Ocimum sanctum* leaf extracts contain ascorbic acid which acts as capping agents for the synthesis of crystalline silver nanoparticles within 8 min[62]. The mechanism ivolved

in the plant-based biosynthesis approach involves three main phases: (i) activation phase in which the reduction of metal ions and nucleation of metal atoms occur, (ii) growth phase in which coalescence and the formation of larger nanoparticles occur and (iii) termination phase in which the final shape of the nanoparticles was determined.

4. NEED FOR OPTIMIZATION OF PARAMETERS INVOLVED IN THE SYNTHESIS:

The morphology of the metal nanoparticles was influenced by some factors such as pH, metal ion concentration, reaction temperature and reaction time. The understanding of the mechanisms involved in the nucleation and subsequent formation of the metal nanoparticles will provide better ideas to control the reaction parameters for the production of the metal nanoparticles.

4.1 Influence of pH:

The size and shape of the nanoparticles are strongly influenced by a change in hydrogen ion concentration of the reaction medium. For example, biosynthesis by *Avena sativa* produced larger Au nanoparticles at pH of 2 and smaller nanoparticles at pH of 3[63]. Reports show that gold and silver nanoparticles of different morphologies were prepared by changing the pH of the solvent medium. The tansy fruit extract produced large size gold and silver nanoparticles at lower acidic pH. From the studies, it was also found that nucleation of the functional groups occurred at the high pH which resulted in small-sized nanoparticles. On the other hand, at lower pH, the devoid of functional groups tends to form aggregates resulted in large sized nanoparticles[64].

4.2 Influence of Temperature:

The reaction temperature plays a crucial role in determining the shape, size and yield of biosynthesised nanoparticles[65]. For instance, synthesis of Au nanoparticles at high temperature via *Cymbopogon flexuosus* produced spherical nanoparticles as well as nanotriangle nanoparticles. When the temperature was lowered, the particles resulted in nanotriangle shapes[66]. It was also found that the higher rate of synthesis of gold nanoparticles occurred at a higher temperature. On the other hand, another study revealed the formation of silver nanoparticles by varying the temperature using the peel extract of *Citrus sinensis*[67]. Initially, the nanoparticles with average size of 35 nm were formed at 25°C temperature. The size of the nanoparticles was decreased to 10 nm when the reaction temperature increased to 60 °C. Report on extraordinary green process for the production of gold nanoparticles by a single step reduction of gold ions with *Magnolia Kobus* and *Diospyros cacao* extract. When the reaction temperature and the concentration of the leaf extract were kept low, the nanoparticles were synthesised in various shapes (triangle, pentagons and hexagon) with size around 5- 300 nm[68]. At higher temperature and at a higher concentration of plant extract, the smaller nanoparticles with spherical shapes were obtained. Nanoparticles formed at high temperature resulted in larger size nanoparticles[69]. Similar results were observed in the silver nanoparticles synthesised using *Diospyros kaki* (persimmon) leaf extract over a temperature range from 25 to 95°C has been reported. At lower temperature conditions, the nanoparticles obtained are of either rod-shaped or plate-likestructure[70]. Therefore, under higher temperature conditions, it was necessary to increase the concentration of the plant extract or by increasing the reaction rate to obtain a decrease in the size of nanoparticles.

4.3 Influence of Time:

The reaction time is one of the significant factors which influences the synthesis of metal nanoparticles. A study found that the aqueous silver nitrate was reduced rapidly by *Ananas comosus* extract within 2 min resulted in spherical shaped nanoparticles. While increasing the reaction time, a slight change in colorwas observed[71]. Similarly, the increase in time of reduction of silver ions by *Chenopodium album* leaf extract[72]found that there was a formation of few nanoparticles even after 2 h. The study on *Azadirachta indica* leaf extract concluded that increase in the reaction time from 15 min to 2 h assisted the change in particle size from 10-35 nm. Furthermore, by varying the reaction time spherical, triangular, hexagonal and rectangular shapes have also been produced[73].

4.4 Influence of Reactant Concentration:

The studies revealed that the reactant concentration is also an important factor in the determination of the shape of the metal nanoparticles. The aqueous chloroauric acid solution was rapidly reduced by changing the concentration of *Aloe Vera* extract resulted in a change of nanoparticle shape from triangular plates to spherical [74]. The concentration of *Cinnamomum camphora* leaf extract was varied to produce different shapes of gold and silver nanoparticles. The studies reported that the presence of carbonyl compounds influences the growth of nanoparticle ranging from 50-350 nm [75]. The morphology of the polysaccharide template nanomaterials varied

with the concentration of both the metal ions and the polysaccharides which were used for reducing the metal ions[76].

4.5 Influence of Plant Extract Concentration:

The concentration of plant extracts modulates the production as well as the formation of the different shapes of nanoparticles such as decahedral, hexagonal, triangular, and spherical [77]. Reports on the neem broth employedfor the synthesis of gold, silver and bimetallic nanoparticles found that the produced nanoparticles were stable in the solution over a period of one month at room temperature conditions. Neem extract reduced the gold ions resulted in the synthesis of nanoparticles predominantly with planar structures than spherical, but silver nanoparticles with spherical morphologies ranging from 5 to 35 nm. When the concentration of the *Cinnamomum Campora* leaf biomass was increased from 0.1 to 0.5 g which reduces the gold ions and the shape was shifted from triangle to spherical[78].

5.0 CHARACTERISATION OF METAL NANOPARTICLES:

The gold and silver nanoparticles exhibit different properties upon the influence of environmental conditions were already discussed. The control of particle size and surface chemistry of the metal nanoparticles leads to tremendous applications in biomedical as well as in the environmental fields. Besides the synthesis procedures, there is a necessity to carry out the characterisation of nanomaterials to study the difference in activity based on their morphological variations. The effect of reaction parameters on biosynthesis and its impact on the size and shape characteristics can be studied using analytical techniques.

5.1 UV- visible Spectroscopy Analysis:

The UV-visible spectroscopy is a primary technique to confirm the nanoparticle formation. The spectroscopy works based on the principle of the light absorbed or scattered by the metal nanoparticles in the UV and visible region of the electromagnetic spectrum (Mock et al. 2002). The metal nanoparticles with unique optical properties exhibit surface plasmon resonance effect due to the excitation of an electron on the metal surface. The excitation varies based on the size, shape, and concentration of metal ions was studied using UV-Vis spectroscopy.

5.2 FTIR Analysis:

FTIR spectrum gives the fingerprint of the functional groups present in the organic as well as inorganic compounds. This spectrum works based on the principle that the particles absorb electromagnetic energy in the infrared region of the spectrum and causes the subatomic molecules to vibrate. These vibrations are quantised at certain positions and the absorption takes place which is designated by particular wave number. This wavenumber extends from 4000 cm^{-1} to 400 cm^{-1}. The shape of the nanoparticles depends on the position of the band and the size of the nanoparticle depends on the intensity of the peaks obtained in the FT-IR spectrum.

5.3 Transmission Electron Microscopy Analysis:

Transmission electron microscopy is a high-resolution technique used to study the morphology of metal nanoparticles. It works based on the principle that an electron beam transmitted through the surface of the metal nanoparticles and the interaction of transmitted electrons produces an image. This analysis provides the information about the particle size, shape and distribution.

5.4 Scanning Electron Microscopy Analysis:

Scanning electron microscopy is a popular technique used for studying morphology and surface topology of the sample. When an electron beam incident on the sample, interaction occurs this causes the emission of secondary electrons, backscattered electrons and Auger electrons.The emission of such electrons depends on the surface geometry of the sample and its composition. This collection of electrons detected in SEM and the signal produced which gives the information about the sample. The imaging of the surfaces was done with the resolution of about 1 nm and it depends on upon the electron probe as well as their interaction with the specimen. Because of such high-resolution ability, it was efficiently employed for the scanning of nanoparticles.

5.5 X-Ray Diffraction Analysis:

X-ray diffraction technique is the most important technique used to determine the geometry of the unknown materials. This technique works based on the principle that when a beam of x rays with a wavelength range of 0.5- 2 Å incident on the sample and gets diffracted by the sample's crystalline surfaces. The crystalline nature of the materials can be identified from their diffraction patterns according to the Bragg's law: $2d \sin\theta = n\lambda$; where d

is the spacing between the diffracting planes, ɵ is the incident angle, n is any integer and λ is the wavelength of the beam. It also gives the information about the scattering peaks which corresponded to interplanar spacing of the crystal lattice. From this, it is also used to determine the size of the crystal using Scherrer equation: D= 0.9 λ/ β cos θ, where 0.9 is the shape factor, λ is the wavelength of X-ray, β is the line broadening at half the maximum intensity in radians and θ is the Bragg angle. The gold nanocrystals were prepared by using *Syzygium aromaticum* plant extract remain stable for more than 6 weeks, which is due to the nanoparticles are surrounded by water soluble flavonoids and biochemical constituents.

5.6 Zeta Potential Analysis:

Zeta potential analysis is an important technique used for determining the stability and aggregation of the nanoparticles in a dispersed state. The analysis involves the electrostatic attraction between the surface charges of the nanoparticle with the oppositely charged ions present in the solution. This creates a double layer of ions and the electric potential at the boundary of this layer is termed as zeta potential. The values are measured in the range from +100 mV to – 100 mV. Nanoparticles with high degrees of stability were observed in the range greater than +25 mV or less than - 25mV.

6.0 CONCLUSION:

The research on synthesis of metal nanoparticles has been developed enormously but biological synthesis offers such economic safer route for the synthesis of metal nanoparticles with high specificity, especially in the medical and pharmaceutical field due to its unique chemical and biological properties. Biosynthesis utilizing natural bioactive molecules acts as stabilizers and the bioreduction mechanisms offer the production of stable nanoparticles.This process can be achieved by optimizing parameters such as i) Type of the reducing agent or precursor used ii) concentration of metal ions iii) reaction parameters involved, (iv) interaction between the reducing agent and the metal and (v) functionalization of the nanoparticle surface. Additionally, The natural extracts were widely utilised for the synthesis of metal nanoparticles due to its availability, biocompatibility, faster synthesis and easy scale up.

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