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Theme

Biosynthesis, Characterization and Application of Silver Nanoparticles for Colorimetric Detection

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Dedication

I dedicate this work with deep love and gratitude to:

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Birane Mohammad

Dedication

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With all my appreciation and affection,

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Ben guettache Yacine

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List of Abbreviations:

$AgNO_3$: silver nitrate

AgNPs: Silver nanoparticles

Ag^+: Silver ion

Ag^0: Neutral charge silver

°C: Celsius unit of temperature

DRX: X-ray Diffraction

FT-IR: Fourier Transform Infrared Spectroscopy

TEM: Transmission Electron Microscopy

BEM: Scanning Electron Microscopy

mg: Milligram

nm: Nanometer

SPR: Surface Plasmon Resonance

ml: unit of volume in the metric system

UV-Vis: UV-Visible Spectroscopy

L-Cys : L-Cysteine

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General introduction

General introduction

The word “nano” is derived from the Greek word “nanos”, meaning “dwarf”, and the nanometric scale represents a part of a billion,one nanometre is therefore equivalent to 10^{-9} metres [1] or roughly the length of three atoms side by side [2]. Nanomaterials are materials with one or more components that have at least one dimension in the range from 1 to 100 nm and include nanoparticles, nanofibers, nanotubes, composites and nanostructured surfaces nanostructured surfaces [3, 4].

The term “nanotechnology” was first defined by Tokyo University of Science, NorioTaniguchi in a 1974 as follows: “Nanotechnology” consists mainly in the transformation of separation, consolidation and deformation of materials by an atom or molecule [5]. Nanotechnology refers to technology implemented at the nanoscale technology with real-world applications. The unique physical and chemical properties of nanomaterials can be exploited for applications that benefit society [6]. Nanoscience is a well-known modern scientific field that includes the study of the basic properties of nanosized objects [7, 8].

Nanoparticles, typically defined as particles with dimensions between 1nm and 100 nm, have emerged as one of the most promising areas of research in materials science and nanotechnology. Due to their exceptionally small size and high surface area-to-volume ratio, nanoparticles exhibit unique physical, chemical, and biological properties that are significantly different from their bulk counterparts. These distinct properties have opened new frontiers in various fields including medicine, electronics, environmental science, biotechnology, bioengineering, and energy. [9]

The interest in nanoparticles can be traced back to ancient times, such as in the stained-glass windows of medieval churches, where metal nanoparticles were unknowingly used for their optical properties. However, the scientific exploration of nanoparticles began in earnest in the late 20th century with the advent of sophisticated characterization tools and synthesis techniques (Sun, 2000). Since then, nanoparticles have been extensively investigated for their potential in targeted drug delivery, enhanced imaging, improved catalysts, and as functional components in electronic devices. [10]

Among the wide range of nanoparticles, metal-based (such as gold, silver, and iron oxide), metal oxide (such as titanium dioxide and zinc oxide), carbon-based (including fullerenes, graphene, and carbon nanotubes), and semiconductor nanoparticles have received considerable attention. Their applications span across multiple industries, contributing to significant advancements in technology and healthcare. [11]

As research continues to grow, the challenge remains to optimize synthesis methods for greater control over particle size, shape, and surface functionality, while ensuring biocompatibility and environmental safety. [12] As a result, researchers are turning to the biosynthesis of metallic nanoparticles, particularly silver nanoparticles, and especially plants, which have distinctive physicochemical properties, as powerful weapons for solving the problem of the emergence of multi-resistant bacteria [13]. In addition, the use of AgNPs means that bacterial cells are less likely to develop antibacterial resistance. Plants (their extracts) are considered a highly desirable system for NPs synthesis due to their great capacity to produce a wide range of bioactive secondary metabolites with high reduction potential [14].

Among the plants with significant pharmacological potential, *Mentha Spicata* and *Artemisia Herba Alba*, are widely grown and used in Algeria. Their biological activity is closely linked to their high content of active substances, such as phenolic compounds. To better understand the value of the bioactive substances found in *Mentha Spicata* and *Artemisia Herba Alba*, we decided to undertake the present work, which focuses on the synthesis of silver nanoparticles using extracts from these two plants, and the evaluation of their biological application, in particular the colorimetric selective detection of various amino acids.

In this context, the overall objective of this work is to study the possibility of silver nanoparticles synthesis using green method and their characterization by infrared FT-IR and UV-Visible spectroscopies. Reasonable chiral discrimination has been achieved using silver nanoparticles technique while improving the sensitivity of chiral recognition is essential and remains a difficult task. UV-Visible spectroscopy is expected to be a feasible method for improving the sensitivity of analysis discrimination of L-Cysteine. The detection sensitivity improved by almost 500 times using the silver nanoparticle method. In short, the method mentioned below makes the detection of chiral amino acid derivative much easier than conventional instrumental analyses.

The dissertation describing this work begins with this general introduction which gives an idea of the importance of the theme addressed while clearly explaining the objective.

This work consists of the following chapters:

- **The first chapter** is devoted to the description and generality of nanoparticles or bibliographical research into the main properties of nanoparticles and the physical, chemical and biological methods used to synthesize silver nanoparticles.
- **The second chapter** includes a general presentation of the plants studied (*Mentha Spicata* and *Artemisia Herba Alba*) with their properties and physiochemical compositions to helps synthesize nanoparticles.
- **Third chapter** is dedicated to the synthesis methods and materials used for silver nanoparticle production and colorimetric selective test.
- **The last chapter** is reserved for discussion of the results obtained and interpretations.

Finally, a conclusion resumes all the results obtained in this work as well as some recommendation for future studies.

References

[1] Hulkoti, N.I., T.J.C. Taranath, and S.B. Biointerfaces, Biosynthesis of nanoparticles using microbes—a review.2014. 121: p. 474-483.

[2] Thakkar, K.N., et al., Biological synthesis of metallic nanoparticles. 2010. 6(2): p. 257-262.

[3] Borm, P.J., et al ,.The potential risks of nanomaterials: a review carried out for ECETOC. 2006. 3(1): p. 1-35.

[4] Jeevanandam, J., et al., Review on nanoparticles and nanostructured materials: history, sources, toxicity and regulations. 2018. 9(1): p. 1050-1074.

[5] Singh ,M., et al., Nanotechnology in medicine and antibacterial effect of silver nanoparticles. 2008. 3(3): p. 115-122.

[6] Bhushan, B., Introduction to nanotechnology, in Springer handbook of nanotechnology. 2017, Springer. p. 1-19 .

[7] Ijaz, I., et al., Greensynthesis of silver nanoparticles using different plants parts and biological organisms, characterization and antibacterial activity. 2022. 18: p. 100704.

[8] Kawasaki, M. and N.J.A.S.S. Nishimura, 1064-nm laser fragmentation of thin Au and Ag flakes in acetone for highly productive pathway to stable metal nanoparticles. 2006. 253(4): p. 2208-2216 .

[9] Dos Santos, C.A., et al., Silver nanoparticles: therapeutical uses, toxicity, and safety issues. 2014. 103(7): p. 1931-1944.

[10] Thamilselvi, V. and K.J.I.J.P. Radha, A review on the diverse application of silver nanoparticle. 2017. 7(01): p. 21-27.

[11] RSC Review (2021*).* Nanomaterials: a review of synthesis methods, properties, recent advances. Materials Advances.

[12] Rai, M.K., et al ,.Silver nanoparticles: the powerful nanoweapon against multi drug resistant bacteria. 2012. 112(5): p. 841-852.

[13] Mishra, S., H.J.A.m. Singh, and biotechnology, Biosynthesized silver nanoparticles as a nanoweapon against phytopathogens: exploring their scope and potential in agriculture. 2015. 99(3): p. 1097-1107.

[14] Sharma, G., et al., Antimicrobial potential of silver nanoparticles synthesized using medicinal herb coptidis rhizome.2018. 23(9): p. 2268

Bibliographic Review

Chapter I

Nanoparticles Generalities

I. Introduction

Nanoscience and nanotechnology are currently emerging as one of the most promising areas of research in the material sciences. They encompass a vast field of technological developments, involving the creation of structures, devices and systems from nano-sized objects. These scientific advances have given rise to the nanoscience.

In recent years, materials of nanometric dimensions have attracted considerable interest due to their specific physical and chemical properties, which are distinct from those of their bulk counterparts. These novel characteristics make nanoparticles a subject of constantly evolving research, exploring new synthesis strategies to obtain nanomaterials of controlled sizes and shapes. [1]

I.1. Nanotechnology

"Nanotechnology" is a generic term that describes applications in many scientific fields, but broadly covers research into the principles and properties existing at the nanometric scale.

The aim of nanotechnology is to produce objects or materials smaller than 100 nanometers. In other words, they cover everything to do with the design, characterization, production and application of structures, devices and systems by controlling shape and size on the nanometric scale. Nanotechnology is applied research. The applications concerned have major economic potential in many fields, including medicine, chemistry, energy, resource management and the environment. [2]

I.2. Nanoscience

Nanoscience focuses on the analysis of phenomena that occur within objects, structures or systems whose dimensions are of the order of a few nanometers (less than 100 nm) in at least one spatial direction, and whose properties are specifically influenced by this nanometric scale. These properties differ from those of similar objects, systems or structures of larger sizes. [3]

I.3. Nanomaterials

A nanomaterial is a natural, accidentally formed or manufactured material containing free particles, in aggregate or agglomerate form, of which at least 50% of the particles, in numerical size distribution, have one or more external dimensions. [4]

I.3.1. Classification of nanomaterials

Two major families of nanomaterials are thus distinguished: nano-objects and nanostructured materials.

✓ **Nano-objects**: are materials (nano-sheet, nano-fiber and nanoparticles) presenting one, two or three external dimensions in the nanometric range. [5]

✓ **Nano structured materials:** are materials (aggregate, nano-composite and nanoporous) includes nanoparticles in its structure, superficially (surface treatment) or throughout its volume i.e. which has an internal or surface structure at the nanometric scale. [5]

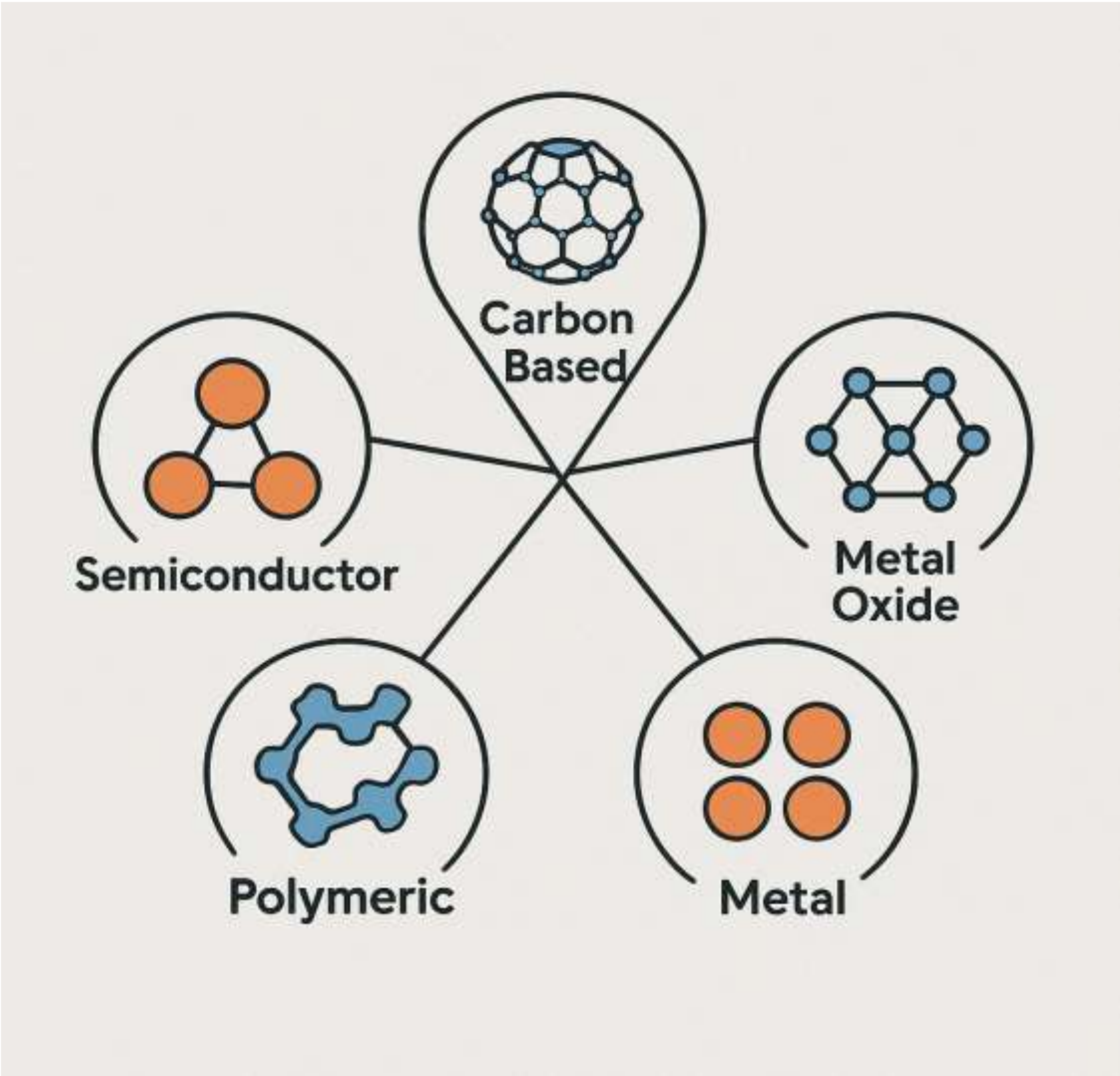

Figure I.1: **S**ummary diagram of different types of nanomaterials

I.4 .Nanoparticles

I.4.1. Definition of nanoparticles

Nanoparticles are defined as particles with dimensions typically ranging from 1 to 100 nanometers. Due to their extremely small size, they exhibit unique physical and chemical properties such as enhanced surface area, quantum effects, and high reactivity compared to their bulk counterparts.

These particles can be metallic, semiconductor, polymeric, or ceramic, and are widely used in fields such as medicine, catalysis, electronics, and environmental remediation. Their nanoscale size allows them to interact with biological systems at the molecular level, offering opportunities in drug delivery, imaging, and therapeutics.

The synthesis methods of nanoparticles include top-down (e.g., milling) and bottom-up (e.g., sol-gel, chemical vapor deposition, green synthesis) approaches, which influence their shape, size, and functionality. The diversity of nanoparticle types and synthesis routes has led to growing research in nanoparticle chemistry, aiming to control their properties for tailored applications. [6]

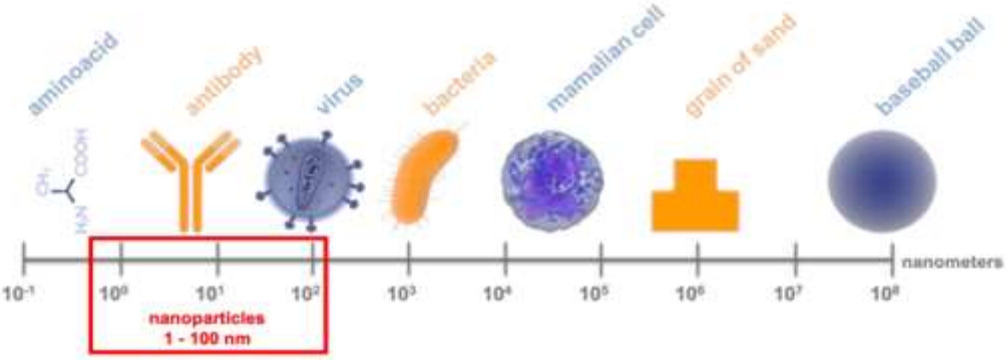

Figure I.2: Comparison of nanoparticles sizes to other structures.[7]

I.4.2. Origin of Nanoparticles

Nanoparticles occur both naturally and can be synthesized artificially.

- **Natural origin**

Naturally occurring nanoparticles have been present in the environment for millions of years. They originate from volcanic eruptions, forest fires, ocean spray, mineral weathering, and biological processes. These particles include clay particles, metal oxides, and organic compounds, and play significant roles in atmospheric chemistry and ecological interactions. [8]

- **Anthropogenic (Man-Made) Origin**

Human-made nanoparticles emerged significantly with advancements in materials science and nanotechnology. Although nanoscale materials have been used historically for instance, in stained glass windows of medieval churches due to colloidal gold and silver systematic research into engineered nanoparticles began in the 20th century. The term "nanotechnology" was popularized by Richard Feynman in his famous 1959 lecture “There’s Plenty of Room at the Bottom”, which inspired the idea of manipulating materials at the atomic scale.

In modern science, nanoparticles are synthesized through chemical, physical, and biological methods to control their size, shape, and surface properties for targeted applications. [8]

I.4.3. Classification of Nanoparticles

I.4.3.1. Dimension 0 materials: These materials occur in dispersed form, either randomly or organized, as in colloidal crystals used in optics or magnetic fluids.

I.4.3.2. Dimension 1 material: These are materials in the form of nanowires or nanotubes.

I.4.3.3. Dimension 2 materials: These materials are found in the form of thin layers, such as in aggregate deposits or thick coatings obtained by plasma spraying or electrochemical means.

I.4.3.4. Dimension 3 materials: These are found in compact form, as in ceramics and nanostructured metals. [9]

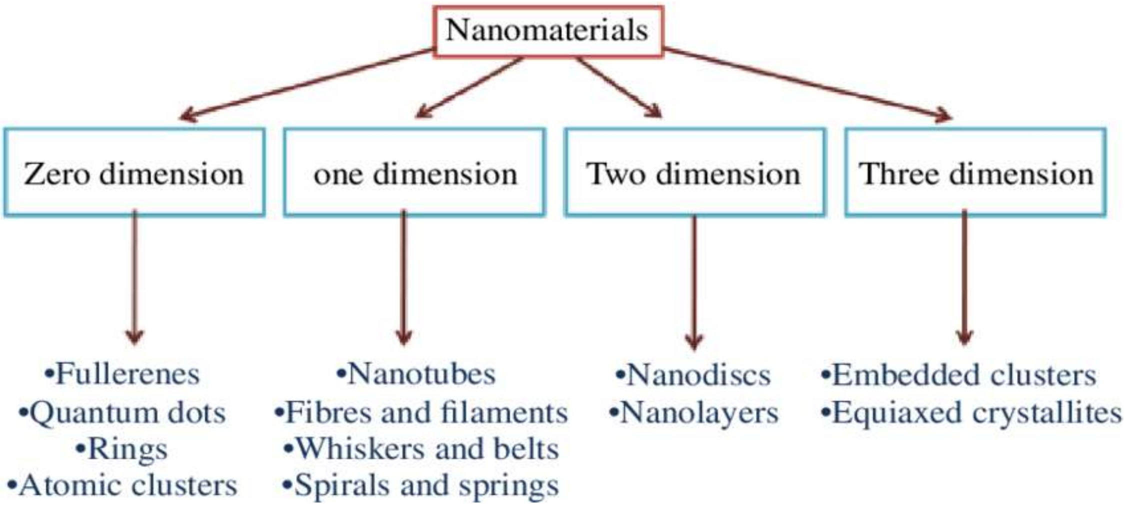

Figure I.3: Classification of nanoparticles on the basis of dimensions

I.4.4.Types of Nanoparticles:

Nanoparticles can be categorized based on their composition, structure, and origin. Here are the major types:

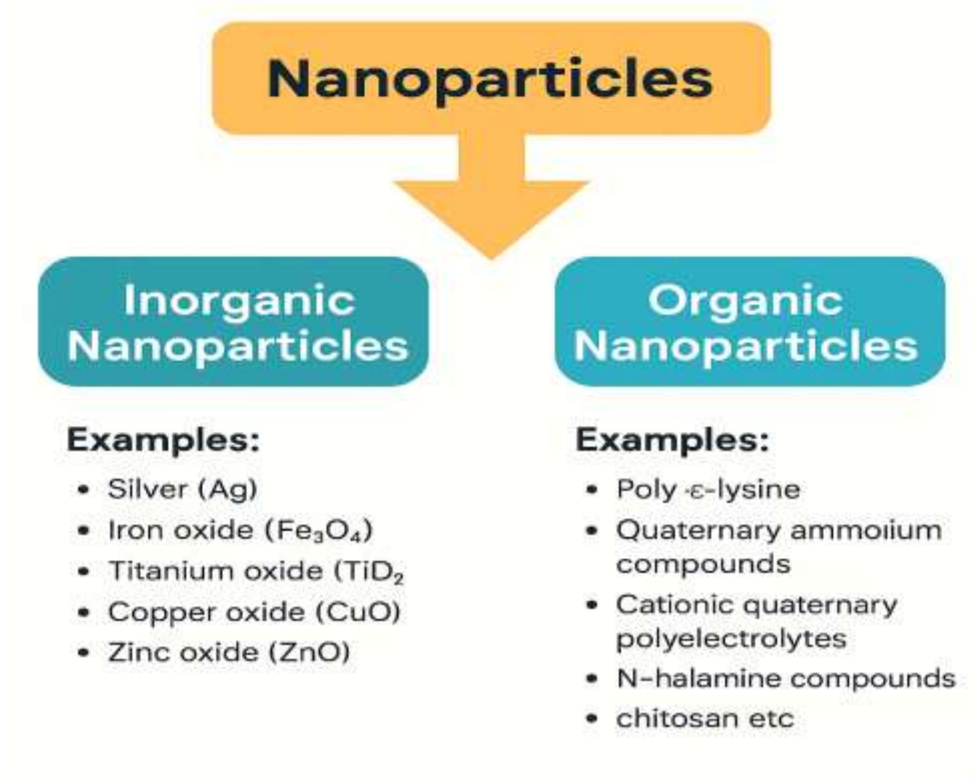

Figure I.4: Different types of Nanoparticles

I.4.4.1. Carbon-Based Nanoparticles:

- **Fullerenes:** Hollow carbon cages (e.g., C_{60}); used in drug delivery and electronics.
- **Carbon Nanotubes (CNTs):** Cylindrical carbon tubes; strong and conductive.
- **Graphene:** Single-layer carbon sheet; ultra-thin, strong, and conductive.

They are known for high electrical conductivity, chemical stability, and thermal resistance. [10]

I.4.4.2. Metal Oxide Nanoparticles:

- **Titanium Dioxide (TiO_2):** UV absorber; used in sunscreens and paints.
- **Zinc Oxide (ZnO):** Antibacterial; common in cosmetics and ointments.
- **Iron Oxide (Fe_3O_4):** Magnetic; used in imaging and targeted drug delivery.
- **Cerium Oxide (CeO_2):** Antioxidant; used in medical and catalytic applications.
- **Aluminum Oxide (Al_2O_3):** Abrasive and chemically stable; used in coatings.

Used in sensors, catalysis, and sunscreens. [11]

I.4.4.3. Semi-conducteur Nanoparticles

- **Zinc Sulfide (ZnS):** Used in photocatalysis and bioimaging due to their wide bandgap.
- **Cadmium Sulfide (CdS):** Photoactive material used in water splitting and sensors.
- **Gallium Arsenide (GaAs):** Used in photonics and electronics for high-speed performance.[12]

I.4.4.4. Polymeric Nanoparticles

- **PLGA (poly (lactic-co-glycolic acid)) Nanoparticles:** Biodegradable; used in drug delivery.
- **Chitosan Nanoparticles:** Natural polymer from crustaceans; antimicrobial and bio adhesive.
- **PEGylated Nanoparticles:** Surface-modified with PEG for stability and stealth behavior in blood.

They are biodegradable and used extensively in drug delivery.[13]

I.4.4.5. Metal Nanoparticles

- **Gold Nanoparticles (AuNPs):** Biocompatible, used in diagnostics and therapy.
- **Silver Nanoparticles (AgNPs):** Antibacterial; used in textiles and medical devices.
- **Platinum Nanoparticles (PtNPs):** Catalytic; used in fuel cells and biosensors.
- **Copper Nanoparticles (CuNPs):** Conductive and antimicrobial; used in electronics.

They have unique optical, electrical, and antimicrobial properties. [14]

I.5. Silver Nanoparticles

I.5.1.Definition of Silver Nanoparticles

Silver nanoparticles (AgNPs) are among the most extensively studied and utilized nanomaterials due to their distinctive physicochemical properties that emerge at the nanoscale. These nanoparticles typically range in size from 1 to 100 nanometers and exhibit remarkable surface area-to-volume ratios, quantum effects, and unique interactions with biological systems. Historically, silver has been used for centuries for its antimicrobial properties, even before the discovery of microorganisms. With the advent of nanotechnology, silver has been reengineered into nanoparticle form to significantly enhance its effectiveness, stability, and range of applications.[15,16]

In recent decades, AgNPs have garnered tremendous attention in diverse scientific fields including medicine, materials science, environmental technology, and food packaging. Their enhanced antimicrobial activity, optical and electrical properties, and ease of synthesis make them ideal candidates for innovations ranging from wound healing materials and implant coatings to diagnostic tools and water purification systems.[17-19]

Moreover, the adaptability of silver nanoparticles in terms of shape, size, and surface functionalization enables researchers to tailor them for specific applications. Various synthesis methods—chemical, physical, and biological—have been developed to produce AgNPs with controlled morphology and stability. However, as their use becomes more widespread, so too do concerns about their potential cytotoxicity, environmental impact, and long-term safety in clinical and consumer applications.[20,21]

As a result, silver nanoparticles represent a double-edged sword: a powerful tool for advancing technology and healthcare, yet one that demands careful study and regulation to ensure safety and sustainability. [21,22]

I.5.2.Properties of silver nanoparticles

AgNPs have distinctive physico-chemical properties, including high electrical and thermal conductivity, chemical stability, catalytic activity and non-linear optical behavior. Plus mechanical and magnetic properties.[23,26]

I.5.2.1. Mechanical properties: Nanometric structure improves mechanical strength. [27]

I.5.2.2. Electrical properties: The use of nanoparticles or nanotubes modifies the electrical conductivity of materials. [23,25]

I.5.2.3. Optical properties: Nanoparticles can improve the transparency of materials due to their dimensions: when the size of the nanoparticle is smaller than the wavelengths of visible light. [23,25]

I.5.2.4. Thermal transfer properties: The presence of nanoparticles can improve the thermal conductivity of materials. [22,27]

I.5.2.5. Magnetic properties: Crystals (0-dimensional nanomaterials) can significantly influence the magnetic behavior of materials. [24,26]

I.5.2.6. Catalytic properties: Some nanomaterials can act as catalysts for specific catalyst for specific reactions, e.g. gold nanoparticles in the oxidation reaction of carbon monoxide (CO). [25,29]

I.5.2.7. Chemical Properties: High chemical reactivity due to large surface area (more atoms on the surface). They have surface functionalizations which make them easily modified with functional groups to improve stability, targeting, or biocompatibility. They also can be prone to oxidation or aggregation unless stabilized by coatings (e.g., polymers or surfactants). [23-27]

I.5.2.8. Biological Properties: Nanoparticles have unique biological properties such as small size, high surface area, and the ability to penetrate cells and tissues. They can be engineered for biocompatibility, targeted drug delivery, and controlled biodegradability. Some can cross the blood–brain barrier and interact with specific cells, while surface modifications help reduce toxicity and immune reactions. These features make them useful in medicine, especially for drug delivery, imaging, and diagnostics. [23-24-30]

I.5.3.Synthesis methods

The synthesis of Silver nanoparticles (AgNPs) is a critical step that determines their size, shape, dispersion, and functionality. Various synthesis strategies have been developed and are broadly classified into two fundamental strategies: Top-Down and Bottom-Up approaches including physical, chemical, and biological methods. Each of these methods offers distinct benefits and challenges depending on the target application, cost, and environmental considerations. [31]

I.5.3.1. Physical Methods

Physical methods for synthesizing silver nanoparticles generally rely on mechanical or thermal energy to break down bulk silver into nanoscale particles. Techniques such as laser ablation, evaporation-condensation, and ball milling are commonly used. In laser ablation, for instance, a pulsed laser is directed at a silver target submerged in a liquid medium, causing nanoparticle formation. Although these methods produce high-purity AgNPs without the use of stabilizers or toxic chemicals, they often require expensive instrumentation, consume significant energy, and offer limited control over particle uniformity and size distribution. [32]

I.5.3.2. Chemical Methods

Chemical reduction is the most frequently used method for synthesizing AgNPs due to its simplicity, cost-effectiveness, and scalability. This technique involves the reduction of silver ions (Ag^+) from silver nitrate ($AgNO_3$) using reducing agents such as sodium borohydride ($NaBH_4$), citrate, or ascorbic acid in the presence of stabilizers to prevent agglomeration. The size and morphology of the nanoparticles can be finely tuned by adjusting reaction parameters like pH, temperature, and reagent concentrations. However, the use of toxic chemicals and the generation of hazardous by-products raise environmental and health concerns, prompting the search for greener alternatives. [33]

I.5.3.3. Biological (Green) Methods

Biological or green synthesis of silver nanoparticles is gaining prominence as an eco-friendly and sustainable alternative. This approach utilizes natural reducing agents such as plant extracts, microorganisms (bacteria, fungi), or biomolecules (enzymes, proteins) to reduce Ag^+ to Ag^0 and stabilize the resulting nanoparticles. For example, plant extracts from mint, neem, or tea contain polyphenols, flavonoids, and terpenoids that serve both as reducing and capping agents. Green synthesis is advantageous due to its simplicity, cost-effectiveness, and low toxicity, making it especially suitable for biomedical applications. However, challenges remain in terms of controlling particle uniformity and achieving reproducible results across batches. [34]

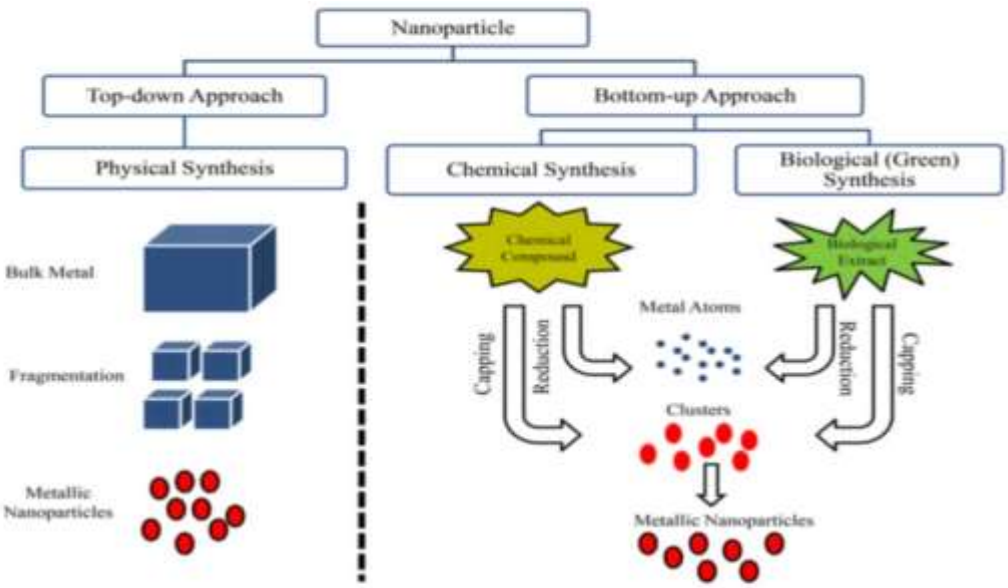

Figure I.5: Top-Down and Bottom-Up Approaches

I.5.4.Characterization of Silver Nanoparticles

Characterization of silver nanoparticles (AgNPs) is essential to determine their physical, chemical, and functional properties, which are critical for their application in various fields. Multiple analytical techniques are used to assess attributes such as size, shape, morphology, crystallinity, surface chemistry, and stability. Below is an overview of the main characterization methods for AgNPs. [35]

I.5.4.1.UV-Visible Spectrophotometry (UV-Vis)

UV-Vis spectroscopy is a primary and widely used technique for monitoring the synthesis and stability of AgNPs. It detects the surface plasmon resonance (SPR) band, a unique optical property of metallic nanoparticles, typically observed in the 200–800 nm range for silver nanoparticles sized 2–100 nm. The position and width of the SPR peak provide information about particle size, shape, and aggregation state. For instance, a strong plasmon band near 410 nm confirms the reduction of silver ions to metallic silver. Changes in the SPR peak (such as red-shift or broadening) can indicate variations in size, shape, or polydispersity. [36]

I.5.4.2.Fourier-Transform Infrared Spectroscopy (FTIR)

FTIR analysis can assist in identifying biomolecules responsible for reducing Ag^{+} ions and stabilizing the AgNPs synthesized. This qualitative analysis is based on using infrared light scanning to observe the chemical bonds of samples. FTIR spectroscopy can be utilized to determine the functional groups responsible for synthesizing AgNPs. In FTIR spectroscopy analysis, the form of the absorption spectrum profile exhibits different peaks representing the high concentration of specific types of chemical bonds, and various functional groups, such as alkanes, ketones, and amines, absorb infrared radiation of different wavelengths, thus allowing the identification of biomolecules. [37]

I.5.4.3.Transmission Electron Microscopy (TEM) and Scanning Electron Microscopy (SEM)

- **Scanning Electron Microscopy (SEM):** Provides detailed images of surface morphology and size distribution of AgNPs. SEM can reveal particle shapes (e.g., spherical, irregular) and clustering behavior. Sizes typically range from 20–80 nm depending on synthesis conditions. [38]

- **Transmission Electron Microscopy (TEM):** Nanoparticles can also be characterized using TEM. Quantitative measurements of the synthesized nanoparticles, such as particle size, size distribution, and morphology, can be obtained using TEM. This technic offers higher-resolution images, allowing visualization of internal structure and precise size measurement. TEM can also show changes in shape (e.g., from spherical to prismatic) as synthesis parameters vary. [39]

I.5.4.4.Dynamic Light Scattering (DLS) and Zeta Potential

- **Dynamic Light Scattering (DLS):** DLS can be used to examine the surface charge, size, and particle size distribution of nanoparticles. This technique depends on the interaction of the Brownian motion of spherical particles with the light passing through a colloidal solution. DLS can measure particles in the range from 1 to 500 nm; however, recording the size of agglomerated particles is problematic. In DLS, a small number of nanoparticles are required to prevent multiple scattering effects. DLS is susceptible to the presence of aggregates, making it better suited for monitoring aggregation in the initial process. [40]
- **Zeta Potential:** Zeta potential is a critical parameter for determining nanoparticle dispersion, effective surface electric charge, and stability. The zeta potential is computed by calculating the peak area and peak number, depending on the particle charge. According to previous research a high positive or negative charge in a particle cause them to repel each other and result in stable particles with a low tendency to aggregate. In general, stable suspensions have a zeta potential of 20–30 mV. [41]

I.5.4.5.X-ray Diffraction (XRD)

XRD is a powerful characterization technique for both qualitative and quantitative analyses of nanoparticles. XRD analyses are used to confirm the formation of nanoparticles and determine their crystal structure. In addition, this technique has been used to calculate the crystalline nanoparticle size and measure the degree of crystallinity. The analysis of materials using this technique depends on the diffraction patterns because each material has a unique diffraction beam. The working principle of XRD is Bragg's law, which helps determine the Bragg reflection of AgNPs. XRD patterns reveal remarkable peaks such as the (111), (200), (220), (311), (331), and (222) crystallographic planes that are specific for AgNPs. [42]

I.5.4.6.Energy Dispersive X-ray Spectroscopy (EDX or EDS)

Energy Dispersive X-ray Spectroscopy (EDS/EDX) is a valuable technique for identifying the elemental composition of nanoparticles. Coupled with SEM or TEM, it detects characteristic X-rays emitted by elements in the sample. EDS confirms the presence of key elements (e.g., Ag in AgNPs) and can reveal residues from capping agents. It also provides elemental mapping to assess the distribution and uniformity of elements in nanoparticles. [43]

I.5.5.Applications of silver nanoparticles

Silver nanoparticles (AgNPs) have a wide range of applications across various fields due to their unique physical, chemical, and biological properties. Here is a concise summary of their key applications.

I.5.5.1.Medical and Healthcare Applications

- **Antimicrobial Activity:** AgNPs are widely recognized for their antimicrobial properties, making them effective against a broad spectrum of pathogens.[44,45]
- **Wound Healing:** Silver nanoparticles have been utilized in wound dressings to promote healing and prevent infections.[45,46]
- **Cancer Therapy**: AgNPs have demonstrated potential in anticancer therapy by inducing cytotoxic effects in cancer cells.[44,45]
- **Biosensing:** Due to their unique optical properties, AgNPs are employed in biosensing applications for detecting various biological molecules.[47]

I.5.5.2.Consumer Product

- **Textiles:** Silver nanoparticles are incorporated into textiles to impart antimicrobial properties, enhancing hygiene and reducing odors.
- **Cosmetics:** AgNPs are used in cosmetic products for their antimicrobial effects, contributing to product preservation and skin health.
- **Household Items:** Silver nanoparticles are found in various consumer products, including packaging, clothing, and surface disinfectants, due to their antimicrobial properties.[48]

I.5.5.3.Environmental Applications

- **Water Purification:** AgNPs are incorporated into membranes and filters for water treatment, effectively removing contaminants and pathogens.[49-50]

- **Pollution Control:** Silver nanoparticles serve as plasmonic sensors for detecting water pollutants, including heavy metals and organic compounds.[50-51]

I.5.5.4.Food Industry:

- **Food Packaging:** AgNPs are applied in food packaging materials to inhibit microbial growth, thereby extending the shelf life of food products.[52]
- **Preservatives:** Silver nanoparticles are utilized in food processing to prevent the proliferation of foodborne bacteria, enhancing food safety.[52]

I.5.5.5.Electronics:

- **Conductive Inks:** AgNPs are used in the formulation of conductive inks for printed electronics, enabling applications in flexible circuits and sensors.[53,54]
- **Sensors:** Silver nanoparticles enhance the performance of electrochemical sensors due to their excellent conductivity and surface properties.[54]

I.5.5.6.Catalysis

AgNPs act as catalysts in various chemical reactions, including oxidation and reduction processes, owing to their high surface area and reactivity. [55]

I.5.5.7.Agricultural Applications

- **Nano-pesticides:** Silver nanoparticles are explored as nano-pesticides to protect crops from bacterial and fungal infections.[56-57]
- **Plant Growth Promoters:** Studies indicate that AgNPs can enhance seed germination and plant growth, contributing to increased agricultural productivity.[57]

II.Conclusion

In this chapter, we conclude that nanotechnologies have considerable potential. There are many possible applications in a variety of fields. We have described the synthesis processes for metal nanoparticles, with particular the green synthesis method. Nanoparticles (NPs) are attracting a great deal of interest due to their extraordinary properties, which make them exploitable in a variety of sectors including industry, food, medicine, cosmetics and many others.[58-60]

References

[1] Berra, D., Synthèse verte et caractérisationde nanoparticules métalliques par l’extrait des feuilles de Phoenix Dactylifera L et leur activité biologique. 2020, University of جامعة الوادي. El Oued

[2] Metiaz, H.M. and A. Boudiba, SYNTHESE, CARACTERISATION DES NANOPARTICULES D’ARGENT A BASE D’EXTRAIT DES FEUILLES DE PLANTES ET EVALUATION DE LEUR ACTIVITE ANTIOXYDANTE ET ANTIMICROBIENNE. , 2020 .جامعة غرداية

[3] Ben Mbarek, W., Synthèse, caractérisation et application des alliages à base de Mn-XY (X= Al; Y= Fe, Co) et Ca-Al dans la dégradation d'un colorant azoïque" Black 5" utilisé dans l'industrie de textile. 2018.

[4] Chami, K., et al., Les nanomatériaux manufacturés dans l’environnement professionnel: un aperçu de l’état de l’art. 2021. 82(1): p. 51-68.

[5] HARRAT, Z.R., Analyse du comportement mécanique des poutres des ponts en béton armé renforcé par des nanoparticules de silice. 2021.

[6] Rahal, H. and S. Messoud, l'Effet d'une Nanoparticule Sur des paramètres de toxicité Chez un indicateur de pollution" Helix aspersa". 2020, Universite laarbi tebessi tebessa.

[7] Mogk, D. (2020, February 6). *Scale of nanoparticles (1–100 nm) compared with antibodies, viruses, bacteria, mammalian cells, grains of sand, and a baseball* [Illustration]. Science Education Resource Center, Carleton College. Available under CC license from US National Cancer Institute, Division of Cancer Treatment and Diagnosis.

[8] Roman, J., Détection et analyse électrique de nanoparticules grâce à un nanopore solide et intégration microfluidique. 2018, Université Paris-Saclay (ComUE) .

[9] Ricaud, M. and O. Witschger, Les nanomatériaux: Definitions, risques toxicologiques, caractérisation de l'exposition professionnelle et mesures de prevention ,2012 .Technical Report ED 6050, INRS.

[10] Debnath, S. K., & Srivastava, R. (2021). Drug delivery with carbon-based nanomaterials as versatile nanocarriers: progress and prospects. Frontiers in Nanotechnology*,* 4, Article 644564.

[11] Smijs, T. G., & Pavel, S. (2011). Titanium dioxide and zinc oxide nanoparticles in sunscreens.

[12] Hasan, M. H., Islam, M. A., & Hossain, N. (2023). Advances and significances of nanoparticles in semiconductor applications – A review. Results in Engineering, 19, 101347.

[13] MDPI (2024). Chitosan combined with ZnO, TiO_2 and Ag nanoparticles for antimicrobial activity.

[14] Khan, A. K., Rashid, R., Murtaza, G., & Zahra, A. (2014). Gold Nanoparticles: Synthesis and Applications in Drug Delivery. Tropical Journal of Pharmaceutical Research.

[15] Pérez-Córdoba, L. J., Gutiérrez, G., & López, V. (2021). Silver nanoparticles and their antibacterial applications. *International Journal of Molecular Sciences*, 22(4), 1609.

[16] Frontiers in Microbiology. (2024). Advances in silver nanoparticles: A comprehensive review on their properties and applications.

[17] ACS Journal. (2023). Demonstrating the synthesis and antibacterial properties of silver nanoparticles.

[18] Frontiers in Chemistry. (2021). History and reengineering of silver's antimicrobial properties at the nanoscale.

[19] MDPI. (2023). Review on silver nanoparticles as a novel class of antibacterial agents. *Applied Sciences*, 11(3), 1120.

[20] PMC. (2018). A systematic review on silver nanoparticles-induced cytotoxicity.

[21] MDPI. (2022). Toxicological aspects, safety assessment, and green synthesis of AgNPs. *International Journal of Molecular Sciences*, 24(6), 5133.

[22] Nanotechnology Reviews. (2021). Ghobashy, M., et al. An overview of methods for production and detection of silver nanoparticles… *Nanotechnology Reviews*, 10(1), 954–977.

[23] Falke, P. B., Shelke, P. G., Hatwar, P. R., Bakal, R. L., & Kohale, N. B. (2024). A comprehensive review on nanoparticle characterization, synthesis methods, silver nanoparticles and its applications. GSC Biological and Pharmaceutical Sciences, 28(1), 171–184.

[24] ACS Omega Editorial. (2024). Silver nanoparticles (AgNPs): Comprehensive insights into bio-optical-electronic-catalytic characteristics. ACS Omega.

[25] PMC. (2023). Silver nanoparticles: structure, properties and applications. PMC Articles.

[26] ResearchGate PDF (2024). Silver nanoparticles properties and behavior at the nanoscale level.

[27] Bio-inspired synthesis review (2023). Distinct mechanical, chemical, electrical, optical, thermal and suspension properties of NPs vs bulk

[28] PMC article (2020). Influence of nanoparticles on thermal & electrical conductivity in composites.

[29] Wikipedia. (2021). Plasmonic catalysis.

[30] Frontiers in Microbiology. (2023). Nanoparticle characterization, types, synthesis, applications and prospects.

[31] Djeghboub, W., Nanoparticules d'or et d'argent déposées sur oxyde de cérium synthétisées sous irradiation.2010.

[32] Tolaymat, T.M., et al., An evidence-based environmental perspective of manufactured silver nanoparticle in syntheses and applications: a systematic review and critical appraisal of peer-reviewed scientific papers.2010. 408(5): p. 999-1006.

[33] Landage, S., et al., Synthesis of nanosilver using chemical reduction methods. 2014. 3(5): p. 14-22.

[34] Nasrollahzadeh, M., et al., Recent developments in the plant-mediated green synthesis of Ag-based nanoparticles for environmental and catalytic applications.2019. 19(12): p. 2436-2479.

[35] Balashanmugam, P., et al. (2013). Mycosynthesis, characterization and antibacterial activity of silver nanoparticles from microporus xanthopus: A macro mushroom. International Journal of Innovation Research and Science Engineering, Technology, 2(11), 6262–6270.

[36] Sharma, K., Guleria, S., & Razdan, V. (2020). Green synthesis of silver nanoparticles using Ocimum gratissimum leaf extract: Characterization, antimicrobial activity and toxicity analysis. Journal of Plant Biochemistry and Biotechnology, 29, 213–224.

[37] Palithya, S., Gaddam, S. A., Kotakadi, V. S., Penchalaneni, J., Golla, N., Krishna, S. B. N., & Naidu, C. (2022). Green synthesis of silver nanoparticles using flower extracts of Aerva lanata and their biomedical applications. Particulate Science and Technology, 40, 84–96.

[38] Chandraker, S. K., Ghosh, M. K., Lal, M., et al. (2021). A review on plant-mediated synthesis of silver nanoparticles, their characterization and applications. Nano Express, 2, 22008.

[39] Rather, M. A., Deori, P. J., Gupta, K., et al. (2022). Ecofriendly phytofabrication of silver nanoparticles using aqueous extract of Cuphea carthagenensis and their antioxidant potential and antibacterial activity against clinically important human pathogens. Chemosphere, 300, Article 134497.

[40] Bamal, D., Singh, A., Chaudhary, G., et al. (2021). Silver nanoparticles biosynthesis, characterization, antimicrobial activities, applications, cytotoxicity and safety issues: An updated review. Nanomaterials, 11, 2086.

[41] Mehata, M. S. (2021b). Green synthesis of silver nanoparticles using Kalanchoe pinnata leaves (life plant) and their antibacterial and photocatalytic activities. Chemical Physics Letters, 778, Article 138760.

[42] Zhang, X.-F., et al. (2016). Silver nanoparticles: Synthesis, characterization, properties, applications, and therapeutic approaches. International Journal of Molecular Sciences, 17(9), 1534.

[43] Ali, I.A.M., Ahmed, A.B. & Al-Ahmed, H.I. Green synthesis and characterization of silver nanoparticles for reducing the damage to sperm parameters in diabetic compared to metformin. Sci Rep 13, 2256 (2023).

[44] Jangid, H., Singh, S., Kashyap, P., Singh, A., & Kumar, G. (2024). Advancing biomedical applications: an in-depth analysis of silver nanoparticles in antimicrobial, anticancer, and wound healing roles. Frontiers in Pharmacology, 15, 1438227.

[45] Premanathan, M., et al. (2023). Silver Nanoparticles in Therapeutics and Beyond: A Review. *Materials*, 12(16), Article 2540.

[46] Witkowska, A., Bechelany, M., & Karav, S. (2024). Silver nanoparticles: Unique properties for wound healing and biosensing. Nanomaterials, 14(20), 1618.

[47] Haridas, E. S., Bhattacharya, S., Varma, M. K. R., & Chandra, G. K. (2022).

[48] Gokarneshan, N., & Velumani, K. (2017). Application of nano silver particles on textile materials for improvement of antibacterial finishes. Global Journal of Nanomedicine, 2(3), Article 555586.

[49] Martínez, P., & Smith, J. (2022). Purifying water with silver nanoparticles: fouling mitigation and membrane performance. Journal of Membrane Science.

[50] Kim, J., & Van Der Bruggen, B. (2010). The use of silver nanoparticles in polymeric and ceramic membranes for water treatment. Environmental Pollution, 158, 2335–2349

[51] Liu, M., et al. (2020). Silver Nanoparticles for Water Pollution Monitoring and Treatment. PMC Journal.

[52] Williams, R., & Thompson, L. (2021). Silver Nanoparticles in Food Packaging and Preservation. ACS Omega.

[53] Zhao, Q., & Sun, H. (2021). Silver Nanoparticle-Based Conductive Inks for Flexible Electronics. MDPI Metals, 12(2), 234.

[54] Bourassa, J., et al. (2019). Water vapor assisted sintering of silver nanoparticle inks for printed electronics. arXiv.

[55] Chen, X., & Patel, R. (2024). Advances in Silver Nanoparticle Catalysis. Advanced Synthesis & Catalysis.

[56] Gupta, S., & Kumar, A. (2023). Impact of Silver Nanoparticles on Plant Health and Disease Protection. Journal of Agricultural Nanotechnology.

[57] Ali, M., et al. (2024). Silver Nanoparticles as Plant Growth Promoters: Effects on Germination and Biomass. Frontiers in Microbiology.

[58] Dikshit, P. K., Kumar, J., Das, A. K., Sadhu, S., Sharma, S., Singh, S., Gupta, P. K., & Kim, B. S. (2021). Green Synthesis of Metallic Nanoparticles: Applications and Limitations. Catalysts, 11(8), 902.

[59] Radulescu, D.-M., Surdu, V.-A., Ficai, A., Ficai, D., Grumezescu, A.-M., & Andronescu, E. (2023). Green Synthesis of Metal and Metal Oxide Nanoparticles: A Review of the Principles and Biomedical Applications. International Journal of Molecular Sciences, 24(20), 15397.

[60] Dikshit, P. K., et al. (2021). Green Synthesis of Silver Nanoparticles: A Comprehensive Review. Science of The Total Environment.

Chapter II

Overview of plants studied

II.1.Medicinal plants

Medicinal plants are those species that contain biologically active compounds capable of producing therapeutic effects in the prevention, diagnosis, or treatment of diseases in humans or animals. They contain active compounds (called phytochemicals) like alkaloids, flavonoids, tannins, saponins, and essential oils that have therapeutic effect. These plants have been traditionally used in various systems of medicine, including Ayurveda, Traditional Chinese Medicine, and Unani, and are now recognized as valuable resources for modern pharmacological research and drug development. [1]

Plant products have an imperative use in the synthesis of nanoparticles (NPs) so, as part of our efforts to enhance the value of Algerian flora, we have focused on two species from two different families, one from the Lamiaceae family (Mentha Piperita) and the other from the Asteraceae family (Artemisia herba-alba). [2]

II.2.Botanical study

II.2.1. Mentha Spicata

II.2.1.1. Mentha Spicata genus

The *Mentha Spicata* genus belongs to the Lamiaceae family and comprises 61 species divided into four sections, namely Pulegium, Tubulosae, Eriodontes and Mentha, which are widespread throughout the world, especially in temperate regions. Natural interspecific hybridizations are observed with high frequency in both cultivated populations and wild species of the *Mentha Spicata* genus. [3]

II.2.1.2. Introducing the plant

Mentha Spicata, commonly known as spearmint, is a perennial aromatic herb belonging to the Lamiaceae family. Native to Europe and Asia, it has naturalized in many parts of the world due to its adaptability and widespread use. The plant is characterized by its lance-shaped, bright green leaves and a distinct, sweet, minty aroma, which comes from its essential oil, predominantly composed of carvone.

Spearmint is widely cultivated for culinary, medicinal, and cosmetic purposes. In traditional medicine, it has been used to treat digestive disorders, respiratory issues, and inflammation. Its essential oil is employed in flavoring foods, beverages, toothpaste, and chewing gum, as well as in aromatherapy and natural remedies. Due to its rich phytochemical composition—such as flavonoids, phenolic acids, and terpenoids—Mentha spicata is also studied for its antioxidant, antimicrobial, and anti-inflammatory properties, making it a valuable plant in both ethnobotany and modern pharmacology. [4]

Figure II.1: The spearmint (*Mentha Spicata*) leaf and flower

II.2.1.3. Origin and geographical distribution

Mint is native to Europe, Asia, and North Africa. Today, it is widely cultivated across the globe, particularly in the United States, India, China, and Mediterranean countries. [5]

For the purpose of this study**,** mint plant samples were collected from Laghouat region (Algeria)**,** which is characterized by a semi-arid climate and sandy clay soils, providing favorable conditions for the growth of this plant. Local samples were specifically selected to study their physical and chemical characteristics unique.

II.2.1.4. Botanical Classification

Table II.1: Presentation of *Mentha Spicata*. [6]

Taxonomic Rank	Classification
Kingdom	Plantae
Phylum (Division)	Magnoliophyta (Angiosperms)
Class	Magnoliopsida (Dicotyledoneae / Eudicots)
Order	Lamiales
Family	Lamiaceae
Genus	*Mentha*
Species	*Mentha Spicata*

II.2.1.5. Vernacular names:

Table II.2: Common names of *Mentha Spicata* in different languages.[7]

Language	Name
Italian	*Mentha Spicata*
French	Menthe verte
English	Spearmint
Arabic	النعناع

II.2.1.6. Bioactive substances

Mentha Spicata contains a wide range of bioactive compounds responsible for its therapeutic and biological activities. These substances are mainly found in the essential oil and various plant extracts (leaves, stems, and flowers). The major bioactive substances include:

Table II.3: The main bioactive compounds in the plant of *Mentha Spicata*

Class	Main Compounds	Biological Activities
Monoterpenes (EO)	Carvone, Limonene, 1,8-Cineole, Menthone	Antimicrobial, antioxidant, spasmolytic
Phenolic acids	Rosmarinic acid, Caffeic acid	Antioxidant, anti-inflammatory
Flavonoids	Luteolin, Apigenin, Diosmin	Antioxidant, vasoprotective, anti-inflammatory
Tannins	Hydrolyzable and condensed tannins	Antimicrobial, astringent
Terpenoids	β-Caryophyllene and others	Anti-inflammatory, analgesic

These bioactive substances contribute to the pharmacological importance of *Mentha Spicata*, making it valuable for pharmaceutical, nutraceutical, and cosmetic industries. [8]

II.2.1.7. Species and Differences:

Peppermint (Mentha × piperita): Rich in menthol (~40–48%), commonly used for respiratory and digestive issues. [9]

Spearmint (Mentha spicata): High in carvone, primarily used in culinary applications. [10]

Common mint (Mentha spp., e.g., garden mint): Milder flavor, widely used in beverages and salads [10,11].

Pennyroyal mint (Mentha pulegium): Known for insect-repellent properties, but its oil is toxic at high doses due to pulegone. [12]

II.2.1.8. Chemical Composition

Table II.4: Chemical Composition of *Mentha Spicata*. [13-15]

Compound	**Typical % Range**
Carvone	67–78%
Limonene	9.6–20.8%
1,8-Cineole	~8.7%
β-Bourbonene	~1.4%
β-Caryophyllene	~0.8–2.7%
Linalool	0.3–0.4%
Cis-Dihydrocarveol	~2.0%
Borneol	~0.2%
Germacrene D	~0.4–2.1%
Minor Monoterpenes	Trace amounts

II.2.1.9. Pharmacological & Nutritional Properties

- **Digestive**: Menthol acts as an antispasmodic, easing indigestion, IBS, cramps, nausea [16,17]
- **Respiratory**: Acts as a decongestant; soothing common cold and cough symptoms [18]

- **Analgesic & topical uses**: Peppermint oil helps relieve tension headaches, muscle and nerve pain[19]
- **Antioxidant & antimicrobial**: Contains flavonoids and phenolics; inhibits oral and food-borne pathogens; shows antibacterial and antifungal activity [20]
- **Aromatherapy & cognitive effects**: Inhaled mint oil may enhance memory and relieve nausea [17,21]

II.2.1.10. Traditional uses:

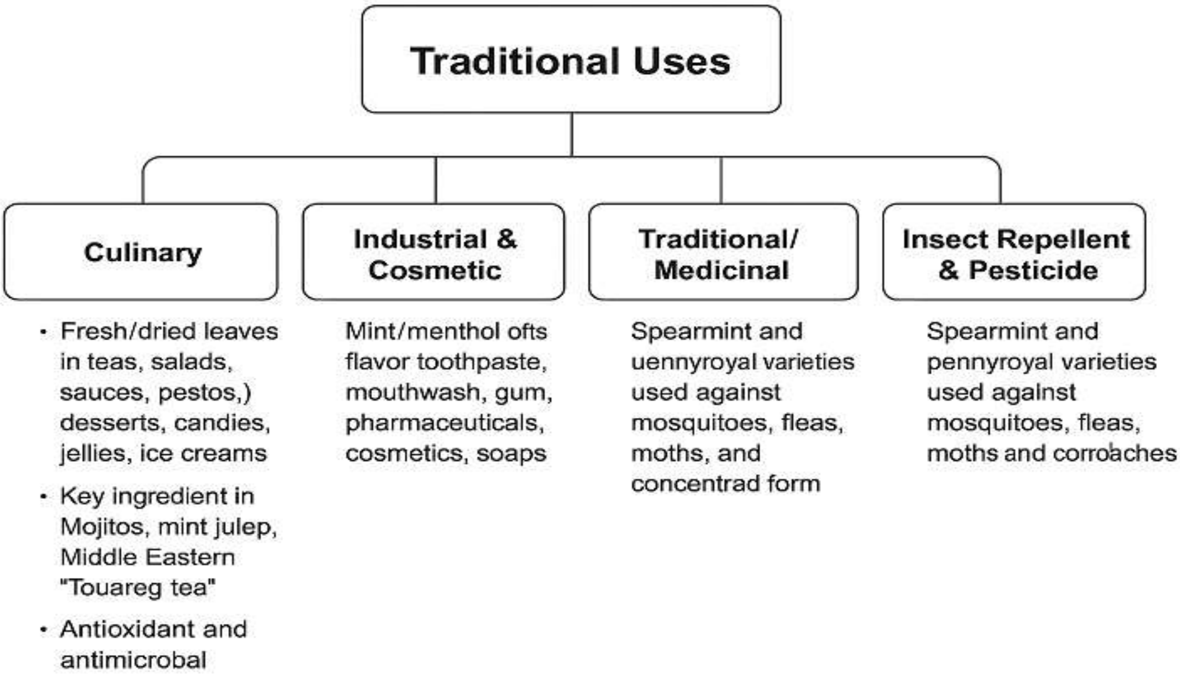

Figure II.2: Flowchart of Traditional Uses of *Mentha Spicata*. [22]

- **Cultivation and Production:**

Mint requires fertile, well-drained soil and a temperate climate with sufficient water. It can be propagated by cuttings or root division. Partial sunlight is optimal for its growth.

- **Essential Oil Extraction Methods:**

Mint essential oil is typically extracted by steam distillation. It can also be obtained using organic solvents or mechanical pressing. Steam distillation is the most common method to preserve oil quality. [22]

II.2.2. Artemisia

II.2.2.1. introducing the plant:

Artemisia Herba Alba commonly known as wormwood is a genus of perennial aromatic herbs in the Asteraceae family. Native to temperate regions of Europe, Asia, and North Africa, these plants have adapted to a wide range of environments. They are typically characterized by finely divided, silver-green leaves and a strong, herbaceous aroma, which is mainly attributed to essential oils rich in compounds such as artemisinin, thujone, camphor, and cineole.

Artemisia Herba Alba species are extensively used in traditional medicine for treating digestive disorders, respiratory issues, parasitic infections, and inflammatory diseases. They are also cultivated for culinary purposes, as insect repellents, and in cosmetic products. The phytochemical richness of Artemisia—including flavonoids, phenolic acids, and terpenoids—provides potent antioxidant, antimicrobial, anti-inflammatory, hepatoprotective, and antiparasitic activities, making them highly valuable in both ethnobotany and modern pharmacology [23-25].

Figure II.3: Picture presents *Artemisia Herba Alba*

II.2.2.2. Origin and geographical distribution:

Artemisia herba-alba, commonly known as desert wormwood, is native to arid and semi-arid regions, particularly in Mediterranean and desert climates. The plant is widely distributed in dry, steppe, and desert ecosystems where it thrives in poor, calcareous soils. Its ability to adapt to harsh, drought-prone environments has made it a significant species in traditional medicine and local flora across these regions. [26]

The *Artemisia Herba Alba* plant samples used in this study were collected from various natural sites within the Algeria Laghouat region especially. This area is characterized by a semi-arid climate and loamy soils that offer favorable conditions for the growth of the plant. The selection of local samples provides an applied dimension closely related to the specific environmental context of the region.

II.2.2.3- Botanical Classification of Artemisia:

Table II.5: Presentation of *Artemisia Herba Alba*. [27,28]

Taxonomic Rank	Classification
Kingdom	Plantae
Phylum (Division)	Magnoliophyta (Angiosperms)
Class	Magnoliopsida (Dicotyledoneae / Eudicots)
Order	Asterales
Family	Asteraceae
Genus	*Artemisia*
Species	*Artemisia Herba Alba*

II.2.2.4. Bioactive substances

Table II.6: The main bioactive compounds in the plant of *Artemisia Herba Alba*. [29-32]

Class	Main Compounds	Biological Activities
Monoterpenes (EO)	1,8- Cineole, Camphor, Thujone α- Pinene	Antimicrobial, antioxidant, antiparasitic
Sesquiterpenes	Caryophyllene, Germacrene D	Anti-inflammatory, antimicrobial
Phenolic acids	Caffeic acid, Chlorogenic acid	Antioxidant, anti-inflammatory
Flavonoids	Quercetin, Rutin, Luteolin	Antioxidant, anti-inflammatory, cytoprotective
Coumarins	Scopoletin	Antimicrobial, anti-inflammatory
Tannins	Condensed tannins	Antimicrobial, astringent
Terpenoids	Artemisinin derivatives (minor presence)	Antiparasitic, anti-inflammatory

II.2.2.5. Chemical Composition:

Table II.7: Chemical Composition of *Artemisia Herba Alba*. [29-32]

Compound	Typical % Range
α-Thujone	20–60%
β-Thujone	5–30%
1,8-Cineole	4–15%
Camphor	2–11%
Chrysanthenone	~3–8%
Borneol	~0.5–4%
β-Caryophyllene	~0.5–2.5%
Germacrene D	~0.3–2.0%
p-Cymene	~0.5–1.5%
Minor Sesquiterpenes	Trace amounts

II.2.2.6. Pharmacological & Nutritional Properties:

Artemisia Herba Alba is widely valued for its medicinal properties. It aids digestion, relieves indigestion, flatulence, and irritable bowel syndrome. It has strong antimicrobial effects against bacteria, fungi, protozoa, and parasites, mainly due to phenolic acids like salicylic and caffeic acids. The plant also shows liver-protective and anti-ulcer activities. Additionally, it may offer neuroprotective and antidepressant benefits, helping with fatigue, insomnia, and mood. Its anti-inflammatory and pain-relieving properties are linked to compounds like absinthin and chamazulene, while its antioxidant and immune-supporting effects are due to its rich flavonoid and phenolic content. [33-36]

II.2.2.7. Medicinal Properties: [37,38]

- Antiparasitic (notably against malaria)
- Anti-inflammatory
- Analgesic
- Antimicrobial
- Antioxidant
- Supports digestive system disorders

II.2.2.8. Uses: [39-42]

A) Medicinal & Herbal:

- Treats indigestion, anorexia, gastritis, anemia, spleen enlargement, menstrual issues, fever, wounds, and parasitic infections.
- Used in clinical research for early IgA nephropathy and Crohn's disease.

B) Beverages & Culinary

- Key bittering agent in absinthe, vermouth, pelinkovac, and other herbal bitters; used historically in beer

C) Antiparasitic & Insect-Repellent

- Effective against helminths; its clippings repel lice, mites, fleas, and root flies

D) Cosmetic & Industrial

- Anti-inflammatory and antimicrobial properties make it useful in cosmetics; used in animal feed additives and functional products.

II.2.2.9. Recent Scientific Studies: [43,44]

Recent studies confirmed the effectiveness of Artemisia extract in fighting malaria parasites, as well as showing antibacterial, antifungal, and strong antioxidant activities.

II.2.2.10. Cultivation and Production: [45,46]

Artemisia grows easily in sandy soils and areas with low rainfall. It can be propagated by seeds or root division. It requires good sunlight exposure and does not tolerate waterlogged soils.

II.2.2.11. Essential Oil Extraction Methods: [47,48]

Artemisia essential oil is commonly extracted by steam distillation, which preserves active compounds like cineole and chamazulene.

II.3.Conclusion :

In this chapter, we highlighted Mentha spicata and Artemisia herba-alba as two valuable medicinal plants rich in bioactive compounds with significant pharmacological, nutritional, and industrial importance. The study demonstrated their diverse chemical compositions and therapeutic properties, including antimicrobial, antioxidant, and anti-inflammatory activities. Their natural abundance in Algeria presents a valuable opportunity for local exploitation in pharmaceutical and nanotechnological applications, reinforcing the importance of utilizing plant-based resources in sustainable scientific innovations.

References

[1] Arif, R., & Uddin, R. (2021). A review on recent developments in the biosynthesis of silver nanoparticles and its biomedical applications. Medical Devices & Sensors, 4(1), Article e10158.

[2] Cherief, F., A. Chebbi, and F.E .Brahmi, Biosynthèse de nanoparticules a base d'extrait de plantes et la caractérisation de leurs activités biologiques. 2018.

[3] Ali, A., Santoro, P., Mori, J., et al. (2024). Effect of UV-B elicitation on spearmint's (Mentha spicata L.) morpho-physiological traits and secondary metabolites production. Plant Growth Regulation, *104*(1), 63–76.

[4] Sfaxi, A., Tavaszi-Sárosi, S., Flórián, K., Patonay, K., Radácsi, P., & Juhász, Á. (2025). Comparative Evaluation of Different Mint Species Based on Their In Vitro Antioxidant and Antibacterial Effect. Plants, 14(1), 105.

[5] Zhang, L., Chen, Y., Li, Z., Li, X., & Fan, G. (2022). Bioactive properties of the aromatic molecules of spearmint (Mentha spicata L.) essential oil: a review. Food & Function, 13, 3110–3132.

|6] El Menyiy, N., El Achbouni, M., Bouyahya, A., & Benjilali, B. (2022). Medicinal uses, phytochemistry, pharmacology, and toxicology of Mentha spicata L. Plants, 11(3), 801.

[7] Zaki, F. S. A., Khalid, K. A., & Ahmed, A. M. A. (2024). Mint species (Mentha longifolia and Mentha spicata L) growth, essential oil generation and chemical components are impacted by turmeric curcumin applications. Discover Applied Sciences, 6, 160.

[8] Mondal, P. C., Kumar, V., Kaushik, P., et al. (2024). New nematicidal compounds from Mentha spicata L. against Meloidogyne incognita. Journal of Plant Diseases and Protection, 131, 1983–1992.

[9] Dua, A., Mittal, S., & Thakur, A. (2023). Chemical and pharmacological properties of peppermint (Mentha × piperita L.). Journal of Ethnopharmacology, 294, 115352.

[10] Bardaweel, S. K., Bakchiche, B., & Gherib, A. (2018). Chemical composition, antioxidant, antimicrobial and antiproliferative activities of essential oil of Mentha spicata L. (Lamiaceae) from Algerian Saharan Atlas. BMC Complementary and Alternative Medicine, 18, 201.

[11] Chauhan, A. K., Kaul, M. K., Shahi, A. K., Kumar, A., & Ram, G. (2009). Chemical composition of essential oils in Mentha spicata L. from North-West Himalayan region, India. Industrial Crops and Products, 29(3), 654–656.

[12] Ghazalpour, F., & Nazary, H. (2021). Toxicological insights and insect-repellent efficacy of Mentha pulegium essential oil: a review. Toxins, 14(5), 347.

[13] Bardaweel, S. K., Bakchiche, B., Gherib, A., Rezzoug, M., & Aouni, M. (2018). Chemical composition, antioxidant, antimicrobial and antiproliferative activities of essential oil of *Mentha spicata* L. (Lamiaceae) from Algerian Saharan Atlas. BMC Complementary and Alternative Medicine, 18(1), 201.

[14] Chauhan, A. K., Kaul, M. K., Shahi, A. K., Kumar, A., Ram, G., & Kumar, S. (2009). Chemical composition of essential oils in Mentha spicata L. accession IIIM (J) 26 from North-West Himalayan region, India. Industrial Crops and Products, 29(3), 654–656.

[15] Grigore, A., Paraschiv, I., & Trifan, A. (2023). Comparative chemical profiling of Mentha spicata L. from Mediterranean populations. Molecules, 29(9), 1970.

[16] Cash, B. D., Epstein, M. S., & Shah, S. M. (2016). A novel delivery system of peppermint oil is effective in patients with irritable bowel syndrome. The American Journal of Gastroenterology, 103(7), 1704–1710.

[17] Pittler, M. H., & Ernst, E. (2019). Peppermint oil for irritable bowel syndrome: a systematic review and meta-analysis. Journal of Clinical Gastroenterology, 34(1), 35–45.

[18] Hayouni, E. A., et al. (2018). In vivo respiratory benefits of peppermint oil: a randomized controlled study. Phytomedicine, 42, 111–115.

[19] Göbel, H., et al. (2023). Does peppermint essential oil relieve headache pain in adults with tension-type headache? Evidence-Based Practice, 26(1), 16–17.

[20] Azwanida, N. N. (2015). A review on the extraction methods use in medicinal plants, principle, strength and limitation. Medical & Aromatic Plants, 4(3), 196.

[21] Eghbali, N., et al. (2021). Effect of peppermint (Mentha piperita) extract on chemotherapy-induced nausea and vomiting. Journal of Integrative Oncology, 1(1), 45–51.

[22] Mahendran, G., Verma, S. K., & Rahman, L. U. (2021). The traditional uses, phytochemistry and pharmacology of spearmint (Mentha spicata L.): A review. Journal of Ethnopharmacology, 278, 114266.

[23] Wani, K. I., Zehra, A., Choudhary, S., Naeem, M., & Khan, R. (2020). Artemisia annua L.: Traditional uses, phytochemistry, and pharmacological activities. Journal of Pharmacognosy and Phytochemistry, 9(3), 1416–1424.

[24] Taijong, J., Meitei, N. T., & Kumar, A. (2020). Phytochemical and pharmacological activities of methanol extract of Artemisia vulgaris L. leaves. Clinical Phytoscience, 6(1), 72.

[25] Abad, M. J., Bedoya, L. M., Apaza, L., & Bermejo, P. (2012). The Artemisia L. Genus: A review of bioactive essential oils. Molecules, 17(3), 2542–2563.

[26] Bora, K. S., & Sharma, A. (2011). The genus Artemisia: A comprehensive review. Pharmaceutical Biology, 49(1), 101–109.

[27] Hmamouchi, M., et al. (2000). Antimicrobial and Antioxidant Activities of Artemisia herba-alba Essential Oils. Journal of Ethnopharmacology, 71(1–2), 265–272.

[28] Mabberley, D. J. (2017). Mabberley's Plant-Book: A Portable Dictionary of Plants, their Classifications, and Uses (4th ed.). Cambridge University Press.

[29] Bensalem, S., et al. (2014). Antioxidant, anti-inflammatory, and antibacterial activities of Artemisia herba-alba extracts. Journal of Medicinal Plants Research, 8(14), 530–537.

[30] El Hassani, F. Z., et al. (2016). Phytochemical composition and biological activities of Artemisia herba-alba essential oils from Morocco. Industrial Crops and Products, 89, 1–12.

[31] Bora, K. S., & Sharma, A. (2011). The genus Artemisia: A comprehensive review. Pharmaceutical Biology, 49(1), 101–109.

[32] Gherib, M., et al. (2015). Chemical composition and biological activities of Artemisia herba-alba essential oil from Algeria. Natural Product Research, 29(6), 582–585.

[33] Abad, M. J., Bedoya, L. M., Apaza, L., & Bermejo, P. (2012). The Artemisia L. genus: A review of bioactive essential oils. Molecules, 17(3), 2542–2566.

[34] Gherib, A., Aoues, A., & Gaceb-Terrak, R. (2013). Hepatoprotective effect of Artemisia herba-alba against oxidative damage induced by carbon tetrachloride in rats. International Journal of Pharmacology, 9(3), 168–175.

[35] Al-Mustafa, A. H., & Al-Thunibat, O. Y. (2008). Antioxidant activity of some Jordanian medicinal plants used traditionally for treatment of diabetes. Pakistan Journal of Biological Sciences, 11(3), 351–358.

[36] Boudjelal, A., Henchiri, C., Sari, M., Sarri, D., & Benziane, M. (2013). Herbalists and wild medicinal plants in M'Sila (North Algeria): An ethnopharmacology survey. Journal of Ethnopharmacology, 148(2), 395–402.

[37] Al-Snafi, A. E. (2015). The pharmacological importance of Artemisia species. International Journal of Pharmacy and Pharmaceutical Sciences, 7(4), 1–8.

[38] Hadi, M. Y., & Kadhim, M. J. (2016). Phytochemical screening and evaluation of antimicrobial activity of Artemisia herba-alba. Journal of Pharmaceutical Sciences and Research, 8(10), 1150–1154.

[39] Abad, M. J., Bedoya, L. M., Apaza, L., & Bermejo, P. (2012). The Artemisia L. genus: A review of bioactive essential oils. Molecules, 17(3), 2542–2566.

[40] Benmehdi, H., Rahmoune, C., Rahmoune, R., & Boucherit-Otmani, Z. (2012). Ethnobotanical study of medicinal plants in the region of Aflou (Laghouat, Algeria). Advances in Environmental Biology, 6(3), 953–960.

[41] El-Hilaly, J., Hmammouchi, M., & Lyoussi, B. (2003). Ethnobotanical studies and economic evaluation of medicinal plants in Taounate province (Northern Morocco). Journal of Ethnopharmacology, 86(2-3), 149–158.

[42] Al-Snafi, A. E. (2015). The pharmacological importance of Artemisia species. International Journal of Pharmacy and Pharmaceutical Sciences, 7(4), 1–8.

[43] Tu, Y. (2016). Artemisinin—A gift from traditional Chinese medicine to the world (Nobel Lecture). Angewandte Chemie International Edition, 55(35), 10210–10226.

[44] Hadi, M. Y., & Kadhim, M. J. (2016). Phytochemical screening and evaluation of antimicrobial activity of Artemisia herba-alba. Journal of Pharmaceutical Sciences and Research, 8(10), 1150–1154.

[45] Boudjelal, A., Henchiri, C., Sari, M., Sarri, D., & Benziane, M. (2013). Herbalists and wild medicinal plants in M'Sila (North Algeria): An ethnopharmacology survey. *Journal of Ethnopharmacology*, 148(2), 395–402. https://doi.org/10.1016/j.jep.2013.04.040

[46] Hadi, M. Y., & Kadhim, M. J. (2016). Phytochemical screening and evaluation of antimicrobial activity of Artemisia herba-alba. *Journal of Pharmaceutical Sciences and Research*, 8(10), 1150–1154.

[47] Abad, M. J., Bedoya, L. M., Apaza, L., & Bermejo, P. (2012). The Artemisia L. genus: A review of bioactive essential oils. *Molecules*, 17(3), 2542–2566. https://doi.org/10.3390/molecules17032542

[48] Boudjelal, A., Henchiri, C., Sari, M., Sarri, D., & Benziane, M. (2013). Herbalists and wild medicinal plants in M'Sila (North Algeria): An ethnopharmacology survey. *Journal of Ethnopharmacology*, 148(2), 395–402.

Chapitre III

Experimental part

The aim of this work is to develop new biomaterials with biological activities, in particular colorimetric detection, based on aromatic and medicinal plants. This work was carried out at the Pedagogical Laboratory of the Departement of Process Engineering and the Research Laboratory of the University of Laghouat.

In this section of our study, we will present the methodology of green synthesis of silver nanoparticles, detailing the experiments we conducted and the results we obtained.

In this experimental part we presented three research axes:

- The first part is dedicated to the extraction and analysis of the plants studied (carried out at the Research Laboratory).
- The second involves characterizing silver nanoparticles by:

    1- UV-visible spectroscopic analysis: carried out in the Engineering Laboratory.

    2- FT-IR analysis: carried out at the Research Laboratory.

- In the third area of selective detection (colorimetric tests) was assessed using a series of solutions are prepared using various amino acids with the same concentration.

This chapter describes the various experimental materials and chemicals used, and detail the experimental methods and techniques employed throughout this work.

III.1. Introduction:

Nanotechnology has emerged as a transformative field with wide-ranging applications in medicine, electronics, agriculture, and environmental science. Among various nanoparticles, silver nanoparticles (AgNPs) have attracted significant attention due to their remarkable antimicrobial, catalytic, and optical properties. Traditionally, the synthesis of silver nanoparticles involves physical and chemical methods that often require toxic reagents, high temperatures, and energy-intensive processes, posing risks to the environment and human health.

In response to these concerns, the green synthesis of silver nanoparticles has gained prominence as a sustainable and eco-friendly alternative. This approach utilizes natural biological resources such as plant extracts, microorganisms (bacteria, fungi, algae), and enzymes as reducing and stabilizing agents. Plant-mediated synthesis is especially advantageous due to its simplicity, rapid synthesis, and the rich diversity of phytochemicals—

such as flavonoids, terpenoids, phenolics, and alkaloids—which facilitate the reduction of silver ions (Ag^{+}) to elemental silver (Ag^{0}) and stabilize the resulting nanoparticles.

Green synthesis not only minimizes the use of hazardous chemicals but also aligns with the principles of green chemistry, making it suitable for large-scale production and biomedical applications. As a result, it represents a promising strategy for the development of nanomaterials with minimal environmental impact and enhanced biocompatibility.[1]

III.2. Plant-Mediated Synthesis:

Plant-based synthesis is the most widely adopted green route due to its simplicity, rapidity, cost-effectiveness, and ease of scaling up. The general protocol Involves:

- Preparation of plant extract from leaves, flowers, fruits, or roots
- Mixing the extract with aqueous $AgNO_3$ solution
- Observation of color change indicating nanoparticle formation.
- Isolation and characterization using techniques such as UV-Visible spectroscopy, FTIR, SEM, TEM, XRD, and zeta potential analysis

III.3. several factors Influence the formation of AgNPs during green synthesis: [2]

These factors include:

- **Higher concentrations of silver Ions:** can lead to larger particles or aggregation if not balanced with sufficient reducing/stabilizing agents.
- **Optimal concentration:** ensures complete reduction and good nanoparticle yield.
- **Concentration of the Reducing Agent:** (e.g., Plant Extract) affects the reduction rate and stabilization. Too little extract may result in incomplete reduction, too much can lead to agglomeration or uncontrolled growth.
- **Temperature:** higher temperatures usually Increase the reaction rate, leading to faster nucleation and smaller particles. Extremely high temperatures may degrade biomolecules or cause agglomeration.
- **Reaction Time:** Insufficient time may not allow complete reduction of silver ions. Prolonged time may lead to aggregation or changes in shape.

- **Mixing or Stirring Conditions:** Proper mixing ensures uniform distribution of reagents, leading to homogenous nucleation. Poor mixing can cause irregular size and shape distribution.
- **Light Exposure:** Some green synthesis processes are photosensitive. UV or sunlight exposure can accelerate reduction in some plant-based syntheses.

III.4. Materials and products used:

The following materials, reagents, and laboratory equipment were used in the synthesis and characterization of silver nanoparticles:

Table III.1: presentation of material used on laboratory

Chemicals and Plant Materials	*Glassware and Containers*	*Instruments and Equipments*	*Filtration and Protection Materials*
- Fresh *Mentha Spicata* - Fresh *Artemisia Herba-Alba* leaves - Silver nitrate ($AgNO_3$), analytical grade - Distilled water	- 500 mL Erlenmeyer flasks - 50 mL and 100 mL beakers - Measuring cylinders (50 mL, 100 mL) - Burette (graduated) - Spatula - Funnels	- Magnetic stirrer with hot plate - Magnetic stirring bars - UV-Visible spectrophotometer - Analytical balance (precision: 0,001 g)	-Whatman filter paper - Aluminum foil - Watch glass or beaker covers - Disposable gloves - Lab coat - Safety goggles

III.5. Experimental protocol:

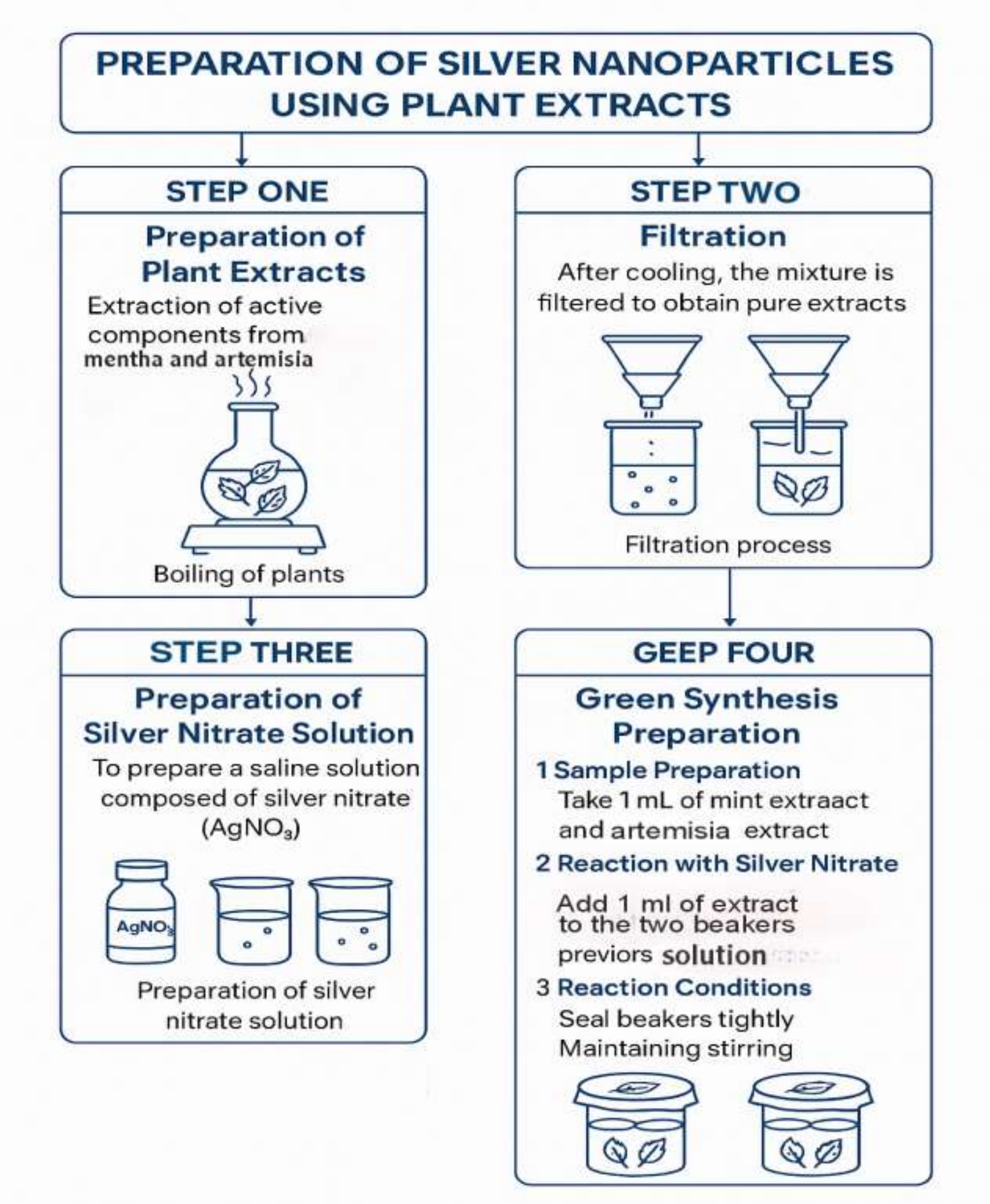

Figure III.1: Flowchart showing the steps on AgNPs

III.5.1. Preparation of aqueous plant extracts

In this process, we will extract the active components from the selected plants used in this study, namely *Mentha Spicata* and *Artemisia Herba-Alba*

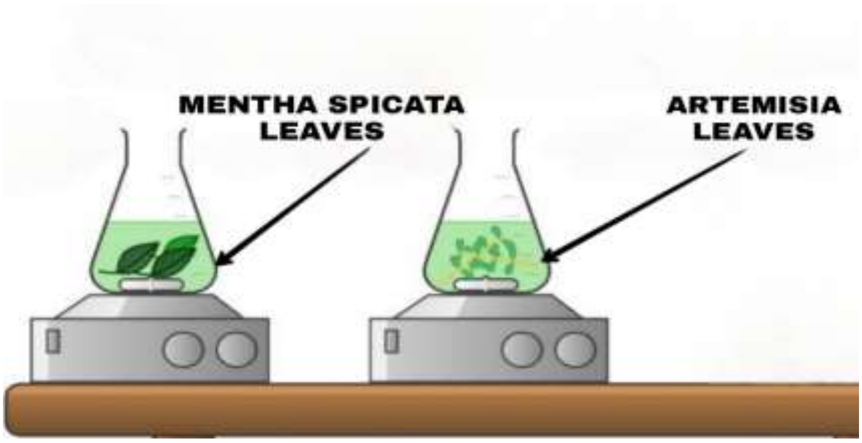

Figure III.2: boiling of plants

Firstly, the leaves of two plants are washed well with tap water, then distilled water, then left to dry for a few days at room temperature.

After drying, the plant material was ground to a fine powder. The aqueous extract was prepared by heating, with stirring, 10 grams of plants leaves (*Mentha Spicata* and *Artemisia Herba-Alba*) in a flask with 200ml of distilled water, and then we let the mixture boil for 30 minutes at a temperature between 75°C to 80°C using a magnetic stirrer.

III.5.2. Filtration

After boiling the plants leaves (*Mentha Spicata* and *Artemisia Herba Alba)* and allowing the mixture to cool completely, we move on to the filtration stage, which is essential to obtain a pure extract free of impurities.

III.5.2.1.Required Tools

- Two clean glass beakers (preferably sterilized).
- Two funnels (one for each beaker).
- Filter papers (coffee filters or laboratory-grade filter paper)

III.5.2.2.Filtration Steps

1- **Prepare the Filtration Setup**

Place a funnel over the first beaker and insert the filter paper properly into the funnel. Repeat the setup for the second beaker.

2- **Filtration Process**

Slowly pour the cooled herbal mixture into the funnel containing the filter paper. Allow the filtered liquid to collect in the beaker below. If the quantity is large, you can use the second setup to speed up the process. If you notice fine residues or plant particles in the filtered liquid, you may repeat the filtration.

- **Collecting the Extract**

Once filtration is complete, you should have a clear extract of *Mentha Spicata* and *Artemisia Herba Alba*. Store it immediately in airtight containers (preferably dark glass bottles to protect from light).

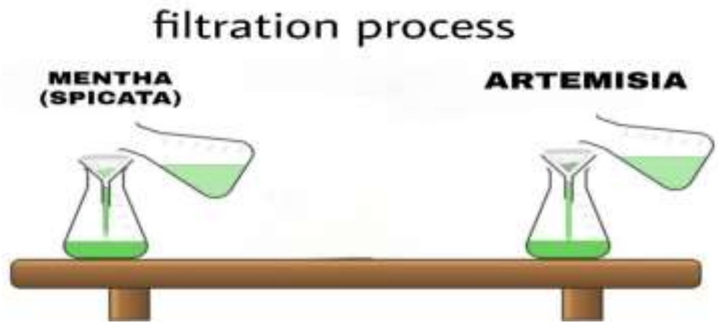

Figure III.3: Filtration process

Figure III.4: Real picture of aqueous plant extracts (*Mentha Spicata* and *Artemisia Herba Alba*)

III.5.3. Preparation of Silver Nitrate Solution

The aim of this stage is to prepare a saline solution composed of silver nitrate ($AgNO_3$).

III.5.3.1.Materials and Equipment

- Silver nitrate powder
- Distilled water
- Two beakers (50 mL capacity)
- Magnetic stirrers with stir bars
- Analytical balance
- Protective covers or aluminum foil (for light protection)

III.5.3.2.Procedure

- Measure 50 mL of distilled water into two separate beakers to prepare two identical solutions.
- Accurately weigh 0,086 grams of silver nitrate powder using an analytical balance.
- Place each beaker on a separate magnetic stirrer and insert a stir bar into each.
- Add the weighed silver nitrate to both beakers, dividing it equally if necessary.
- Activate the magnetic stirrers to ensure continuous stirring until the silver nitrate is completely dissolved.
- During the mixing process, cover the beakers completely with appropriate protective materials to prevent exposure to light, as silver nitrate is light-sensitive.

III.5.4. Biosynthesis of silver nanoparticles AgNPs

III.5.4.1. Sample Preparation

Take 1 mL of *Mentha Spicata* extract and 1 mL of *Artemisia Herba-Alba* extract separately.

III.5.4.2. Reaction with Silver Nitrate solution

In two beakers covered with aluminum foil (to protect from light), each containing a previously prepared solution of silver nitrate ($AgNO_3$), we add 1 mL of *Mentha Spicata* extract to the first beaker and 1 mL of *Artemisia Herba-Alba* extract to the second beaker.

III.5.4.3. Reaction Conditions

Each beaker must be sealed tightly to ensure isolation from light and air. Continuous stirring is maintained to ensure proper Interaction between the extract and the silver nitrate.

III.5.4.4. Monitoring

After initiating the reaction, begin measuring the absorbance using a UV-Vis spectrophotometer to determine the wavelength at which maximum absorption occurs, this indicates the formation of silver nanoparticles.

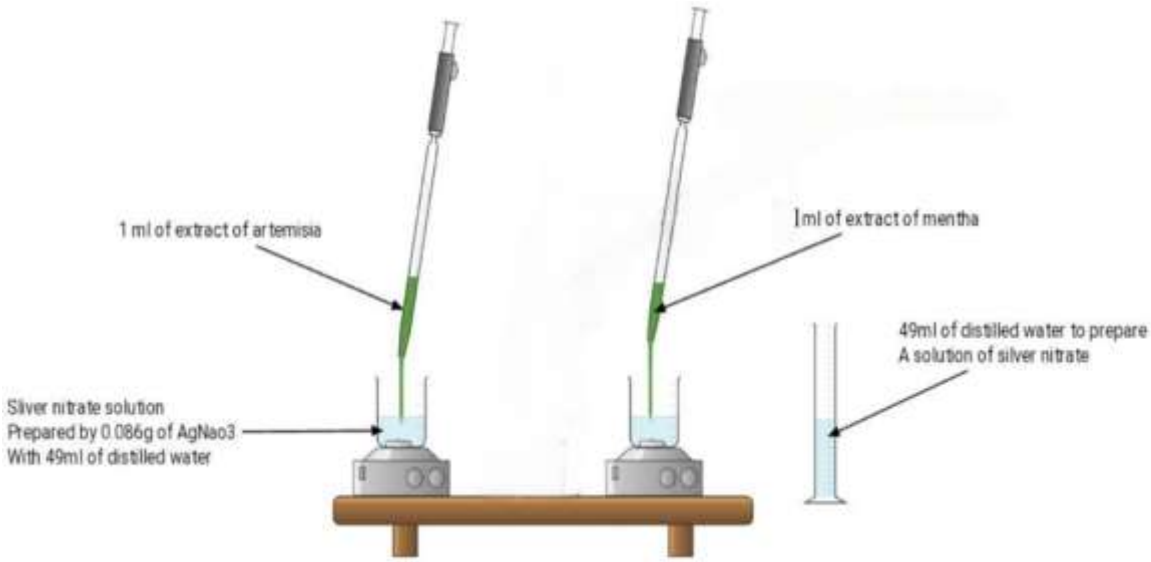

Figure III.5: Addition of extract to $AgNO_3$ to synthesize silver nanoparticles

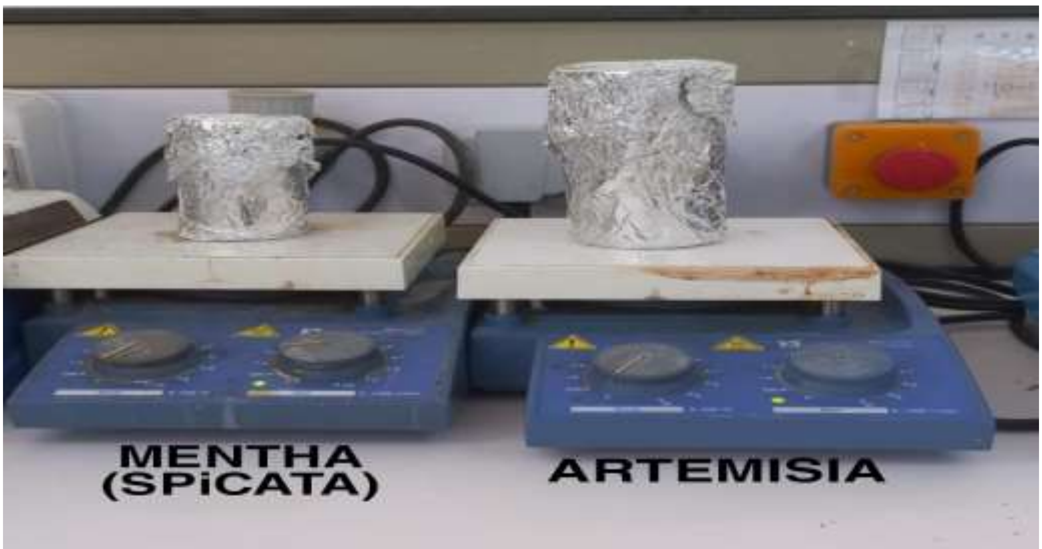

Figure III.6: Real picture present agitation of the synthesis ($AgNO_3$ + extract)

III.6. Mechanism of Green Synthesis

The green synthesis of AgNPs involves the reduction of silver ions (Ag^+) to metallic silver (Ag^0) using photochemical or microbial metabolites as reducing agents. These biomolecules—such as flavonoids, phenols, alkaloids, terpenoids, and proteins—also act as capping or stabilizing agents, thereby influencing the morphology and stability of the resulting nanoparticles. A color change from pale yellow to brown typically indicates the formation of AgNPs due to Surface Plasmon Resonance (SPR) phenomena. [3]

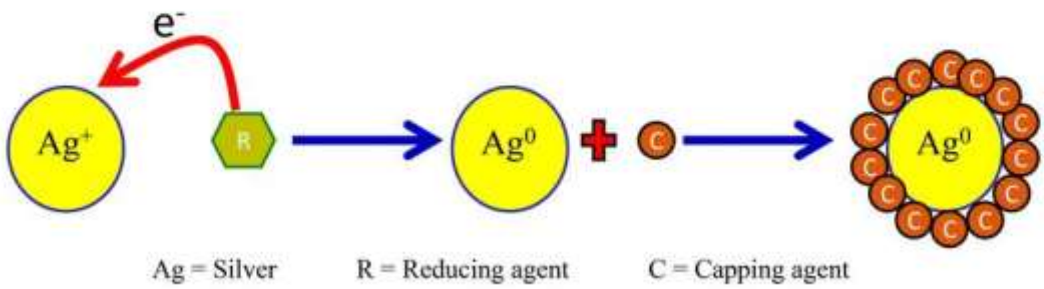

Figure III.7: Schematic Diagram of Silver Nanoparticle Synthesis Process. [3]

The process of forming nanoparticles in solution is as complex as the formation of metal nanoparticles. In plants and plant extracts, this process takes place in three main stages, and numerous parameters can interfere with nanoparticle formation, such as: temperature, concentration, nature of reagents and reducing agent. [4]

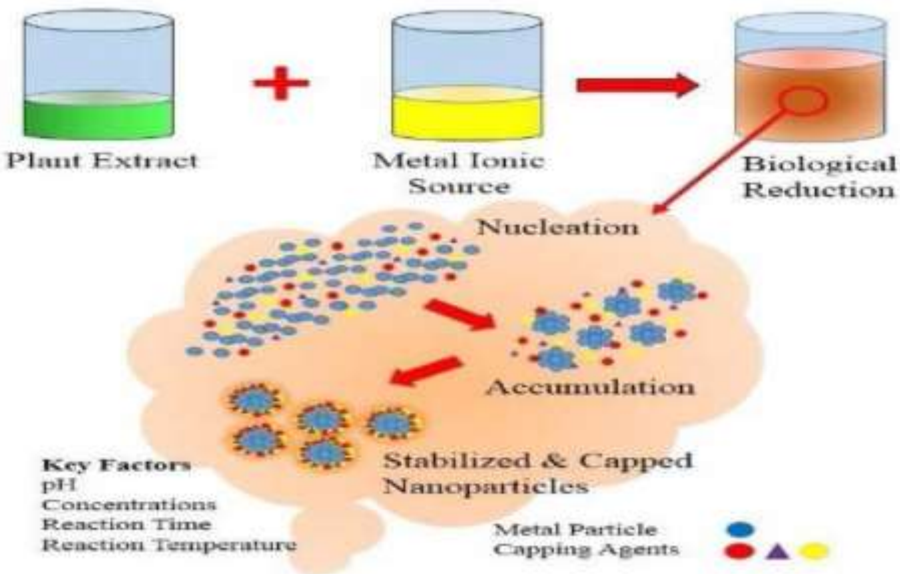

Figure III.8: Green synthesis of nanoparticles from plant extracts.[5]

The mechanism of nanoparticle formation is derived from the literature, taking into account the fact that the plant extract is very rich in polyphenols. The presence of Ag^+ causes the oxidation of hydroxyl groups to form a silver complex intermediate, followed by a quinone and Ag^+ ions, the latter of which are reduced to metallic Ag in the presence of free electrons.

$$2Ag^+ + 2e^- \longrightarrow 2Ag^0$$

Ou

$$2H^+ + 2e^- \longrightarrow H_2$$

$$2Ag^+ + H_2 \longrightarrow 2Ag^0 + 2H^+$$

Figure III.9: Mechanism of AgNPs formation. [6]

Colloidal stability of the nanoparticles is ensured by the interaction between the hydrogens of the phenolic group in the aqueous extract and the negatively charged silver nanoparticles. At the end of formation and stabilization, the AgNPs take on a spherical shape.

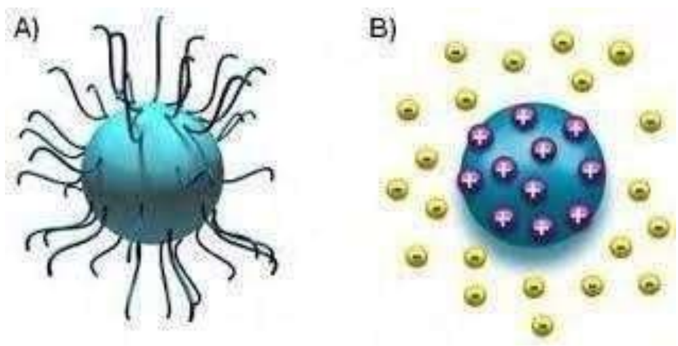

Figure III.10: Stabilization of AgNPs. [7]

III.7. Method of characterization of silver nanoparticles:

III.7.1. UV-Visible Spectroscopy:

UV-Vis spectroscopy is an analytical technique that measures the amount of discrete wavelengths of UV or visible light that are absorbed by or transmitted through a sample in comparison to a reference or blank sample. This property is influenced by the sample composition, potentially providing information on what is in the sample and at what concentration. [8]

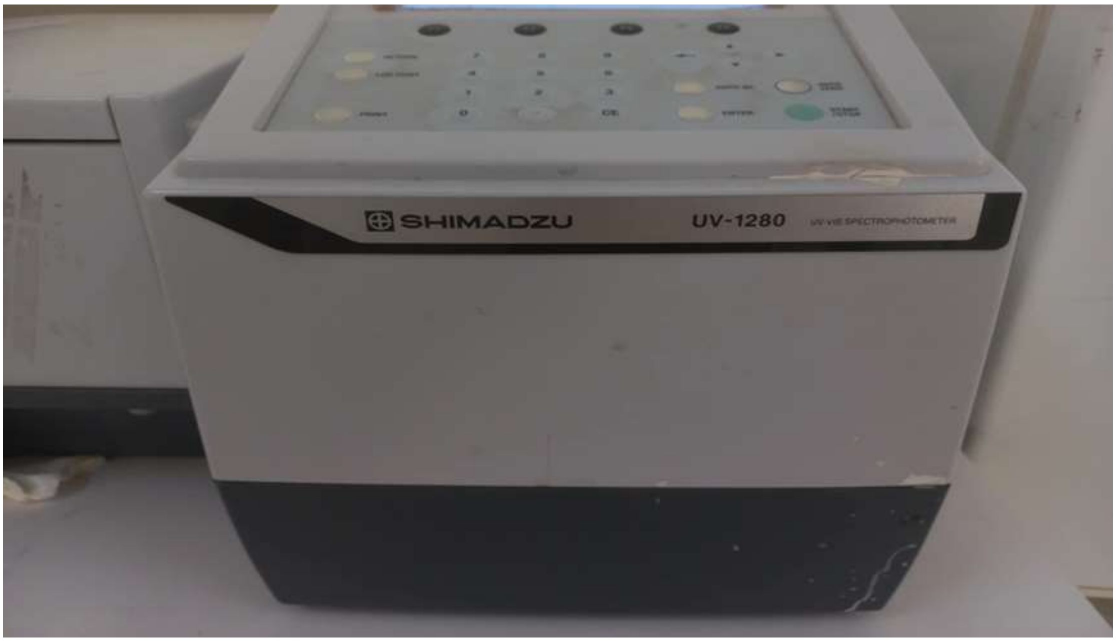

Figure III.11: Picture of Ultra violet spectrophotometer SHIMADZU-UV-1280**.**

Spectrophotometric measurements were carried out on a double-beam UV-visible spectrophotometer type SHIMADZU-UV-1280 (thermo) for the two extracts prepared (AgNPs and extract), using a quartz cell with a 10 mm optical path. The spectrophotometer chamber is thermo stated at 25°C. Analysis is performed between 200 and 600 nm.

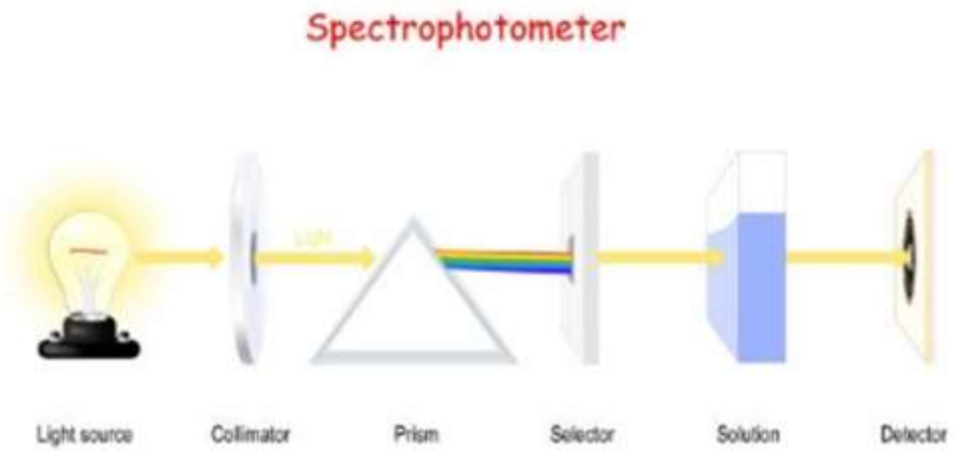

Figure III.12: Ultraviolet spectrophotometer operating principle. [8]

III.7.2. Fourier Transform Infrared Spectroscopy (FTIR)

FTIR spectroscopy is used to identify the functional groups present on the surface of silver nanoparticles to understand the nature of interactions between the nanoparticles and the capping or stabilizing agents. During synthesis, various biomolecules or chemical agents may bind to the AgNPs, influencing their stability and properties.

The FTIR spectrum reveals characteristic absorption bands corresponding to different chemical bonds such as O–H, C=O, N–H, and C–N. These peaks help confirm the presence of proteins, phenols, amines, or other organic molecules involved in the reduction and stabilization of the nanoparticles. Comparing the FTIR spectra of pure stabilizers with that of the nanoparticle mixture can help identify the specific groups attached to the nanoparticle surface. [6]

Figure III.13: Picture of FT-IR Spectrometer JASCO FT/IR4200.

The FTIR spectrum reveals characteristic absorption bands corresponding to different chemical bonds such as O–H, C=O, N–H, and C–N. These peaks help confirm the presence of proteins, phenols, amines, or other organic molecules involved in the reduction and stabilization of the nanoparticles. Comparing the FTIR spectra of pure stabilizers with that of

the nanoparticle mixture can help identify the specific groups attached to the nanoparticle surface. [10]

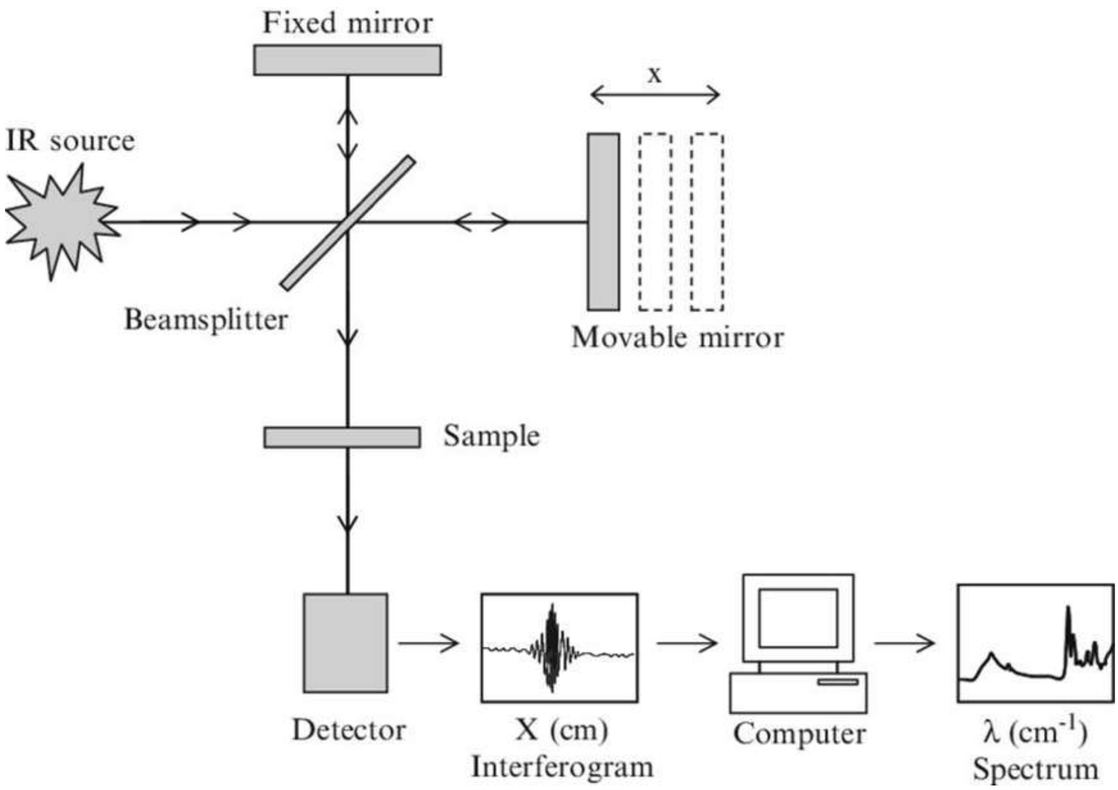

Figure III.14: FT-IR spectrophotometer operating principle. [10]

III.8. Selective Detection (Colorimetric Tests)

In this section, a series of solutions are prepared using the compounds of various amino acids (L-Cysteine, L-Arginine, L-Lysine, and L-Tyrosine, N-Acetyl-L-Cysteine). Each compound is dissolved at a concentration of 10^{-2}M in 10 mL of distilled water to produce the colorimetric test solutions. These prepared solutions are subsequently utilized for performing selective colorimetric detection experiments.

A volume of 0,1 mL from each test solution is transferred into individual small vials. Subsequently, 0,9 mL of the silver nanoparticle (AgNPs) solution is added to each vial. After an incubation period of 5 minutes, the resulting mixtures are subjected to analysis.

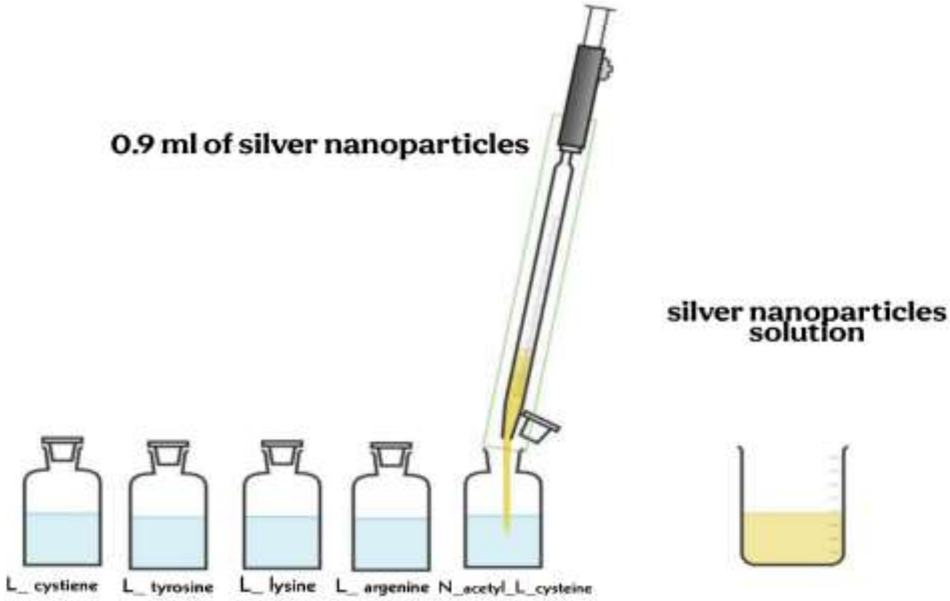

Figure III.15: Colorimetric Detection of Amino Acids Using (AgNPs)

III.9.Conclusion:

In this part of our study, we conducted laboratory work that involved going through various necessary experiments. As a result, we obtained numerous findings, which we collected at each stage of the experiment. We will analyze these different results in the upcoming section of our study.

References

[1] Ahmed, S., Ahmad, M., Swami, B. L., & Ikram, S. (2016). A review on plants extract mediated synthesis of silver nanoparticles for antimicrobial applications: A green expertise. Journal of Advanced Research, 7(1), 17–28.

[2]https://www.researchgate.net/figure/Mechanism-of-green-synthesis-of-silver-nanoparticles_fig2_332016721.

[3] https://www.researchgate.net/figure/General-mechanism-of-metallic-nanoparticles-synthesis-using-reducing-and-capping-agents_fig1_363878460

[4] Shah, M., et al., Green synthesis of metallic nanoparticles via biological entities. 2015. 8(11): p. 7278 .7308- .

[5] Wang, X., et al., Preparation of silver nanoparticles by solid-state redox route from hydroxyethyl cellulose for antibacterial strain sensor hydrogel. 2021. 257: p. 117665. .

[6] Mollick, M.M.R., et al., Studies on green synthesized silver nanoparticles using Abelmoschus esculentus (L.) pulp extract having anticancer (in vitro) and antimicrobial applications. 2019. 12(8): p. 2572-2584.

[7] Srikar, S.K., et al., Green synthesis of silver nanoparticles: a review. 2016. 6(1): p. 34- 56

[8]https://www.technologynetworks.com/analysis/articles/uv-vis-spectroscopy-principle-strengths-and-limitations-and-applications-349865#:~:text=What%20is%20UV%2DVis%20spectroscopy?%20UV%2DVis%20spectroscopy%20is,comparison%20to%20a%20reference%20or%20blank%20sample.

[9] https://www.istockphoto.com/illustrations/spectrophotometer-illustrations

[10] Ahmed, S., Saifullah, Ahmad, M., Swami, B. L., & Ikram, S. (2016). Green synthesis of silver nanoparticles using Azadirachta indica aqueous leaf extract. Journal of Radiation Research and Applied Sciences, 9(1), 1–7.

Chapter IV:

Results & discussions

IV.1. Introduction:

This chapter presents a comprehensive interpretation of the results obtained before and after the modification of silver nanoparticles, employing various analytical techniques. The analysis focuses on data derived from UV-Visible spectroscopy, Fourier-transform infrared (FTIR) spectroscopy, and colorimetric chiral sensing.

Part1:

IV.2. UV-Visible spectrophotometry analysis:

- <u>Extract of *Mentha Spicata*</u>

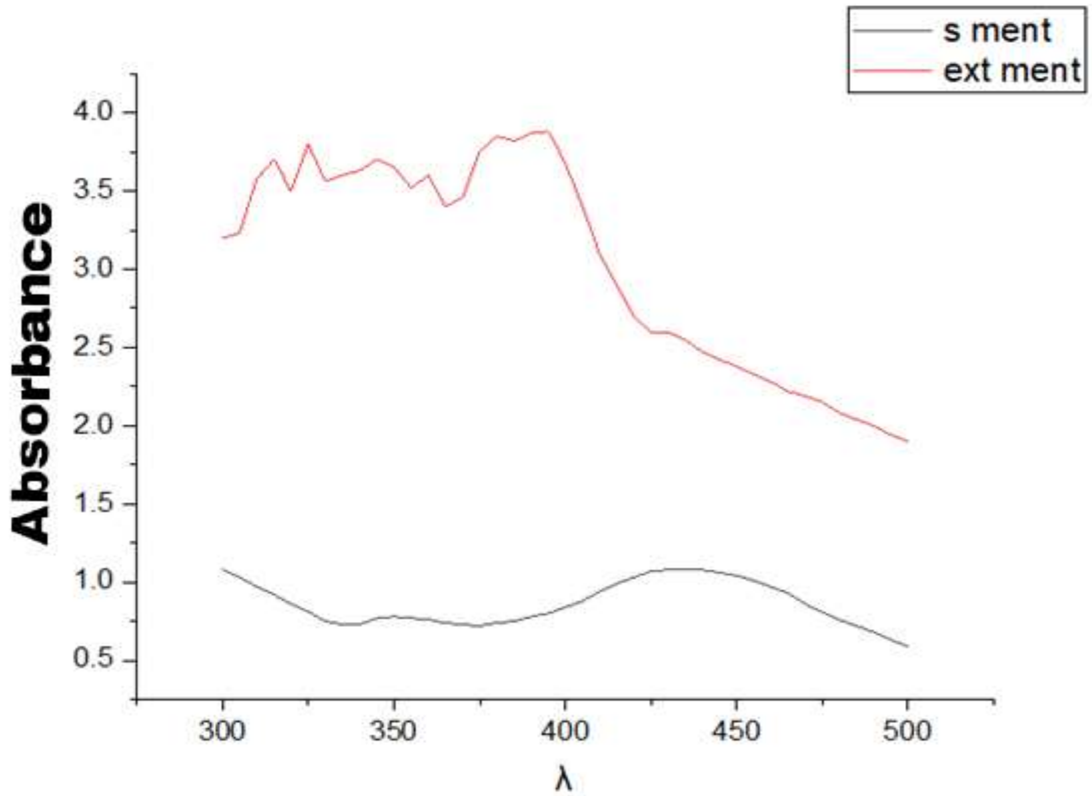

Figure.IV.1: UV spectrum of *Mentha Spicata* extract and Synthesis of AgNPs.

In confirming nanoparticle formation. A strong absorbance peak is typically observed between 420–460 nm, indicative of the surface plasmon resonance (SPR) of AgNPs.

The absorption characteristics of AgNPs are highly dependent on their size, shape, distribution, and the dielectric constant of the surrounding medium. Spherical AgNPs usually exhibit a sharp peak around 430 nm, whereas deviations in shape or increased size result in a broader and red-shifted peak. The presence of a single sharp peak suggests monodispersity and spherical morphology, while multiple peaks or peak broadening .may indicate polydispersity or anisotropic shapes The UV–Vis spectrum of silver nanoparticles synthesized using *Mentha Spicata* extract shows a distinct SPR peak at approximately 430 nm, indicating the formation of small, spherical, and welldispersed nanoparticles. This peak position corresponds to particles typically. The high intensity of the peak reflects a high concentration of AgNPs, confirming the strong reducing power of Mentha phytochemicals and the efficiency of the synthesis process. Furthermore, the narrow width of the peak suggests a uniform size distribution, good colloidal stability, and minimal aggregation, due to the stabilizing action of natural compounds in the extract. These spectral features collectively demonstrate that Mentha-based synthesis produces stable, monodisperse, and concentrated silver nanoparticles via an ecofriendly and effective green synthesis route Visible color change is observed: from dark brown to more light brown (less dark). This color change results from SPR, a phenomenon where conduction electrons on the nanoparticle surface oscillate in response to light.

Figure.IV.2: Real picture present *Mentha Spicata* extract & synthesis

➢ <u>Extract of *Artemisia Herba-Alba*</u>

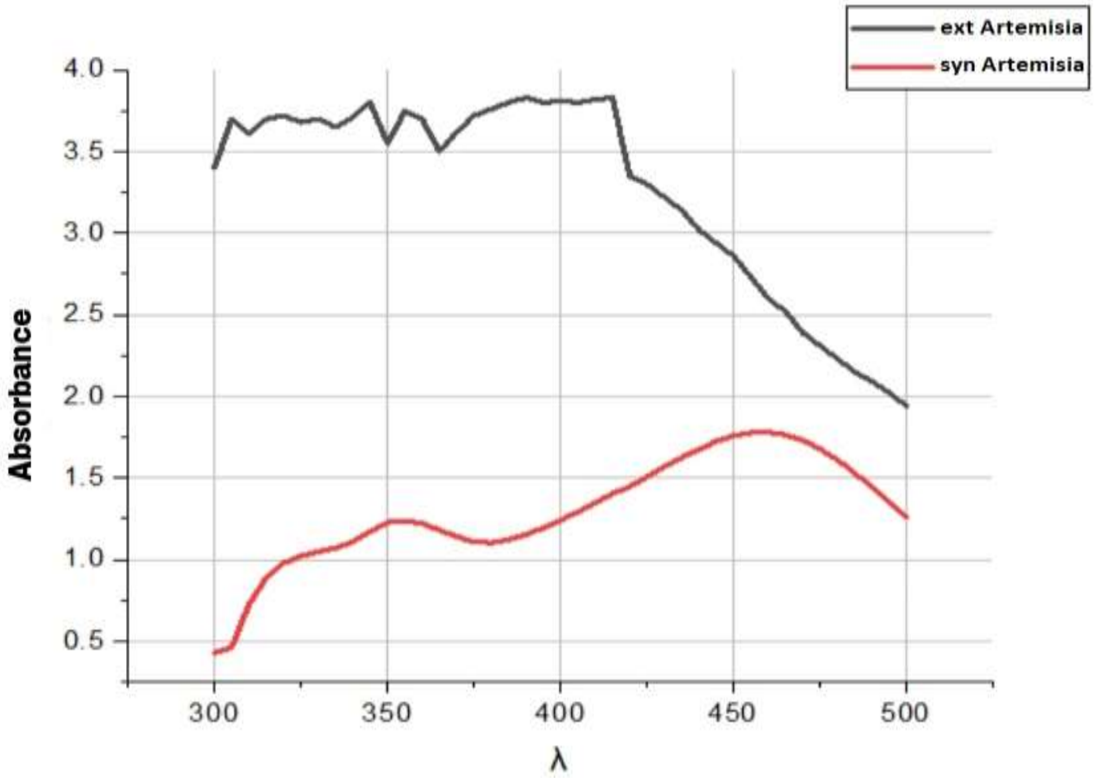

Figure.IV.3: UV spectrum of *Artemisia Herba-Alba* extract and Synthesis of AgNPs

In the present analysis, a sharp and distinct absorption peak observed in the range of 420–450 nm provides strong evidence confirming the successful synthesis of AgNPs. The presence of this SPR band is a direct indicator of metallic silver in the nanoscale regime. Furthermore, the exact position and intensity of the SPR band are crucial indicators of the physical properties of the nanoparticles.

➢ **Peak Position (Wavelength):**

A blue shift (toward shorter wavelengths) typically suggests the formation of smaller-sized nanoparticles, whereas a red shift (toward longer wavelengths) may indicate an increase in particle size, agglomeration, or changes in the refractive index of the surrounding medium.

- **Peak Intensity:**

Higher absorbance intensity usually reflects a higher concentration of nanoparticles in the colloidal solution. However, excessive broadening of the peak may be indicative of polydispersity or aggregation within the sample.

- **Peak Width and Shape:**

The full width at half maximum (FWHM) of the SPR peak is also a valuable parameter. A narrow and symmetric peak is characteristic of a monodisperse nanoparticle population, meaning that the nanoparticles are uniform in size and shape. In contrast, a broadened or asymmetric peak could suggest a heterogeneous size distribution or instability in the colloidal dispersion.

Moreover; the optical properties observed in the UV-Vis spectrum are closely linked to the surface chemistry of the nanoparticles. The presence of phytochemicals or capping agents from plant extracts in green synthesis routes can slightly modify the SPR band due to their interaction with the nanoparticle surface, which in turn affects electron density and dielectric properties around the particles.

During the green synthesis of AgNPs using *Artemisia Herba-Alba* extract, a color change from pale yellow to lighter yellow is typically observed within minutes to hours after mixing the plant extract with the silver nitrate solution. This color transformation is the first qualitative evidence of AgNP formation.

Figure.IV.4: Real picture present *Artemisia Herba-Alba* extract & synthesis of AgNPs.

➢ **Comparison with Control Sample:**

A control solution containing only silver nitrate without *Artemisia Herba-Alba* extract should be analyzed in parallel. This control typically shows no absorbance peak around 420–440 nm and remains colorless, which confirms that no nanoparticles form .without the reducing agents from the plant extract.

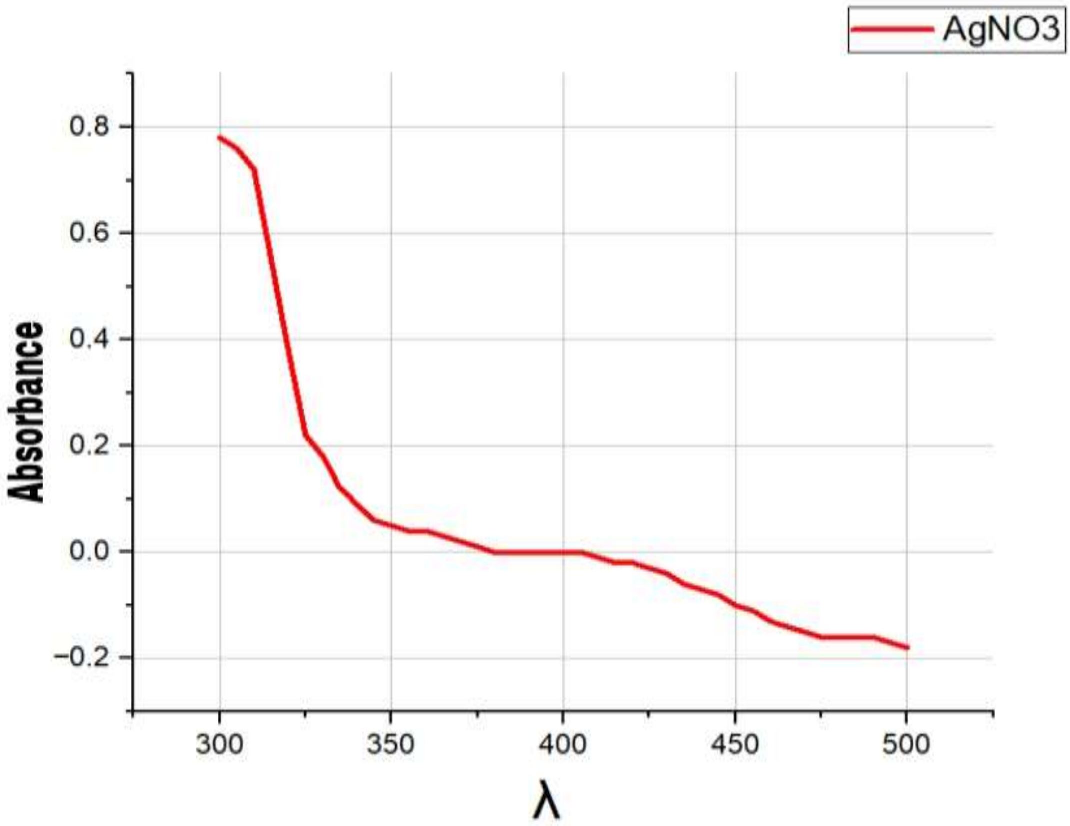

Figure.IV.5: UV spectrum of AgNao3 solution

IV.3. Conclusion:

The UV-Visible spectroscopy results for silver nanoparticles synthesized using *Artemisia Herba-Alba* plant extract confirm the successful reduction of Ag^+ ions and formation of colloidal AgNPs. The characteristic SPR peak, typically centered at ~425 nm, validates the nanoparticle formation and provides critical insights into the reaction's progress, nanoparticle stability, and dispersion quality. As part of a broader characterization framework, UV-Vis spectroscopy remains an indispensable tool for green nanotechnology applications, especially in eco- friendly biosynthesis processes like the one involving *Artemisia Herba-Alba*.

Part2:

IV.4. AgNP Formation Confirmed:

The increase in absorbance over time for both extracts confirms the successful biosynthesis of silver nanoparticles, due to the Surface Plasmon Resonance (SPR) effect—typical of metallic .nanoparticles like AgNPs

IV.4.1. Mentha Spicata – Fast and Efficient:

Rapid Synthesis: High absorbance (1.76) at the first time point .shows immediate nanoparticle formation

- **High Yield:** The absorbance increases to 1.87 (after ~1 hour) and 1.99 (after several hours), indicating strong reducing and .stabilizing activity
- **Interpretation:** The extract is rich in active compounds (e.g., phenolics, flavonoids, terpenes) that reduce Ag^{+} quickly and .stabilize AgNPs effectively

IV.4.2. Artemisia-Herba-Alba– Slower and Weaker Response:

- **Delayed Reaction:** Initial absorbance is low (0.59 at 1 hour), .increasing slowly to 0.68 than to 0.81, suggesting slower synthesis
- **Lower Yield:** The gradual rise shows limited reducing capacity .under the same conditions
- **Interpretation:** *Artemisia Herba-Alba* contains bioactives capable of Ag^{+} reduction but requires longer time or optimization to match *Mentha Spicata*'s efficiency.

IV.4.3. Comparison Summary:

Mentha spicata clearly outperforms Artemisia in speed and yield of AgNP synthesis. Its phytochemicals enable faster and more complete conversion of silver ions.

Table.IV.1: UV-Vis Absorbance of Silver Nanoparticles Synthesized Using Plant Extracts

Plants	Volume of extract (ml)	Absorbance	wavelength
Menthe Spicata	**1**	**1.76** **1.87** **1.99**	**420-445**
Artemisia Herba Alba	**1**	**0.59** **0.68** **0.92**	**430-440**

IV.4.4. Important Limitation – Wavelength Unclear:

Absorbance should be measured around 400–450 nm, the SPR range for AgNPs. The unclear wavelength data raises concerns about accuracy. Results must be confirmed with proper wavelength settings.

IV.5. Conclusion:

Both plants extract successfully synthesized AgNPs, but *Mentha Spicata* was significantly more efficient. Proper confirmation of the measurement wavelength is essential, and further optimization may improve *Artemisia Herba-Alba*'s performance.

Part 3:

IV.6. FT-IR analysis:

IV.6.1. *Mentha Spicata*:

Blue Line: *Mentha Spicata* extract (before synthesis)

Orange Line: *Mentha Spicata* -mediated silver nanoparticle synthesis

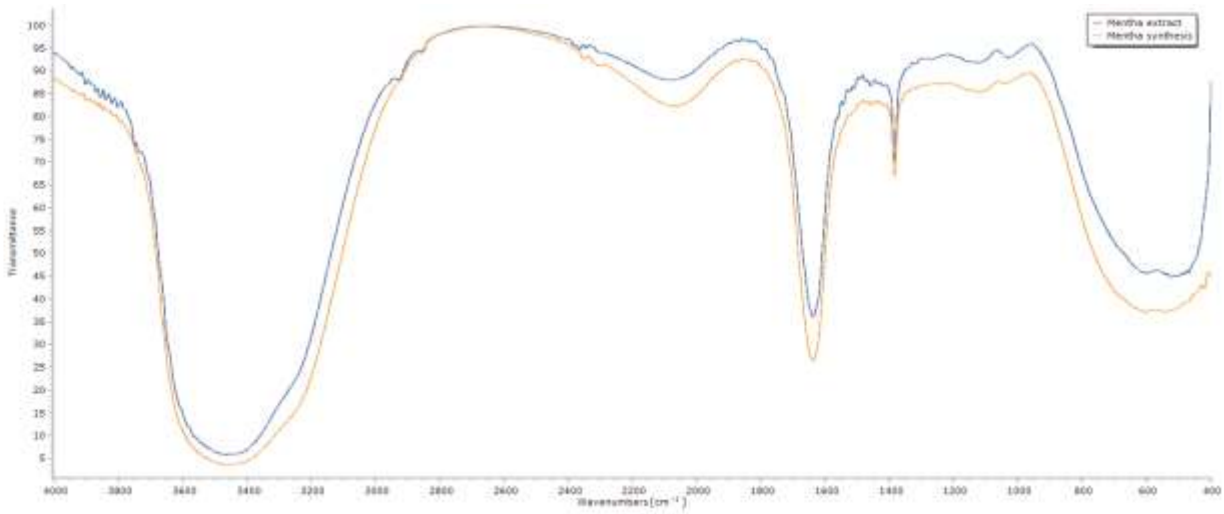

Figure.IV.6: IR spectrum on *Mentha Spicata*

The FTIR spectra compare *Mentha Spicata* extract and silver nanoparticles synthesized using it. We observe:

- Broad peak around 3300 cm^{-1} indicates O–H possibly of carboxylic acid group or phenolic or alcohol, suggesting their role in reducing and stabilizing AgNPs.
- Peaks near 2900 cm^{-1} show C–H bonds from organic compounds present in both samples.
- Shift near 1600 cm^{-1} suggests interaction of carbonyl or aromatic compounds with AgNPs.
- Bands around 1400–1000 cm^{-1} reflect involvement of C–N and C–O groups in nanoparticle formation.
- Changes in low-frequency region (<700 cm^{-1}) may indicate Ag–O or Ag–N bonding.

These changes confirm that *Mentha Spicata* extract contains active biomolecules responsible for reducing silver ions and stabilizing the nanoparticles.

IV.6.2. Artemisia Herba-Alba:

The FTIR spectra present two curves:

Blue Line: *Artemisia Herba-Alba* extract (before synthesis)

Orange Line: *Artemisia Herba-Alba* -mediated silver nanoparticle synthesis

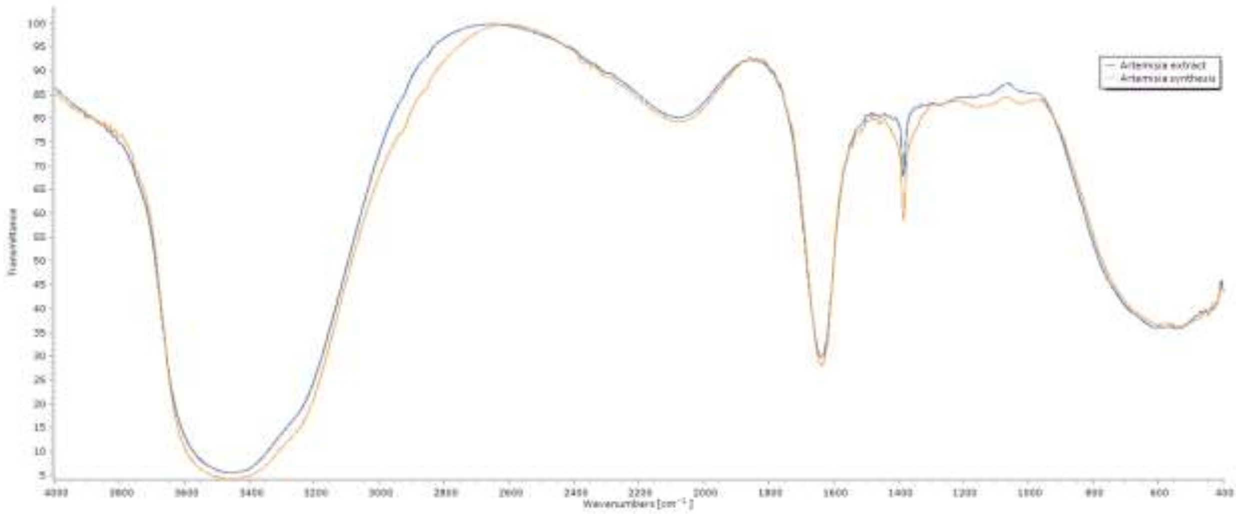

Figure.IV.7: IR spectrum on *Artemisia herba-alba*

We observed deferent types of peacks:

- Broad Peak around ~3400 cm^{-1}

Assignment: O–H stretching vibration of hydroxyl groups (–OH), possibly from polyphenols, alcohols, carboxylic acid or water content.

Observation: This peak is present in both spectra but slightly shifts and changes in intensity after synthesis, indicating the involvement of hydroxyl groups in the reduction/stabilization of Ag^+ to Ag^0 nanoparticles.

- ~2900–2850 cm^{-1}

Assignment: C–H stretching vibrations (aliphatic $–CH_2$ and $–CH_3$ groups).

Observation: Minor change after synthesis, indicating limited interaction with AgNP formation.

- ~1650 cm^{-1}

Assignment: C=O stretching of amide I or conjugated ketones, or possibly aromatic C=C stretching.

Observation: Noticeable decrease in intensity or shift suggests involvement of carbonyl or conjugated systems in nanoparticle formation.

- ~1400 cm^{-1}

Assignment: C–N stretching or O–H bending (phenolic compounds).

Observation: Shift and broadening indicate complexation or binding to silver nanoparticles.

- ~1050–1150 cm^{-1}

Assignment: C–O stretching vibrations (alcohols, ethers, esters).

Observation: Slight variation post-synthesis implies involvement of ether or alcohol groups in the capping process.

- Below 700 cm^{-1}

Assignment: Metal–O bonds (possibly Ag–O or Ag–N interactions).

Observation: Emergence or enhancement of peaks in this region after synthesis confirms the formation of AgNPs and their interaction with Artemisia phytochemicals.

IV.7. Conclusion

The FTIR analysis reveals that the bioactive compounds present in the Artemisia and mentha extract especially hydroxyl, carbonyl, and possibly amide groups—are actively involved in:

- Reducing Ag^{+} ions to metallic Ag^{0} nanoparticles.
- Stabilizing/capping the synthesized silver nanoparticles via functional group interactions.

These spectral changes (shifts, peak intensity differences, and appearance of new bands) confirm the successful green synthesis of silver nanoparticles using these two extracts.

Part 4:

IV.8. Detection Analysis of Silver Nanoparticles Synthesized via Green Methods (*Mentha Spicata* & *Artemisia Herba-Alba*):

IV.8.1 Objective:

To investigate the selective colorimetric response of green synthesized AgNPs (using *Mentha Spicata* and *Artemisia Herba-Alba* extracts) upon interaction with different amino acids to evaluate their potential as sensing agents.

IV.8.2. Materials Detected:

The Image shows vials labeled as follows:

- L-cysteine
- L-tyrosine
- L-lysine
- N-acetyl-L-cysteine
- L-arginine

Figure.IV.8: Colorimetric Detection of Various Amino Acids Using AgNPs Synthesized from *Mentha spicata* Extract

Figure.IV.9: Colorimetric Detection of Various Amino Acids Using AgNPs Synthesized from *Artemisia Herba-Alba* Extract

Each vial contains a mixture of silver nanoparticles and one amino acid, used to observe a potential visual colorimetric response indicative of a chemical interaction.

IV.8.3. Visual Observations and Interpretation:

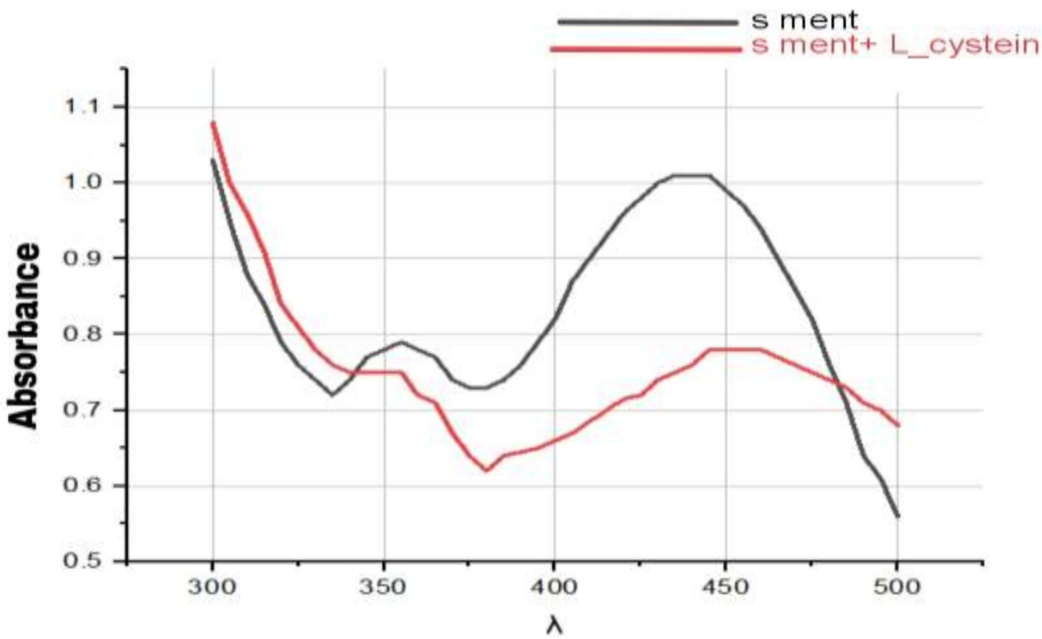

Figure.IV.10: UV sprectrum of *Mentha Spicata* with L-cysteine detection

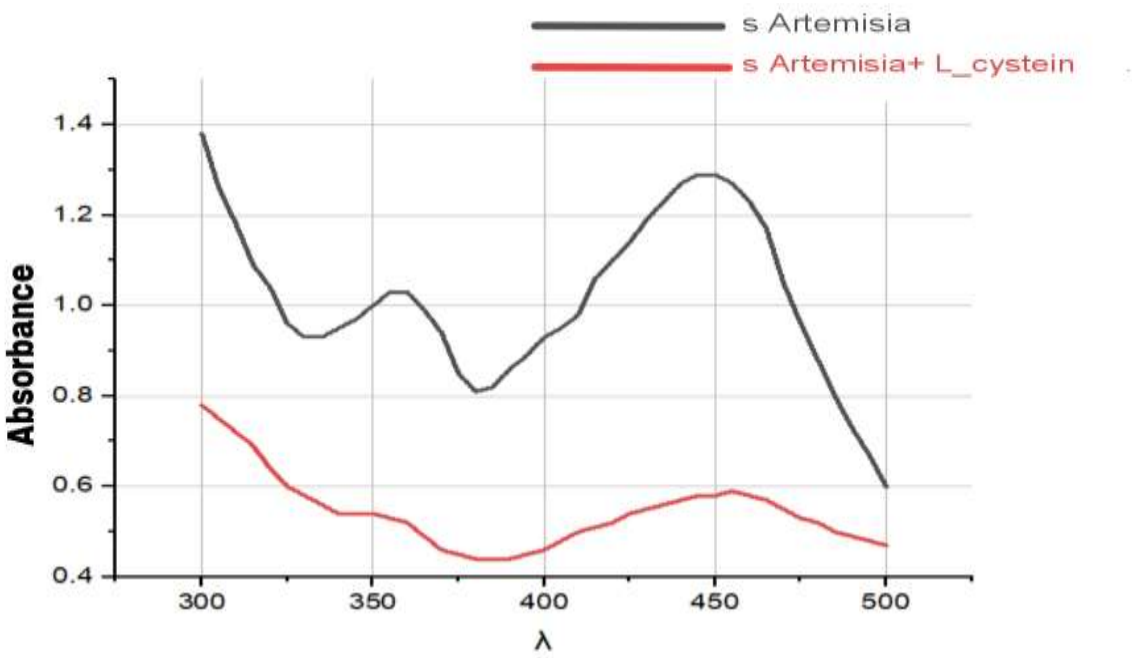

Figure.IV.11: UV sprectrum of *Artemisia herba-alba* with L-cysteine detection

- ***L-Cysteine (leftmost vial):***

Color: Slightly darker yellow to orange hue

Interpretation: L-cysteine contains a thiol (-SH) group that has a strong affinity for silver. This likely leads to a more significant interaction with the AgNPs, causing aggregation or surface modification, reflected by the distinct color change.

Conclusion: Positive detection. Strong Interaction due to the presence of sulfur

- ***L-Tyrosine:***

Color: Light yellow

Interpretation: Tyrosine has a phenolic hydroxyl group, whichh can interact with AgNP surfaces, but the interaction is weaker .compared to thiol-containing compounds

Conclusion: Moderate detection, indicating minor Interaction with AgNPs.

- ***L-Lysine:***

Color: Light yellow

Interpretation: Lysine has an amino group; whichh may interact electrostatically with AgNPs, but does not cause substantial color change

Conclusion: Weak detection. Minimal change Indicates weak or .no interaction

- ***N-Acetyl-L-Cysteine:***

Color: Slight yellow, comparable to lysine or tyrosine

Interpretation: The thiol group in cysteine is acetylated, reducing its binding capability to AgNPs. Hence, weaker .interaction than pure L-cysteine.

Conclusion: Low to moderate detection. Functionalization .reduces reactivity with AgNPs.

- ***L-Arginine:***

Color: Light yellow.

Interpretation: Arginine contains guanidinium and amino groups, which may interact with AgNPs weakly. No evident change suggests low affinity.

Conclusion: Minimal detection.

IV.9. Discussion:

IV.9.1. Mechanism of Detection:

The green-synthesized AgNPs (from Mentha and Artemisia) interact with biomolecules primarily through:

- Electrostatic attraction
- Hydrogen bonding
- Covalent binding (especially thiol-silver interaction)

The colorimetric change (i.e., visible color shift in solution) is due to SPR changes resulting from nanoparticle aggregation or surface modifications.

Sensitivity Hierarchy Based on Visual Response From strongest to weakest:

L-Cysteine > L-Tyrosine ≈ N-acetyl L-cysteine > L-Arginine ≈ L-Lysine

IV.10. Conclusion:

This experiment successfully demonstrates that green synthesized AgNPs—especially from Mentha and Artemisia— can act as selective sensors for specific biomolecules like L-cysteine, which exhibit distinct interactions due to the presence of functional groups such as thiols. Such detection systems are promising for biosensing applications, particularly in low-resource or eco-friendly contexts.

General conclusion

General conclusion

The work presented in this dissertation concerns the development of silver nanoparticles to replace the use of chemical reducers. To this end, we have chosen two medicinal plants, *Mentha Spicata* and *Artemisia Herba-Alba*, to implement the manufacture of nanoparticles with biological effects.

This study has explored the synthesis, characterization, and potential applications of silver nanoparticles (AgNPs) through an environmentally friendly approach using Mentha spicata and Artemisia herba-alba extracts. Through the combination of nanotechnology and green chemistry, we have demonstrated that plant-mediated synthesis offers a simple, cost-effective, and sustainable method to produce stable and biologically active nanoparticles.

In the first part of this work, we presented a comprehensive overview of nanomaterials, with a focus on the unique physicochemical properties and wide-ranging applications of silver nanoparticles. The limitations of conventional chemical and physical synthesis methods were highlighted, which paved the way for the adoption of green synthesis techniques using natural reducing agents found in plants.

The practical part of this research involved the successful biosynthesis of AgNPs using aqueous extracts of *Mentha* and *Artemisia*, followed by characterization using UV-Vis Spectrophotometry and qualitative visual changes. The appearance of a characteristic surface plasmon resonance (SPR) peak confirmed the formation of AgNPs. Experimental observations also indicated the impact of factors such as temperature, extract concentration, and reaction time on the size and stability of the synthesized particles.

Furthermore, selective colorimetric detection experiments demonstrated the responsiveness of AgNPs to specific biomolecules, suggesting potential applications in biosensing. The findings support the viability of plant-mediated synthesis as a sustainable alternative for nanoparticle production, with significant potential in antimicrobial applications, environmental monitoring, and nanomedicine.

In conclusion, this research not only affirms the effectiveness of green synthesis methods but also contributes to the growing body of knowledge on the integration of traditional herbal resources in modern nanotechnology. The results obtained open the door for further investigations into the biomedical and environmental applications of plant-derived AgNPs.

In the future, it would be desirable to compare the results of this approach to studying chemical and biological effects "in the mass" with a molecular approach that would target all fractionated major and minor constituents in order to study their biological activity individually.

عنوان المذكرة: التخليق الحيوي والتوصيف وتطبيقات الجسيمات النانوية الفضية في الكشف اللوني

اللقب : بيران **الاسم:** محمد أمين **المؤطر:** بوصوار إيمان

بن قطش ياسين

الملخص:

يهدف هذا العمل إلى توصيف الجسيمات النانوية الفضية المُخلقة بيولوجيًا انطلاقًا من مستخلصات النباتات الطبية النعناع و الشيح حيث استُخدمت هذه المستخلصات كمرجع لأيونات الفضة في وسط مائي.

تمت دراسة خصائص الجسيمات النانوية الفضية الناتجة باستخدام تقنيتي التحليل الطيفي بالأشعة فوق البنفسجية-المرئية و تحت الحمراء، واللتان أكدتا وجود وتفاعل الجسيمات النانوية الفضية على المستوى الجزيئي
وفي هذا البحث، تم تطوير حساس لوني بسيط وحساس للكشف عن الحمض الأميني ال-سيستئين باستخدام الجسيمات وقد أظهر هذا الحساس حساسية وانتقائية محسّنة مقارنة بالطرق البصرية التقليدية . النانوية الفضية

الكلمات المفتاحية: الجسيمات النانوية الفضية، التخليق الأخضر، النعناع، الشيح، الكشف اللوني، ال-سيستئين.

Titre : Biosynthèse, caractérisation et application des nanoparticules d'argent pour la détection colorimétrique

Nom : BIRANE **Prénom :** Mohamed Amine **Encadreur :** BOUSSOUAR Imene

BEN GUETTACHE Yacine

Résumé :

L'objectif de ce travail est de caractériser des nanoparticules d'argent bio synthétisées à partir d'extraits de des plantes médicales *Mentha Spicata* et *Artemisia Herba-Alba*, ces extraits sont utilisés comme référence pour les ions d'argent Ag^{+} en milieu aqueux. Les propriétés des nanoparticules d'argent résultantes ont été étudiées par les techniques de diagnostic spectroscopie UV-visible et infra rouge, qui a confirmé la présence et l'interaction moléculaire des nanoparticules d'argent. Dans cette étude, un capteur colorimétrique simple et sensible a été développé pour la détection de l'acide aminé L-Cystéine en utilisant des nanoparticules d'argent (AgNPs). Ce capteur présente une sensibilité et une sélectivité améliorées par rapport aux méthodes optiques conventionnelles.

Mots-clés : nanoparticules d'argent, synthèse verte, *Mentha Spicata, Artemisia Herba Alba* , détection colorimétrique, L-Cystéine.

Title: Biosynthesis, Characterization and Application of Silver Nanoparticles for Colorimetric Detection

Last name: BIRANE **First name:** Mohamed Amine **Supervisor:** BOUSSOUAR Imene
BEN GUETTACHE Yacine

Abstract:

The aim of this work is to characterize bio-synthesized silver nanoparticles from extracts of the medicinal plants *Mentha Spicata* and *Artemisia Herba-Alba*, which are used as a reference for Ag+ silver ions in aqueous media. The properties of the resulting silver nanoparticles were investigated using the UV-visible and infra red spectroscopy diagnostic technique, which confirmed the presence and molecular interaction of silver nanoparticles. In this study, a simple and sensitive colorimetric sensor was developed for the detection of the amino acid L-Cysteine using silver nanoparticles (AgNPs). This sensor offers improved sensitivity and selectivity over conventional optical methods.

Keywords: Silver nanoparticles, green synthesis, *Mentha Spicata*, *Artemisia Herba-Alba*, colorimetric detection, L-Cysteine.