GREEN SYNTHESIS OF SILVER NANOPARTICLES USING ALOE VERA GEL EXTRACT

TAAKA JOANITA MUSUMBA

BU/UP/2023/1856

A PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF CHEMISTRY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF SCIENCE EDUCATION DEGREE OF BUSITEMA UNIVERSITY

JUNE 2026

DECLARATION

I, **TAAKA JOANITA MUSUMBA** declare that this research report is my piece of work, and it has not been submitted elsewhere for examination, the award of a degree, or publication. Where other people's work has been used, it has been duly acknowledged and referenced in accordance to the requirements of Busitema University.

Signature…………………………… Date 19th/08/2026

APPROVAL

This report has been submitted for examination with the approval of my supervisor.

MR. MUSAGALA PETER

Signature……pmusagala…… Date ……19/08/2026……

ACKNOWLEDGEMENT

I thank God the Almighty for his sufficient grace, wisdom and strength that saw me through the completion of this research report. Without his provision, this work would not have been possible.

I wish to express my deepest and sincere gratitude to my supervisor Mr. Musagala Peter for his patient guidance, insightful corrections and encouragement throughout this research work.

I am proudly grateful to my father Mr. Musumba Nabongo, whose financial and spiritual support has been the bedrock to my education. Thank you for believing in me and for the countless sacrifices you have made to see me succeed.

My appreciations also extend to the chemistry department of Busitema university Nagongera campus for providing a conducive environment for learning and research. Special thanks go to the laboratory technicians; Madam Amado Mary and Mr. Chebet Collins for their assistance with the practical aspect and to all lecturers who imparted knowledge required for this research.

May the almighty bless you all.

TABLE OF CONTENTS

LIST OF FIGURES

ABBREVIATIONS

NPs: Nanoparticles

AgNPs: Silver Nanoparticles

UV: Ultraviolet

Vis: Visible

SPR: Surface Plasmon Resonance

ABSTRACT

This research project explores green synthesis of silver nanoparticles (AgNPs) using Aloe vera gel extract as a natural and stabilizing agent. Silver nitrate solution was reacted with Aloe vera gel extract under controlled pH (8-9) adjusted by dilute sodium hydroxide, followed by an incubation at 60ºC for 6 hours. The synthesis process was monitored by observing color changes from colourless to yellow and then brown, indicating nanoparticles formation. UV Vis spectroscopy showed a characteristic Surface Plasmon Resonance (SPR) peak around 400- 500 nm, confirming the synthesis of silver nanoparticles.

The study demonstrates that Aloe vera gel extract effectively facilitates the eco-friendly synthesis of silver nanoparticles (AgNPs) with reaction conditions such as pH and temperature playing a very important role in nanoparticle formation and stability. This green synthesis method offers a sustainable alternative to other chemical methods, with potential applications in medicine, catalysis and material science.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Green synthesis is a method of using plant extract for the biosynthesis of nanoparticles. It is widely used by researchers because it is considered cheap, easy and environmentally friendly. During this method of synthesis of nanoparticles, plants are used are bioreactors where plants transform inorganic metal ions (bioaccumulation) into metal nanoparticles through the reductive capacities of the metabolites (such as terpenoids, alkaloids, polyphenols, tannins and steroids) (Khairan & Jalil, 2019).

Nanoparticles are defined as particulate dispersions or solid particles with a size in the range of 10- 1000nm(Mohanraj & Chen, 2006). Nanoparticles can be directly emitted from combustion processes that include both stationary and mobile sources. They can be formed in the atmosphere through reaction or nucleation of vapor precursors or by radioactive decay and are also commonly produced in industrial settings(Biswas & Wu, 2012). Nanoparticles have potential benefits for the environment; that is to say they can be used to improve efficiency of water treatment, air filtration and soil remediation, and develop new types of renewable energy technologies(Álvarez-chimal & Arenas-alatorre, n.d.). Among the metal Nanoparticles (NPs), Silver Nanoparticles (AgNPs) have substantial potential applications due to their unique physical, chemical and biological properties.

Aloe vera is a perennial, drought-resisting succulent plant species with thick fleshy serrated leaves that store water. It is a traditional medicinal plant which belongs to the family of Liliaceae and it is used to treat several diseases(Biosci et al., 2019). Aloe vera plant is privileged with the therapeutic benefits especially in skincare due to its unique curative properties. Aloe vera is opted for the synthesis of silver nanoparticles because of the presence of natural phytochemicals which provide natural capping and reducing agents.

This research aims at using Aloe vera leave extract as a low cost and ecofriendly environmental approach to green synthesis of Silver Nanoparticle (AgNPs).

1.2 Problem Statement

Silver nanoparticles can be synthesized using a variety of chemical and physical methods that involve chemical reduction, photochemical reduction, electrochemical reduction, heat vaporization, sol-gel method, microwave assisted synthesis and ultra sonication method (Supriya & Chaitanya, 2019). The chemical agents used in reduction are often toxic, expensive and non-ecofriendly in nature thus there is need to develop an ecofriendly process that breaks the practice of using toxic chemicals synthesis of nanoparticles.

Therefore, this research is aimed at reducing the usage of toxic chemicals which are released to the environment during the synthesis of Silver Nanoparticles and so Aleo vera plant extract will be used to prepare silver nanoparticles.

1.3 Objective of the study

The overall objective is to synthesize Silver Nanoparticles using Aloe vera gel extract by green synthesis method.

The overall objective will be achieved by the following specific objectives;

i) To prepare Aloe vera gel extract and use it for the green synthesis of Silver Nanoparticles.

ii) To optimize the conditions for the synthesis of Silver Nanoparticles.

iii) To characterize the synthesized Silver Nanoparticles using UV-VIS spectroscopy.

1.4 Justification of the Study

Nanoparticles are commonly prepared by use of chemical and physical methods in the world. Therefore, use of green synthesis method like use of Aloe vera extract to synthesize Silver Nanoparticles can be considered in this research because it is cheap, harmless to human beings and the environment.

1.5 Literature Review

1.5.1 Nanoparticles

In the recent years, biologically synthesized nanoparticles are in great demand when compared to their chemical and counterparts due to their applications in various areas like medicine, catalysis, energy and materials.

The key products that contain Nanoparticles are coatings, paints and pigments, catalytic additives and cosmetics. Nanoparticles enter the environment along their life cycle through emissions such as release during production of raw materials of nano-enabled products, release during use and release after disposal of nano-containing products (waste handling). Generally, the synthesis of nanoparticles has been carried out using three different approaches; physical, chemical and biological methods. However, physical and chemical methods of synthesis of nanoparticles are very expensive and extremely hazardous to the environment and make use of toxic chemicals, therefore to overcome the shortcomings of chemical and physical methods, biological methods have emerged as viable options because they are seen to be simple, cost effective, dependable, environmentally friendly(Zhang et al., 2016).

Amalgamation of nanoparticles is based on the two unique methodologies i.e. 'top-down' and 'bottom-up'(Journal et al., 2019). Top -down approach is where a suitable bulk material is broken down into smaller fine particles by size reduction using techniques like sputtering, grinding, milling while in bottom- up approach, nanoparticles are synthesized using chemical and biological methods by self -assembly of atoms to new nuclei which grow into nano size particles.

Physical approach of synthesizing particles is mainly a top-down approach while the chemical approach the main components are metallic precursors, stabilizing agents and reducing agents.

1.5.2 Silver Nanoparticles

Silver nanoparticles (AgNPs) have been studied for many decades due to their unique features and wide range of applications. They are nanoparticles of silver having size range between 1 and 100 nm. Their uses include catalysis, biosensing, imaging, and antibacterial activity(Tippayawat et al., 2016). Among these applications, antibacterial activities have gained much attention because they potentially offer a solution to the problem of antibiotic resistance.

The synthesis of silver nanoparticles encompasses physical, chemical and biological (green) approaches, each offering distinct advantages and limitations based on application demand and environmental considerations.

The use of plant extract to synthesize silver Nanoparticles has emerged as a viable alternative because it is cheap, cost effective, provide greater yields and it is ecofriendly (Burange et al., 2021). The biological activity of Silver Nanoparticles (AgNPs) is regulated by the size distribution, surface chemistry, particle shape, chemical composition, agglomeration, capping agent, particle response, ion release and the reducing agents utilized during the AgNPs synthesis (Burange et al., 2021).

Silver ions form complexes and the effect remain for a short time, therefore this has been overcome by use of silver nanoparticles which are in an inert form and so exhibit antimicrobial function by inducing the production of reactive oxygen species. Silver nanoparticles have large surface to volume ratio, high dispersion and crystallographic surface structure. This enables them to display strong biomedical properties like antimicrobial, anticancer, antidiabetic, antioxidant and anti-inflammatory. They are also extensively used in food processing industries, medical implants, in fabrication of ointments and creams to inhibit burns and wounds related infections (Supriya & Chaitanya, 2019). When compared to other metal nanoparticles, silver nanoparticles have gained much attention due to the surface plasmon resonance (SPR) (strong absorption in the UV-visible spectroscopy) (Supriya & Chaitanya, 2019). Silver nanoparticles are widely recognized for their unique physiochemical properties such as high surface area to volume ratio, electrical conductivity and plasmonic behavior which make them suitable for a variety of applications.

Silver nanoparticles are extremely employed in biomedicine due to their potent antibacterial, antiviral and, anticancer properties, combined together with relative biocompatibility and size-dependent functionality. Their Nano scale size allows for direct interaction with microbial membranes leading to membrane disruption, generation of reactive oxygen species (ROS), DNA damage and inhibition of enzymatic activity. These mechanisms collectively contribute to the suppression of microbial growth and replication.

Silver nanoparticles are applied in water purification systems to mitigate bio fouling and microbial contamination. Their antibacterial effect is largely attributed to silver ion (Ag^{+}) release, which disrupts cell wall and interferes with cellular respiration and replication processes. To enhance their stability and performance, silver nanoparticles are typically immobilized onto support materials such as ceramic membrane to ensure sustained activity and reduce leaching.

Silver nanoparticles are also applied in the electronics industry since they are valued for their high electrical conductivity and tunable morphology. Ultrafine silver powders, precursors for silver nanoparticles are engineered to have varied shapes (spheres, rods and plates), typically within the nanometer and sub-micron scale. The morphology of these nanostructures directly affects surface area and thus performance, particularly in antibacterial coatings and conductive inks.

1.5.3 Need for green synthesis of silver Nanoparticles

Silver is a basic element which is non-toxic. Green synthesis is an emerging approach which overcomes the disadvantages of physiochemical approaches through utilization of natural herbs which are non-toxic(Galatage et al., n.d.). Green synthesis utilizes natural antioxidants mainly from plant extracts to covert initial salts into nanoparticles. This method is preferred because plants are widely available, easy to handle and contain diverse a wide range of phytochemicals that act as both reducing agents and capping agents.

Green synthesis of silver nanoparticles has emerged as a sustainable and ecofriendly alternative to conventional chemical and physical synthesis routes. This method employs natural biological agents, including plants, fungi, bacteria, yeasts, algae, and biopolymers that act simultaneously as reducing and capping agents. Unlike traditional techniques, green synthesis avoids toxic solvents and harsh reaction conditions, making it particularly attractive for biomedical, environmental and catalytic applications (Hosny et al., 2025).

Green synthesis relies on biological extracts rich in bioactive compounds such as phenols, flavonoids, alkaloids, terpenoids, and proteins which reduce silver ions (Ag^+) to elemental silver (Ag^+) and stabilize the resulting nanoparticles (Hosny et al., 2025). The general mechanism involves electron donation by these biomolecules, which leads to nucleation and growth of silver nanoparticles, both intracellular and extracellular enzyme-mediated pathways are involved, particularly oxidoreductases, which facilitate the electron transfer necessary for reduction. For example, in plant-mediated synthesis, hydrophytes are proposed to use dehydrogenation of acids and alcohols, xerophytes utilize keto-enol tautomerism, and emophytes may rely on both pathways. These mechanisms directly influence the rate of nucleation and final nanoparticle size and shape.

The effectiveness and reproducibility of green synthesis of silver nanoparticles are strongly influenced by several key experimental parameters including, the concentration of the biological extract, silver nitrate ($AgNO_3$) concentration, pH of reaction medium, reaction temperature and duration. These factors not only affect the yield but also play a critical role in determining the morphology, size distribution, and surface chemistry of the resulting silver nanoparticles. For example acidic conditions generally promote the formation of smaller nanoparticles due to accelerated nucleation, whereas alkaline environments may cause aggregation and increased polydispersity.

The morphology of silver nanoparticles synthesized via biological routes vary widely, ranging from spherical and rod-like to triangular and quasi-spherical, depending in the type and composition of the biological agent used.

1.5.4 Synthesis using plant extract

Plant leaf extract presents a versatile and cost-effective process that could be adopted soon as a sustainable method for nanoparticle production. Recently, the synthesis of AgNPs with diverse sizes and shapes using various fruit peels has gained significant interest among food pack aging companies. The nano-biotechnology is one of the most energetic platforms, exploring the contemporary substantial discipline where plants and various plant products find an imperious use in the fabrication of nanoparticles The AgNPs are found to exhibit unique properties such as conductivity, chemical stability, and catalytic and biological (antibacterial, anti-viral, antifungal, and anti-inflammatory) activities (Hosny et al., 2025). Despite various other methods of synthesizing nanoparticles, the eco-friendly approach has been the most preferred. In addition to microbial synthesis, the phytochemical or plant-based synthesis of nanoparticles has gained significant attention due to its accessibility, consistency, and dependability. Plant-based approaches for synthesizing AgNPs are more efficient, less biodegradable, and do not require active cell cultures, thus largely replacing micro-organism-based methods. Plants can produce AgNPs in various shapes, such as spherical or oval, through the extraction of several plant components, including callus, bark, flowers, peel, fruit, rhizome, leaves, seed, and stem. These foods are rich in polyphenols, enzymes, flavonoids, and proteins. Rather than employing sodium borohydride ($NaBH_4$) and other potentially deleterious substances, these phytochemicals are extracted and employed directly as reducing and stabilizing agents in the manufacture of cell-free metallic nanoparticles (Hosny et al., 2025). The precise mechanism underlying this phenomenon remains ambiguous due to the extensive variety of phyto constituents. Although proteins, organic acids, and polyphenols are widely recognized as the primary reducing agents, it is believed that various phytochemicals work synergistically in the process. This approach is generally considered a cost-effective method for large-scale nanoparticle production. Several bioactive phytochemicals, including terpenoids, polysaccharides, phenolics, alkaloids, flavones, amino acids, alcoholic compounds, and enzymes, can facilitate the reduction of Ag^+ to AgNPs. Plant extracts are regarded as an ideal choice for green synthesis over microorganisms like bacteria or fungi due to their non-pathogenic nature, environmentally friendly reaction conditions, and efficient one-step synthesis process.

Furthermore, in contrast to chemically synthesized AgNPs, plant-derived AgNPs demonstrated greater bioactivity (Hosny et al., 2025). The surface of green synthesized nanoparticles comprises flavonoids and phenolic compounds, which possess antioxidant properties and may be utilized to prevent and treat degenerative diseases. The use of eco-friendly materials, such as plant extracts and enzymes, in the synthesis of AgNPs offers notable benefits, including environmental sustainability and suitability for pharmaceutical and biomedical applications. This method eliminates the reliance on toxic chemicals in the synthesis process

1.5.5 Methods of Synthesizing Silver Nanoparticles

Several methods have been developed for the synthesis of silver nanoparticles, and each comes with its own drawback that has driven researchers toward greener alternatives.

Silver nanoparticles (AgNPs) are conventionally produced through three broad routes; physical, chemical, and biological methods. Each route offers a distinct combination of yield, particle control, and cost, but each also carries a specific technical limitation that has driven researchers towards green, plant-mediated alternatives. A bibliometric analysis of over 10,000 publications on AgNP synthesis between 2010 and 2020 confirmed that chemical methods remain the most widely reported, followed by biological and then physical routes, reflecting both the accessibility and the drawbacks of each approach (Services & Search, n.d.).

1.5.6 Chemical methods

Chemical reduction, photochemical reduction, and electrochemical reduction are the most common chemical routes. Here a reducing agent (commonly sodium borohydride, hydrazine, or similar compounds) converts silver ions (Ag^+) into metallic silver (Ag^0) in solution. The precise challenge with this route is toxicity, the reducing and capping agents used are frequently hazardous, and residues of these chemicals persist on the nanoparticle surface, restricting the particles' use in biomedical and food-related applications. The process is also comparatively expensive and generates chemical waste that carries environmental and occupational health risks. The chemicals may pose risks to human health and aquatic ecosystem. Therefore, additional purification steps are needed before biomedical application (Services & Search, n.d.).

It is frequently applied method for the preparation of AgNPs as stable, colloidal dispersions in water or organic solvents. Most commonly used reductant is citrate. In aqueous solution reduction of silver occurs and nanosize colloidal silver ions are generated. Stability of any colloidal dispersion has prime importance and which could be achieved by stabilizing agent (dodecanethiol) which adsorbed on surface and produce protective sheath. It can avoid agglomeration and crystal growth of the system. During the synthesis of AgNPs, minute changes in parameters (Polymers) makes drastic changes in size, shape, morphology, polydispersibility index, self assembling and zeta potential (stability). This method uses toxic chemicals, it is cost effective because some reagents are expensive (Galatage et al., n.d.).

In this method, a metal salt precursor such as silver nitrate is reduced using a reducing agent such as sodium borohydride or hydrazine in the presence of a stabilizing agent (Burange et al., 2021).

Although the method is simple, low-cost, and capable of large-scale production, the reducing agents involved are highly toxic and generate hazardous by-products, and the rapid, uncontrolled reduction rate often produces nanoparticles with inconsistent size and shape (Journal et al., 2019).

1.5.7 Physical method

Physical synthesis encompasses techniques such as laser ablation, gamma irradiation, electron-beam irradiation, and microwave-assisted processing. These "top-down" methods break bulk silver into nanoscale particles without the use of chemical reducing agents, which is often presented as an advantage. However, the precise challenge with physical methods is that they demand large amounts of energy and specialists, costly equipment such as lasers and vacuum chambers, and the resulting particles frequently lack a capping or stabilizing layer, operate at very high temperatures and pressure and there is difficulty in scaling up for industrial production. Without such a layer, the particles agglomerate readily, which undermines the size uniformity that most applications require (Services & Search, n.d.).

The physical method also includes heat vaporization and evaporation-condensation techniques, produces nanoparticles of high purity without solvent or chemical residues. However, this method requires very high energy input, expensive equipment, and long processing time, which makes it costly and difficult to scale up (Zhang et al., 2016).

During of synthesis of AgNPs by physical method, evaporation and condensation has major importance. Temperature gradient play important role in cooling of vapors at desired rate. Minimum inhibitory concentration in toxicity studies can be easily achieved by production of nano scale nanoparticles in high concentration. AgNPs also synthesized by laser ablation of metallic particles. One important advantage of laser ablation technique compared to other methods for production of metal colloids is the absence of chemical reagents in solutions. Therefore, pure and uncontaminated metal colloids for further applications can be prepared by this technique. Wide range of material can be synthe sized in nanoparticels by physical method such as Ag. Synthesis of AgNPs by tube furnace has ample of disadvantages such as requirement of larger space. AgNPs synthesized by laser ablation strongly depend on laser wavelength, time of laser pulse, laser fluence, the ablation time duration and the effective liquid medium (Galatage et al., n.d.). Ejection of AgNPs synthesized by laser ablation requires little power and particle size is precisely depends on laser fluence. However morphology, size and shape of AgNPs mainly depend on contact of laser light passing. Also, the formation of nanoparticles by laser ablation is terminated by the surfactant coating. The nanoparticles formed in a solution of high surfactant concentration are smaller than those formed in a solution of low surfactant concentration. One advantage of laser ablation compared to other conventional method for preparing metal colloids is the absence of chemical reagents in solutions. Therefore, pure colloids, which will be useful for further applications, can be produced by this method.

1.5.8 Biological (Microbial) Methods

Biological synthesis uses microorganisms such as bacteria, fungi, and algae, which reduce silver ions through enzymes (notably nitrate reductase) and other secreted biomolecules. Although this avoids hazardous chemical reagents, the precise challenge is that microbial synthesis is slow, requires the maintenance of living cultures under sterile conditions, and produces nanoparticles whose size and shape are difficult to reproduce between batches. Downstream purification to separate nanoparticles from microbial biomass adds further time and cost (Services & Search, n.d.).

Currently green chemistry is rapidly growing technique utilized for synthesis of AgNPs with naturally occurring stabilizing, reducing and capping agents to synthesize AgNPs without toxic adverse effects. Reduction of metal ions by combined efforts of herbs and certain enzymes, proteins, micro organisms, bacteria and fungi etc. in biological synthesis has been successfully reported

Synthesis of silver nanoparticles by plants green synthesis is an excellent tool that can be utilized for synthesis of AgNPs as it uses natural origin medicinal herbs and its extracts which contain wide range of metabolites specifically water-soluble flavones, which cause rapid and quick reduction of silver when compared to fungi and microbes. Green chemistry approach is safe, cost efficient, easily scalable to mass productions, easily to access raw materials at a cheaper cost.

The high energy demand and agglomeration risk of physical methods, the toxic residues and cost of chemical methods, and the slow, hard-to-standardize nature of microbial methods explain why plant-mediated (green synthesis) has become the preferred research direction. Plant extracts supply the same reducing and capping function as chemical or microbial agents through their natural phytochemicals (phenolics, flavonoids, terpenoids, and polysaccharides), while being faster than microbial culturing, cheaper than physical processing, and free of the toxic residues associated with chemical reduction.

1.5.9 Plant Species Used in the Green Synthesis of Silver Nanoparticles

A wide range of plant species has been explored for the green synthesis of silver nanoparticles because of the diverse phytochemicals they contain. Commonly used species include Azadirachta indica (neem), Ocimum sanctum (tulsi), Moringa oleifera, Curcuma longa (turmeric), Camellia sinensis (green tea) and Allium sativum (garlic), whose extracts have all been reported to successfully reduce and stabilize silver ions into nanoparticles (Manvitha & Bidya, 2014).

Aloe vera has also featured in a number of earlier studies. Aloe vera gel has been used for the biosynthesis of silver nanoparticles with reported antimicrobial and therapeutic potential, its extract prepared through a hydrothermal method has demonstrated antibacterial synergy, and it has further been combined with Thuja orientalis leaf extract in comparative green synthesis studied.

Despite the number of plant species already investigated, the phytochemical composition, and consequently the reducing and capping efficiency of a plant extract, varies considerably with species, geographical location, soil composition, climate, and even the age of the plant material used. This variability means that the nanoparticle size, shape, yield, and stability obtained from the same plant species can differ from one study to another, and results reported for one region cannot always be generalized to another (Burange et al., 2021). Therefore, there is a continued need to investigate locally available plant species, and to re-examine already studied species such as aloe vera under new environmental and reaction conditions, in order to establish more reliable, reproducible, and optimized green synthesis protocols (Biosci et al., 2019). This justifies the use of aloe vera sourced from Nagongera in the present study, to generate locally relevant data on its performance as a reducing and capping agent for silver nanoparticle synthesis.

1.6.0 Aloe vera plant

Aloe vera plant is a succulent with thorns in its branches with a waxy coating that grows easily in arid conditions. Its leaves have three layers; the outer layer which is thick and protective and has a high proportion of cellulose. The middle layer contains major flavanone (aloin A and B) and the inner layer has a fresh gel that contains an acetylated glucomannan, sugar, vitamins (A,B,C and E), amino acids, proteins and anthraquinones (Alwhibi et al., 2021). Aloe vera gel is utilized in many cosmetic products especially skincare. It is also considered to be effective for treating burns and wounds which is known for its soothing effect on the affected skin as well as treating a wide range of health-related disorders. There are a number of biologically active constituents in aloe vera leaves and these include lignin, hemicellulose, pectin which can be used in the reduction of silver ions (Tippayawat et al., 2016). Aloe vera extract are weakly bound to silver ions and function as complexing agent

1.6.1 Why a Further Search for New Plant Sources

Although Aloe vera has already been used for AgNP synthesis in several published studies, this does not close the research gap that this project addresses, for the following reasons:

Reported protocols diverge sharply in method, some use a simple room temperature mixing of gel extract with silver nitrate, while others use hydrothermal treatment at 100 – 200°C for several hours. These differences produce particles of very different sizes and antibacterial performance, so the extraction and reaction conditions are not yet standardized (Tippayawat et al., 2016).

Plant material is highly variable with geography, cultivar, soil, and climate. A review of aloe vera-based nanoparticle synthesis noted that working concentrations, reducing efficiency, and resulting particle size reported across studies vary widely, which the authors attributed partly to differences in the source plant material rather than to the metal salt chemistry alone.

A recent large-scale review of plant extract-mediated nanoparticle synthesis identified a persistent gap in the detailed chemical characterization of the plant extracts themselves, meaning that even for a well-studied species such as aloe vera, the specific phytochemical profile driving reduction in a given regional sample is often not established.

Comparative studies across five unrelated plant species have shown that a plant's antioxidant activity and total phenolic content both of which vary by ecotype and growing conditions directly determine reaction rate, particle size, and the degree of agglomeration. This means that Aloe vera sourced from a specific locality (such as Uganda/East Africa) cannot be assumed to behave identically to aloe vera used in previously published studies from Thailand, India, or elsewhere, and therefore constitutes a legitimate, literature-supported basis for further investigation.

Several authors have explicitly framed the search for new or under-studied plant sources as an active research priority, on the grounds that biodiversity rich regions hold largely untapped potential for green nanoparticle synthesis using locally available flora.

These points together justify presenting aloe vera gel extract, particularly when sourced and characterised in a specific regional context, as a continuing and legitimate line of green-synthesis research rather than a closed question.

CHAPTER TWO

EXPERIMENTAL

2.1 Apparatus

Weighing of samples was done on a AX523 Analytical balance to ensure precise weighing.

The filter paper and funnel were used to clarify the Aloe vera extract by removing residues.

The absorption spectra of the synthesized nanoparticles were recorded using the UV-VIS Spectroscopy.

Heating of the sample mixture was done using a hot plate and magnetic stirrer, while digesting the sample to a specific volume was done using a volumetric flask. A measuring cylinder was used to precisely measure and transfer liquid reagents, and the pH of the solution mixture was measured using a pH meter.

2.2 Materials

All materials used were of analytical grade and included; Siver nitrate ($AgNO_3$), Distilled water, Aloe vera, sodium hydroxide pellets (NaOH).

2.2.1 Preparation of aqueous Aloe vera gel extract

Fresh Aloe vera leaves were collected from around Nagongera town, washed thoroughly with tap water to remove dirt and then rinsed with distilled water. The washed aloe vera leaves were then chopped into fine pieces and the inner gel scooped out. (20 g) of the extracted gel were weighed, placed in a (250 mL) beaker and dissolved in (250 mL) of deionized water and the mixture boiled in an open container for 20 minutes and allowed to cool. The cooled solution was filtered using a filer paper and the resultant filtrate was used as the aloe vera extract and stored the refrigerator for further use.

2.2.2 Silver nitrate solution

Silver nitrate powder (0.085 g) was weighed carefully and placed into a (250 mL) volumetric flask. Then deionized water (50 mL) was added and stirred gently until the crystals dissolve. The volumetric flask was then filled with deionized water up to the (250 mL) mark.

2.2.3 Sodium hydroxide solution

Sodium hydroxide pellets (0.04 g) were weighed carefully and placed into a (100 mL) volumetric flask. Then (100 mL) of distilled water was added and stirred gently until all the pellets dissolved.

2.3 Procedure

Silver nitrate (90 mL) was carefully measured into a (250 mL) volumetric flask and slowly Aloe vera gel extract solution (10 mL) was added and the pH of the mixture measured.

Dilute sodium hydroxide solution was then be added one drop at a time while stirring. The pH of the mixture after each drop was measured until it is 8-9.

The mixture was then be incubated at a temperature of 60^0 C for 6 hours and the color changes were observed from pale yellow to brown. This was confirming the reduction of Ag^+ to Ag^0. The solution mixture was then monitored under the UV- Vis spectroscopy via continuous scanning at 300 - 700 nm to confirm the formation of silver nanoparticles.

CHAPTER THREE

RESULTS AND DISCUSSION

3.1 Green synthesis of silver nanoparticles

The synthesis of silver nanoparticles (AgNPs) was initiated by the addition of Aloe vera gel extract solution to a silver nitrate solution ($AgNO_3$) solution. Initially, the reaction mixture was colourless but upon adjusting the pH to an alkaline range (8-9) using dilute sodium hydroxide solution (NaOH), an immediate color change to light yellow was observed.

Following a 6 - hour incubation of the mixture at 60^0 C with constant stirring, the solution turned to a brown solution. This color change was a primary indicator of the formation of silver nanoparticles, the reduction of silver ions (Ag^+) from silver nitrate to metallic silver nanoparticles (Ag^0) by the bioactive compound in the aloe vera gel extract.

3.2 Factors that affect the synthesis of silver nanoparticles

Manufacturing silver nanoparticles is a very critical process where the environmental factor is temperature and pressure.

The green synthesis of silver nanoparticles is a critical process whose outcome, in terms of nanoparticle yield, size, shape and stability, is highly sensitive to the specific reaction conditions employed. In this study, particular attention was paid to three principal variables that were deliberately controlled during the synthesis; the reaction temperature and incubation time, the pH of the reaction medium, and the concentration of silver nitrate relative to the plant extract. A fourth variable, the concentration and phytochemical composition of the plant extract itself, was not independently varied but is discussed below because of its close interaction with the other three.

Each of these factors is discussed in turn, drawing on the nucleation and growth theory outlined in section.

3.2.1 Reaction temperature and incubation time

Temperature has a specific effect on the process of synthesis of silver nanoparticles. In this synthesis, the temperatures were adjusted to 60^0C during incubation. Increased reaction temperature leads to a rapid reduction in the Ag^+ ions to Ag^0 enabling the development of small size silver nanoparticles. In terms of the nucleation and growth theory discussed earlier, a higher temperature tends to promote a faster, more intense burst of nucleation, which consumes the available free silver atoms quickly and can favor the formation of a large number of small nuclei rather than the slow, continuous formation of fewer, larger particles.

Time is equally important, because it governs how long the newly formed nuclei are allowed to grow once nucleation has taken place. A longer incubation period allows more Ag^+ ions to be reduced and permits existing particles to grow further in size, as reducing biomolecules continue to donate electrons to silver ions adsorbed at the particle surface. However, an excessively long incubation time can allow secondary processes, particularly Ostwald ripening and inter-particle collision, to dominate, leading to the growth of larger particles and, in more extreme cases, to visible aggregation and eventual precipitation or settling of the silver nanoparticles out of suspension.

In this experiment, the mixture was incubated at 60^0C for 6 hours. This temperature was high enough to accelerate the reduction reaction meaningfully without degrading the thermolabile bioactive compounds in the aloe vera extract, most of which, such as polyphenols and flavonoids, begin to lose their reducing and antioxidant activity only at considerably higher temperatures.

However, a 6-hour incubation period is comparatively long relative to protocols reported for some other plant-mediated syntheses, where visible color change and SPR development can occur within a much shorter window. It is seen that the extended incubation time used here allowed sufficient opportunity for Ostwald ripening and partial aggregation of the larger, less stable particles to occur, which would be expected to reduce the concentration of well-dispersed, individually suspended nanoparticles remaining in solution by the time the UV-Vis measurement was taken. This provides one explanation for the comparatively weak absorbance recorded in the ultraviolet-visible spectrum since particles that have aggregated and settled, or that have grown very large, contribute far less to the characteristic, sharp SPR absorbance than an equivalent mass of smaller, well-dispersed particles. However, the long incubation may have led to partial aggregation or settling of larger particles contributing to the weak UV Vis peak observed.

3.2.2 pH

pH is one of the most influential parameters governing the reduction and stabilization capacity of plant extracts used in green synthesis. In this synthesis, dilute sodium hydroxide was added to raise the pH of the reaction mixture into the alkaline range of 8-9. Raising the pH in this way deprotonates the hydroxyl groups present on the phenolic and flavonoid compounds in the aloe vera gel extract, converting them into phenolate anions. Because phenolate anions are considerably more electron-rich, and therefore more readily oxidized, than their protonated (neutral hydroxyl) counterparts, this deprotonation substantially increases the reducing power of the phytochemicals present, making them more effective electron donors capable of reducing a greater proportion of the available Ag^+ ions to Ag^0 within a given time.

In addition to enhancing the intrinsic reducing capacity of the extract, alkaline pH conditions also influence the surface charge of the nanoparticles as they form. Under alkaline conditions, deprotonated phenolic and carboxylate groups adsorbed at the nanoparticle surface impart a net negative surface charge, which can provide a degree of electrostatic (charge) stabilization against aggregation, complementing the steric stabilization provided by the adsorbed biomolecular capping layer. At the same time, pH values that are too high can accelerate nucleation to the point where an excessive number of nuclei form almost simultaneously, competing for a limited pool of Ag^+ ions and biomolecules, which can in turn promote polydispersity, since not every nucleus will have equal access to the reducing and capping agents needed to grow uniformly.

The choice of pH 8-9 in this study therefore represents a deliberate compromise, a pH high enough to activate the phenolic reducing groups in the aloe vera gel extract and to confer a measure of electrostatic stability on the resulting particles, but not so high as to trigger uncontrolled, near-instantaneous nucleation throughout the entire mixture. The fact that the alkaline conditions used were sufficient to drive the reaction to visible completion, as shown by the color change to brown, confirms that the reducing capacity of the extract was successfully activated. However, the broad SPR band obtained during characterization suggests that some degree of polydispersity, of the kind theoretically expected under alkaline nucleation conditions.

3.2.3 Silver nitrate concentration

The concentration of silver nitrate determines the number of available silver ions for reduction. Too low concentration yields very few nanoparticles resulting into a weak SPR peak. Too high concentrations can cause rapid, uncontrolled nucleation followed by aggregation leading to polydisperse particles and a broad Surface Plasmon Resonance (SPR) band.

In this experiment, (0.085g) of silver nitrate were dissolved in (250 mL) of distilled water and (90 mL) of this solution was mixed with 10ml of the aloe vera extract. The weak absorbance at 0.138

suggests that either nanoparticle yield was low or the particles formed were not uniformly suspended.

The concentration of silver nitrate used in a green synthesis reaction determines the number of Ag^+ ions available for reduction, and, critically, the ratio of these ions to the concentration of reducing biomolecules present in the plant extract. If the concentration of $AgNO_3$ is too low relative to the reducing capacity of the extract, very few nanoparticles are produced, resulting in a weak SPR peak simply because there is little silver present to form nanoparticles in the first place.

If the concentration of $AgNO_3$ is too high relative to the available reducing agents, however, a different problem arises, nucleation can occur rapidly and somewhat uncontrollably as the limited pool of reducing biomolecules is quickly consumed, after which any remaining Ag^+ ions are deposited unevenly onto the relatively small number of nuclei that did manage to form, producing large, polydisperse particles and a correspondingly broad SPR band.

In this experiment, 0.085 g of silver nitrate was dissolved in 250 mL of distilled water, and 90 mL of this solution was mixed with only 10 mL of the Aloe vera extract, giving a reaction mixture in which the silver nitrate solution constituted 90% of the total volume while the plant extract, the source of reducing and capping biomolecules, constituted only 10%. This high silver nitrate to extract ratio means that, once the phenolic reducing groups within the small volume of extract present had been consumed through electron donation to Ag^+, a comparatively large excess of unreduced Ag^+ ions, together with any nuclei that had not received adequate capping, may have remained in a less stable, more aggregation-prone state. The weak absorbance value of 0.138 recorded during characterization is therefore consistent with the interpretation that the overall silver nitrate yield achieved was low relative to the total silver introduced into the system, either because insufficient reducing agent was available to convert all of the Ag^+ present into stable, wellcapped nanoparticles, or because a proportion of the nanoparticles that did form were not uniformly suspended by the time the reading was taken, having aggregated or settled.

This finding highlights that the extract-to-precursor ratio used in a synthesis protocol is not merely a matter of convenience but is itself a variable with direct, explicable consequences for the final nanoparticle population, and it points toward a specific, testable adjustment, which includes increasing the proportion of aloe vera extract relative to silver nitrate, that future work arising from this study could investigate in order to improve nanoparticle yield and dispersity..

3.3 Characterization of silver nanoparticles

The UV-Vis was used to characterize the synthesized silver nanoparticles with scanning range from 300 nm to 700 nm. The peak width observed was broad ranging from 400 -500nm indicating that few silver nanoparticles were synthesized. The broadness of the peak indicates polydispersity where the synthesized silver nanoparticles were of different sizes. The difference in the sizes might have been caused by the capping reagent used, since aloe vera has many types of reducing molecules such as polyphenols, sugars and proteins working at different speeds which creates a variety of sizes thus making the spectrum to stretch to cover all the sizes hence resulting into a broader peak.

The broad peak displays an absorbance value of 0.138 implying that the solutions used for the green synthesis were dilute, also during the filtration of the aloe vera gel extract, more powerful reducing fibers were reduced.

The spectrum is not smooth because this is green synthesis and here the solution is not just silver and water but also leftover organic matter from the Aloe vera. These organic molecules can cause slight interference or noise in the reading, making the line look less smooth.

Absorbance

Wave length (nm)

Figure 1: *Absorbance versus wave length spectrum of synthesized silver Nanoparticles*

Figure 2: *Aloe vera leaves used for extracting the gel*

Figure 3: *Aloe vera gel extract*

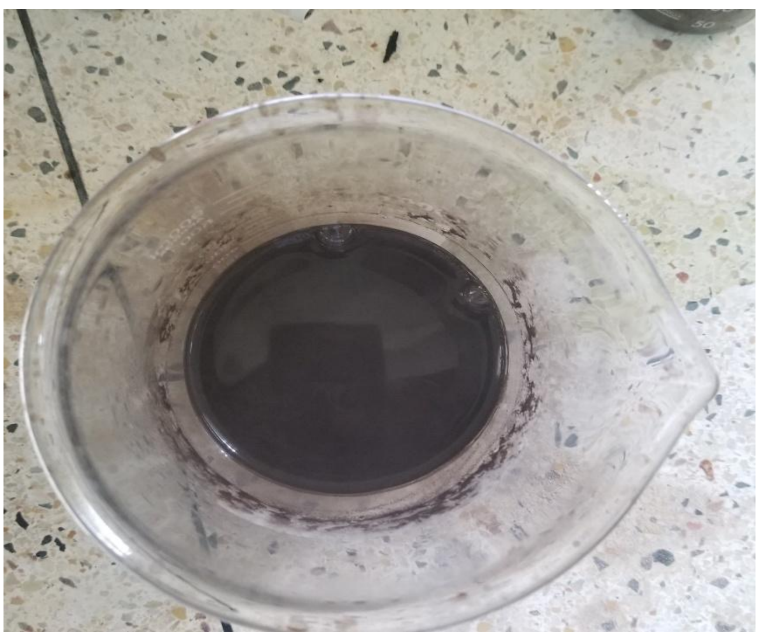

Figure 4: *The synthesized silver nanoparticles from the mixture of Aloe vera gel extract and Silver nitrate solution*

CHAPTER FOUR

CONCLUSIONS AND RECOMMENDATION

4.1 Conclusions

The green synthesis of silver nanoparticles using aloe vera gel extract was successfully achieved. The bioactive compound in aloe vera acted as a reducing and stabilizing agent while the pH adjustments and incubation temperature played key roles in nanoparticle formation. UV-Vis spectroscopy confirmed the presence of silver nanoparticles through the characteristic Surface Plasmon Resonance (SPR) peak.

With respect to the first objective; to prepare aloe vera gel extract and use it for the green synthesis of silver nanoparticles, this objective was fully achieved. Fresh aloe vera gel was successfully extracted, filtered and combined with silver nitrate solution, and the reaction produced the characteristic, visually distinct color progression from colourless to pale yellow to brown that is the accepted qualitative signature of silver nanoparticle formation. This confirms that the bioactive compounds present in aloe vera, most likely its polyphenols, flavonoids and reducing sugars, acted effectively as reducing and stabilizing agents in place of the toxic chemical reagents used in conventional synthesis routes.

With respect to the second objective; to optimize the conditions for the synthesis of silver nanoparticles, this objective was partially achieved. The reaction pH was successfully adjusted and held within the target alkaline range of 8-9, and the temperature and incubation time were controlled at 60^0C for 6 hours; both of these conditions were sufficient to drive the reduction reaction to visible completion. The optimization process undertaken in this study should therefore be understood as an initial, informative step that has identified, with clear mechanistic justification, the specific parameters, particularly the extract-to-precursor ratio and the incubation time, that most warrant systematic adjustment in future work, rather than as a fully optimized final protocol.

With respect to the third objective; to characterize the synthesized silver nanoparticles using UV-Vis spectroscopy, this objective was fully achieved. UV-Vis spectroscopy, performed over a scanning range of 300 to 700 nm, confirmed the presence of silver nanoparticles through a characteristic band from 400 nm – 500 nm. The breadth of this band, and its comparatively low absorbance value of 0.138, were interpreted, in light of established nucleation and growth theory and the Beer-Lambert relationship, as evidence of a polydisperse, relatively dilute nanoparticle population, consistent with, and explicable by the specific reaction conditions discussed under the second objective.

Taken as a whole, therefore, this study has demonstrated that the overall objective, to synthesize silver nanoparticles using aloe vera gel extract by the green synthesis method, was successfully accomplished. The bioactive compounds in aloe vera acted as effective reducing and stabilizing agents, while pH adjustment and incubation temperature played key, mechanistically explicable roles in nanoparticle formation, and UV-Vis spectroscopy provided direct confirmatory evidence of nanoparticle formation, even as it simultaneously revealed specific respects in which the synthesis protocol could be refined further.

4.2 Recommendations

On the basis of the findings discussed in this report, I do recommend the future researchers to highly adopt the green synthesis method for the production of silver nanoparticles, since it is simple to use, cheap, and non-toxic to the environment, in comparison with conventional chemical and physical synthesis routes.

Since the silver nanoparticles synthesized in this study were characterized using only UV-Vis spectroscopy, future researchers are urged to make use of complementary instruments, such as Fourier Transform Infrared Spectroscopy (FTIR) to identify the specific functional groups responsible for reduction and capping, X-Ray Diffraction (XRD) to confirm the crystalline nature of the nanoparticles, and Scanning or Transmission Electron Microscopy (SEM/TEM) to directly determine particle size, shape and morphology, all of which would substantially strengthen and extend the interpretive conclusions reached indirectly in Chapter Three of this report.

Future work should systematically involve varying the volume ratio of aloe vera extract to silver nitrate solution, for example by testing ratios more favorable to the extract than the 10:90 ratio used here, to establish whether nanoparticle yield and SPR peak sharpness can be improved.

I also recommend that future studies should also consider systematic varying of the incubation time independently of temperature, including collecting UV-Vis spectra at intermediate time points during the reaction, to determine more precisely the point at which further incubation begins to promote aggregation rather than continued useful nanoparticle formation.

Further emphasis should be placed on exploring the use of other locally available plant extracts for green synthesis, in order to compare their efficiency and the properties of the nanoparticles produced with those obtained from Aloe vera in this study.

REFERENCES

Álvarez-chimal, R., & Arenas-alatorre, J. Á. (n.d.). *Green Synthesis of Nanoparticles : A Biological Approach*. 2.

Alwhibi, M. S., Soliman, D. A., Awad, M. A., Alangery, A. B., Dehaish, H. Al, & Alwasel, Y. A. (2021). *Green synthesis of silver nanoparticles : Characterization and its potential biomedical applications*. 412–420.

Biosci, I. J., Dilshad, E., Tazeem, S. S., Bashir, Z., Iqbal, A. H., Khokhar, S., Zahra, N., Khan, M. A., & Ismail, H. (2019). *Silver nanoparticles of Aloe vera gel as strong therapeutic candidates*. *6655*, 361–374.

Biswas, P., & Wu, C. (2012). *Nanoparticles and the Environment Nanoparticles and the Environment*. *2247*(2005). https://doi.org/10.1080/10473289.2005.10464656

Burange, P. J., Tawar, M. G., Bairagi, R. A., Malviya, V. R., Sahu, V. K., Shewatkar, S. N., Sawarkar, R. A., & Mamurkar, R. R. (2021). Synthesis of silver nanoparticles by using Aloe vera and Thuja orientalis leaves extract and their biological activity : a comprehensive review. *Bulletin of the National Research Centre*. https://doi.org/10.1186/s42269-021-00639-2

Galatage, S. T., Hebalkar, A. S., Dhobale, S. V, Kumbhar, P. S., Nikade, S. V, & Killedar, S. G. (n.d.). *Silver Nanoparticles : Properties , Synthesis , Characterization , Applications and Future Trends*.

Hosny, S., Gaber, G. A., Ragab, M. S., Ragheb, M. A., Anter, M., & Mohamed, L. Z. (2025). A Comprehensive Review of Silver Nanoparticles (AgNPs): Synthesis Strategies , Toxicity Concerns , Biomedical Applications , AI-Driven Advancements , Challenges , and Future

Perspectives. *Arabian Journal for Science and Engineering*. https://doi.org/10.1007/s13369-025-10612-0

Journal, A. I., Gour, A., & Jain, N. K. (2019). Advances in green synthesis of nanoparticles. *Artificial Cells, Nanomedicine, and Biotechnology*, *47*(1), 844–851. https://doi.org/10.1080/21691401.2019.1577878

Khairan, K., & Jalil, Z. (2019). *GREEN SYNTHESIS OF SULPHUR NANOPARTICLES USING AQUEOUS GARLIC EXTRACT (Allium sativum)*. *12*(1), 50–57.

Manvitha, K., & Bidya, B. (2014). *Aloe vera : a wonder plant its history , cultivation and medicinal uses*. *2*(5), 85–88.

Mohanraj, V. J., & Chen, Y. (2006). *Nanoparticles – A Review*. *5*(June), 561–573.

Services, A., & Search, A. (n.d.). *search menu share announcement format _ quote question _ answer*.

Supriya, G., & Chaitanya, S. (2019). *Green synthesis of silver nanoparticles using Aloe vera extract and assessing their antimicrobial activity against skin infections*. *6*(1), 60–65.

Tippayawat, P., Phromviyo, N., & Boueroy, P. (2016). *Green synthesis of silver nanoparticles in aloe vera plant extract prepared by a hydrothermal method and their synergistic antibacterial activity*. 1–15. https://doi.org/10.7717/peerj.2589

Zhang, X., Liu, Z., Shen, W., & Gurunathan, S. (2016). *Silver Nanoparticles : Synthesis , Characterization , Properties , Applications , and Therapeutic Approaches*. https://doi.org/10.3390/ijms17091534