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Unleashing the extract of silver nanoparticles from vegetable waste of *Solanum tuberosum* peels and *Coriandrum sativum* stems: Targeting antitumor, antioxidant and antimicrobial activity

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Abstract

Silver nanoparticles are an important innovation in nanotechnology, due to their high stability and low chemical reactivity in comparison to other metals having received much attention in biological application because of their unique physicochemical properties. The prospective uses of biosynthesized AgNPs in different fields, including antitumor, antioxidant, and antimicrobial activity. Even the nutrient rich vegetables are commonly wasted, despite their numerous useful applications. Utilizing vegetable waste to produce silver nanoparticles through green synthesis is an advantageous, economical, and environmentally friendly method for producing valuable products while addressing waste management concerns. The main emphasis of this study was to synthesize silver nanoparticles (AgNPs) by using vegetable waste from *Solanum tuberosum* (potato) and *Coriandrum sativum* (coriander). The utilization of plant extracts for the biogenic synthesis of nanoparticles has garnered attention because of their economical and environmentally friendly attributes, along with their potential for large scale production. Among the metallic nanoparticles, silver is highly efficient against various pathogens, biocompatible and easy to incorporate into medicinal applications. This investigation focuses on the use of potato peel extract and coriander stem for formation of silver nanoparticles.

Keywords: Silver nanoparticles (AgNPs); Coriander stem; Potato peels; Antitumor; Antioxidant; Antimicrobial; Vegetable waste

1. Introduction

1.1. Introduction of *Solanum tuberosum* [Potato]

The global use of potatoes is shifting from fresh consumption to processed forms, such as fries, chips, canned potatoes, mashed varieties, and ready-to-eat meals [1]. *Solanum tuberosum* L. (Solanaceae), commonly known as the potato, is currently the fourth most crucial staple food crop worldwide, following maize, wheat, and rice, with an annual production of 368 million tonnes [2]. Potatoes are highly nutritious, containing 22% carbohydrates, 2% protein, 0.1% fat, and 74% water, as well as essential minerals and trace elements like potassium, sodium, iodine, magnesium, folic acid, vitamin B6, vitamin C, and iron [3].

It is also known with different names in different languages (Table.1).

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Table 1 Different Vernacular Names of *Solanum tuberosum* L

Sr. No.	Name	Language
1	Aalu	Bengali
2	Batata	Gujarati
3	Alu	Hindi
4	Urulaikkilangnku	Tamil
5	Potato	English
6	Alugedde	Kannada

In addition to being one of the most widely eaten foods globally, potato waste like peels and damaged potatoes contains valuable compounds that can be used for biofuel or animal feed. Potatoes also have significant medicinal properties and can be consumed in various forms, including mashed, raw, boiled, or peeled. They contain phenolic compounds that help protect against microorganisms like bacteria, fungi, viruses, and insects. Potatoes are known for their strong anti-oxidant properties, with Russet potatoes being one of the top varieties in North America, ranking just below broccoli in antioxidant capacity. Potato peels are particularly rich in fiber, zinc, iron, calcium, potassium, and vitamins B and C. Overall, potatoes (*Solanum tuberosum*) are a great source of bioactive compounds, including starch, crude fiber, vitamins, amino acids, and minerals, along with many natural anti-oxidants [4]. The phenolics and amino acids in potatoes help protect against tissue damage, reactive oxygen species, and diseases like atherosclerosis, diabetes, kidney failure, and cancer [5]. Research shows that the highest concentration of bioactive compounds is found in the leaves, rather than in the stems and roots [6]. Potato peels contain phenolic acids, with chlorogenic acid (CGA) being the most abundant. Other phenolics, such as caffeic acid (CFA), gallic acid (GAC), and protocatechuic acid (PCA), are present in smaller amounts in potato peels [7].

Figure 1 Potato Peels

Figure 2 Potato

1.2. Historical Background

Potato is originally a native of South American continent, where it used to grow as a wild plant right from about 7000 to 9000 years ago. Historical evidences suggest the potato was a well-established garden crop in Surat and Karnataka as early as in 1675. Potato cultivation was introduced in the Simla (now Shimla) hills in 1828 and in Nilgiri hills in 1830. By late 18th or early 19th century, the potato was an important established vegetable crop in the hills and plains of India. However, till that time, potato cultivation in the country remained restricted and the entire Indian subcontinent contributed only less than 1% of world's potato area and production up till 1941. The primary reason for this slow growth in potato development in India was unsuitability of long day conditioned potato varieties (bred in Europe and other temperate countries) under short day Indian conditions [8].

1.3. Biological Background

Potato plants are herbaceous perennials that can grow up to 1 meter (3.3 feet) tall, with hairy stems. Their leaves typically have about four pairs of leaflets. The flowers can be white, pink, blue or purple, with yellow centers, and are pollinated by insects. The plants produce tubers to store nutrients; these are actually thickened stems that develop from rhizomes at the ends of long, thin stolons, not roots. The surface of the tubers has eyes, which are protective vegetative buds from which new stems grow, arranged in a spiral pattern. Additionally, the tubers have small breathing holes called lenticels, which are circular and vary in number based on the size of the tuber and environmental conditions. Tubers typically form in response to shorter day lengths, although this trait has been reduced in commercial varieties [11].

After flowering, potato plants produce small green fruits that look like green cherry tomatoes. Each fruit contains around 300 tiny seeds [12].

Table 2 Scientific Classification of *Solanum tuberosum*

Scientific Classification	
Kingdom	Plantae (plants)
Division	Tracheophyta
Class	Magnoliopsida (dicotyledons)
Order	Solanales
Family	Solanaceae
Genus	*Solanum L.*
Species	*Solanum tuberosum L.*

Table 3 Nutritional Composition of Raw Potato (per 100 g) [13]

Nutrients	**FW**	**DW**	**Bioactive Compounds**	**FW**	**DW**
Moisture	72–85 g	305–360 g	Phenolic compounds	137–965 mg	596–4196 mg
Carbohydrates	13–18 g	55–79 g	Phenolic acids	58–303 mg	252–1319 mg
Dietary fibre	1.0–2.0 g	4.3–8.7 g	Flavonoids	0.03–0.06 mg	0.13–0.26 mg
Protein	0.6–2.1 g	2.6–9.1 g	Anthocyanins	58–542 mg	253–2357 mg
Lipid	0.1–0.2g	0.3–0.9 g	Vitamin C	5–54 mg	20–235 mg
Potassium	280–564 mg	1217–2452 mg	Vitamin E	0.02–0.1 mg	0.07–0.4 mg
Phosphorus	30–60 mg	130–261 mg	Carotenoids	0.1–5.8 mg	0.2–23.3 mg
Magnesium	14–18 mg	61–78 mg	Glycoalkaloids	1–20 mg	4–87 mg

1.4. Uses and Effectiveness

Possibly Ineffective for

- Cancer.
- Colon cancer, rectal cancer.
- Heart attack.
- Stroke.

Insufficient Evidence for

- Heart disease.
- Indigestion (dyspepsia).
- High blood pressure.
- Boils.
- Burns.
- Infections.
- Obesity.
- Osteoarthritis.
- Other conditions. [14]

1.5. Introduction of *Coriandrum sativum*

Coriandrum sativum Linn. (C. sativum), commonly known as coriander, is well-known for its diverse uses in cooking and traditional medicine for various health conditions [15]. Each part of the plant roots, leaves, fruits, and seeds contains different chemical compounds that contribute to its many applications [16]. Some of these compounds include gallic acid, thymol, and bornyl acetate, which are believed to have anti-cancer, anti-inflammatory, and relaxation-inducing effects, respectively [17]. Linalool, a terpene alcohol in coriander, is particularly noted for its therapeutic properties, offering neuroprotective, anxiolytic, anti-convulsant, and analgesic effects [18].

Phytochemicals found in *C. sativum* (coriander), including flavonoids, phenolic acids, phytosterols, and terpenes, have considerable potential for cardiovascular health. They have shown the ability to inhibit angiotensin-converting enzyme (ACE) and possess cardioprotective, antihyperlipidemic, and properties that may help prevent cardiometabolic disorders [19].

Figure 3 Coriander

Table 4 Common Indians Names

Language	Name
Bengali	Dhane, Dhania
Gujarati	Kothmiri, Konphir, Libdhane
Kashmiri	Daniwal, Kothambalari
Marathi	Khana, Kothimber
Punjabi	Dhania
Tamil	Kothamali
Telugu	Dhaniyal

1.6. Historical Background

Archaeological evidence suggests that coriander seeds were used as early as 5000 BCE. Coriander originated in the Mediterranean and the Middle East and grows wild in Egypt and Sudan. The ancient Egyptians valued coriander highly, using it both in cooking and in religious rituals. It was one of the earliest flavors used by humans and has been cultivated for centuries. In ancient Greece and Rome, coriander was used not only as a culinary herb but also as a medicinal plant. It is mainly grown in tropical regions and countries such as Morocco, Romania, Bulgaria, France, Spain, Italy, the Netherlands, Myanmar, Pakistan, Turkey, Mexico, Canada, Argentina, Australia, and parts of the U.K. and the U.S.A [20]. India is the world's largest coriander producer, with major cultivation in Andhra Pradesh, Rajasthan, and Tamil Nadu. It plays a central role in traditional dishes from a wide range of cultures, and it remains a key ingredient in many spice blends, including curry powder and garam masala [21].

1.7. Biological Background

Coriandrum sativum, commonly known as coriander or "dhaniya," belongs to the Apiaceae family. This annual herb is native to the Mediterranean and Middle Eastern regions and is cultivated worldwide for both its seeds and fresh leaves. The plant has a taproot system and an upright, hollow stem that reaches between 20 and 120 cm in height. Its leaves are green and vary in shape the lower leaves are broader and lobed, while the upper leaves are more finely divided and feathery. After 45–60 days from sowing, *Coriandrum sativum* begins to flower [22]. Its leaves are green and lance-shaped. Its producing small clusters of white or light pink flowers arranged in umbels. These flowers have an asymmetrical structure with petals that face outward from the center. The fruit, commonly known as the coriander seed, is a small, round, dry schizocarp that splits into two mericarps when mature. The plant’s smooth, pale green stems and aromatic qualities make it valuable in both culinary and medicinal applications across diverse cultures. [23].

Table 5 Scientific Classification of *Coriandrum sativum*

Scientific Classification	
Kingdom	Plantae
Division	Tracheophyta
Class	Magnoliopsida
Order	Apiales
Family	Apiaceae
Genus	Coriandrum L.
Species	*Coriandrum sativum* L.

Table 6 Nutritional Composition of *Coriandrum sativum* stem per 100g [24]

Composition	**USDA**
Water	7.3 g
Food energy (kcal)	279.00 g
Protein	21.83 g
Fat	4.76 g
Carbohydrates	52.10 g
Ash	14.02 g
Calcium	1.24 g
Phosphorus	481.00 (mg)
Sodium	211.00 (mg)
Potassium	4.466 (mg)

Iron	42.46 (mg)
Vit – C	566.7 (mg)

1.8. Uses and Benefits

- Constipation.
- Irritable bowel syndrome (IBS)
- Anxiety.
- Bacterial or fungal infections.
- Diabetes.
- Joint pain and swelling.
- Nausea and diarrhea.
- Stomach upset.
- Nausea.
- Other conditions:
    - Prevents Anemia
    - Prevents Arthritis
    - Treats Wounds & Mouth Ulcers
    - Rich Source of Calcium
    - Reduces Skin Inflammation
    - Controls Blood Pressure
    - Diuretic Properties [25]

1.9. Introduction to Nanoparticles

Nanotechnology involves creating, designing, and manipulating materials at the nanoscale to give them unique properties for various applications [26]. Metal nanoparticles (MNPs) like silver, copper, and zinc have gained significant attention as a new type of nanoparticle. Among them, silver nanoparticles (AgNPs) are especially popular for their properties, making them useful in areas like composite fibers, biosensors, pollution cleanup, wastewater treatment, food packaging, storage containers, cosmetics, and water purifiers [27,28]. Nanoparticles (NPs) are tiny particles, typically between 1 and 100 nano-meters in size. Their unique magnetic, optical, chemical, electrical, physical, and biological properties make them more effective than larger, bulk materials [29]. Working with materials at the nanoscale allows scientists to change qualities like permeability, melting and boiling points, solubility, and shelf life. Because of their small size, NPs have a large surface area, which enhances their chemical and physical properties and produces quantum effects that are easy to observe [30].

1.10. Introduction of silver nanoparticles (AgNPs)

AgNPs are an important innovation in nanotechnology. AgNPs are a significant naturally occurring noble metal that possesses a variety of physical, chemical and biological properties, including electrical conductivity, high thermal behavior, optical properties, nonlinear catalytic activity and biochemical characteristics. These properties are necessary to maximize the potential applications of AgNPs in various fields while minimizing their risks to humans and the environment [31]. AgNPs a suitable candidate for multiple applications such as textiles, electronics, optical receptors antiseptic agent, healthcare medicines, food packaging, food preservation, water disinfectants, larvicidal potential, anti-cancer potential, surgical instruments, biolabeling, and drug delivery applications [32]. AgNPs have been used in diverse healthcare products such as wound care products, antimicrobial dressing or bandages, breathing tubes and catheters. AgNPs have good potential to be also used as anti-tumor agents to treat human lung cancer cells. Furthermore, AgNPs have good optical properties like Surface Plasmon Resonance (SPR), which makes nano-silver suitable for use in imaging, drug administration, diagnostics, and biosensors [33]. AgNPs are widely used as an ingredient in a wide range of consumer products, including pastes, soaps, and cosmetics. AgNPs are also used in electronics products including high conductive pathways, transistors, photonic and antireflective materials and optical fibers because of their very low electrical resistance and greater stability [34]. The biomedical use of AgNPs includes its use as antitumor, antioxidant, antimicrobial, anti-inflammatory [35] antiviral [36] and anti-diabetic agent [37].

1.11. Graphical extract

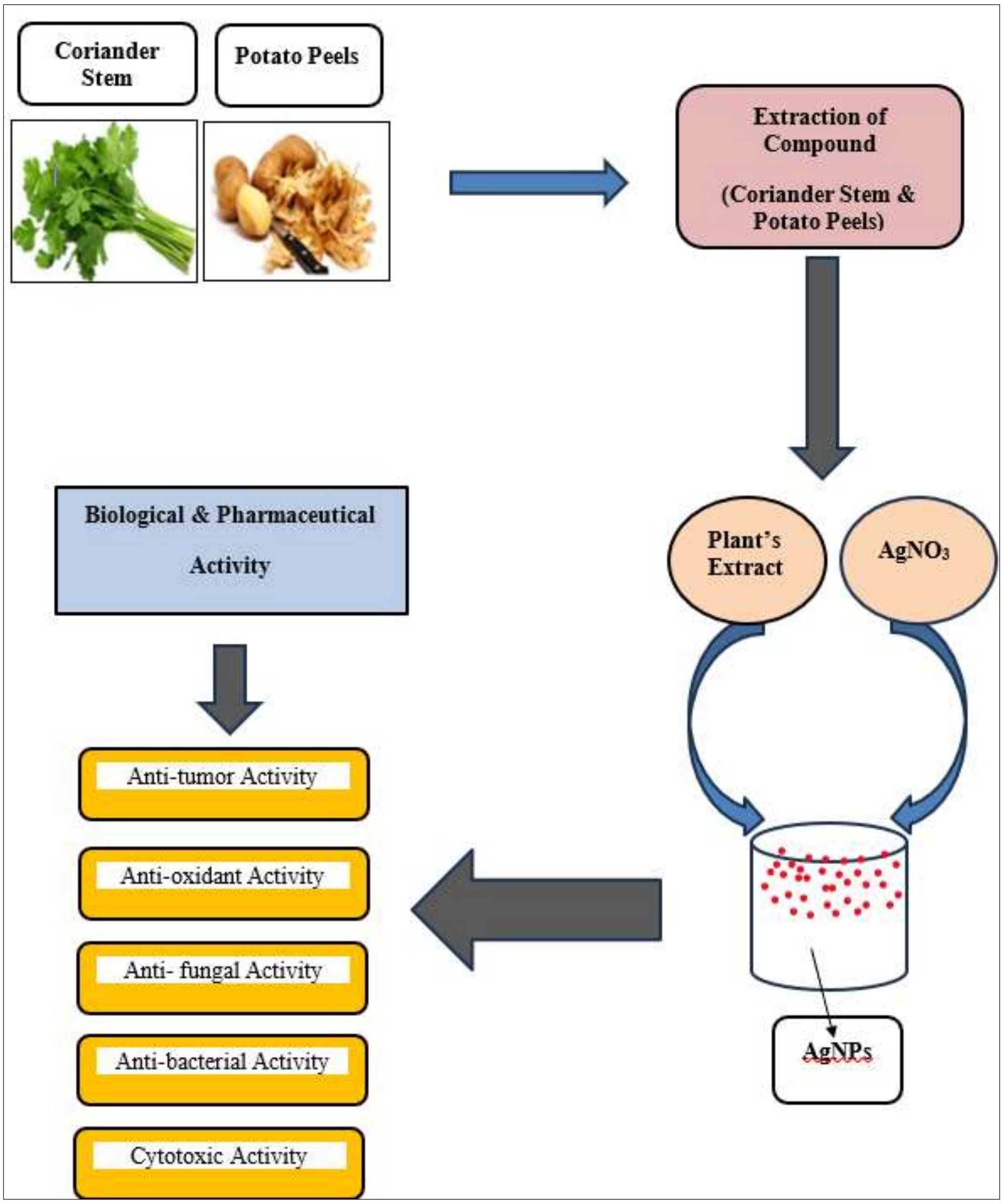

Figure 4 Graphical extract of AgNPs

2. Materials and methods

2.1. Collection of Plant Samples

Potato peels and coriander stems were collected from kitchen vegetable waste. The collected samples underwent meticulous processing: Separation and cleaning to eliminate dirt and impurities then drying in a shaded area to prevent moisture retention. Grinding the dehydrated samples into a fine powder using a mortar and pestle. The powdered potato peels and coriander stems were stored separately for future analysis and utilization.

2.2. Plant Extraction Protocol

The dried potato peels (*Solanum tuberosum*) and coriander stems (*Coriandrum sativum*) were utilized to prepare aqueous extracts.

Extraction Procedure: 60 g of powdered plant material (potato peels and coriander stems) was mixed with 100 mL of distilled water. The mixture was allowed to left at room temperature (23-27 °C) for 72 hours (3 days). This aqueous extraction method facilitated the dissolution of bioactive compounds from the plant materials, yielding potent extracts for further analysis.

2.3. Extraction and Purification Procedure

The plant material was subjected to ultra-sonication in an ultrasonic bath for 30 minutes at 23-27 °C to efficiently extract bioactive compounds. The resulting extracts underwent repeated filtration (twice) using Whatman filter No. 1 paper to remove impurities. The combined filtrates were concentrated through evaporation using a vacuum rotary evaporator. Lastly, the concentrated extracts were dried using a vacuum dryer set at 45 °C for the final crude extracts. This optimized extraction process ensured maximum recovery of bioactive compounds from the plant material, yielding high-quality crude extracts for further analysis and application.

2.4. Synthesis of Silver Nanoparticles (AgNPs)

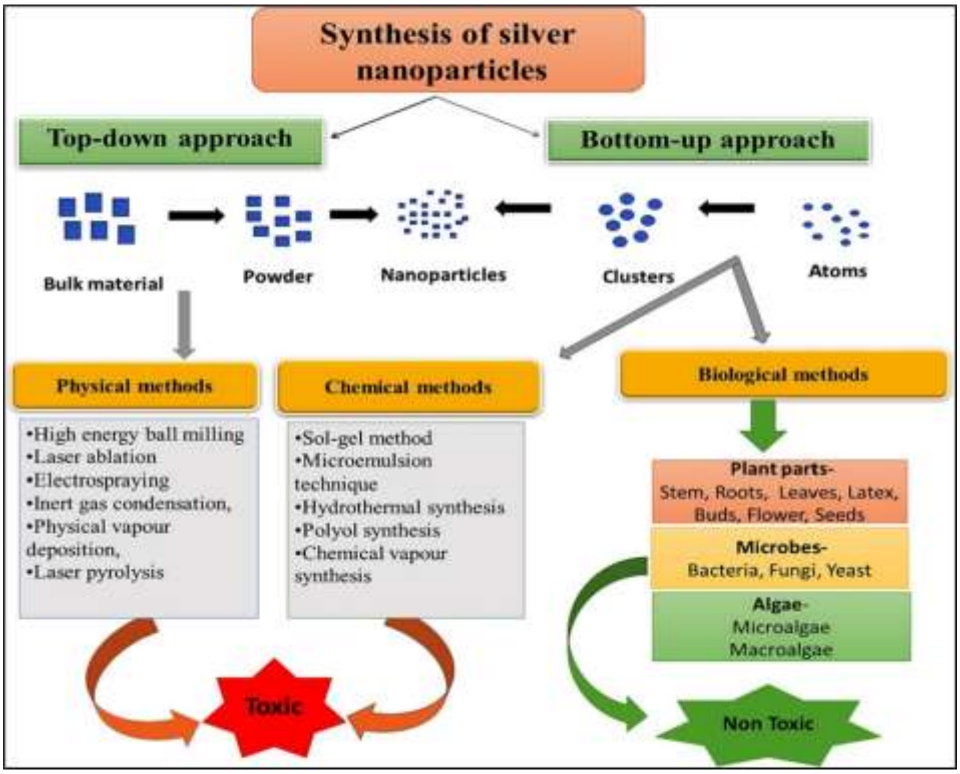

Figure 5 Methods used for synthesis of Nanoparticles

A green synthesis approach utilized potato peels and coriander stem extracts to synthesize AgNPs.

Procedure: 10 mL of extract was combined with 1 mM silver nitrate (AgNO3) solution. Mixtures were kept in the dark for 24 hours to prevent photochemical activation. A distinct color shift indicated successful AgNPs synthesis. Extracts were spread thinly on Petri plates and dried at 60°C overnight. Resulting dried powder was used for characterization.

This eco-friendly synthesis method leveraged plant extracts as reducing agents, yielding AgNPs for further analysis [38].

3. Pharmacological activity

3.1. Antitumor Activity

Cancer is a group of diseases, generating various pathological and metabolic changes in cellular environments. It is developed through diverse signaling mechanisms including cell proliferation, angiogenesis, and metastasis. Cancer cells have abnormal metabolic activities in aerobic glycolysis, mitochondrial DNA depletion, and alterations in respiratory chains and genomic expressions. The physical and chemical treatments of cancer are limited at different stages.

However, currently available therapies have an adverse effect and affect normal cell functions while giving excess drug and radiation exposures. Moreover, the genotoxicity of AgNPs is supported by the generation of double stranded DNA breaks along with chromosomal instability that drives the initiation of apoptotic execution. This acting mechanism implies that AgNPs can be mutually associated with a great many DNA-targeting anticancer drugs [39].

Silver nanoparticles (AgNPs) have been extensively studied for their potential anti-tumor activity, and several mechanisms of action have been proposed.

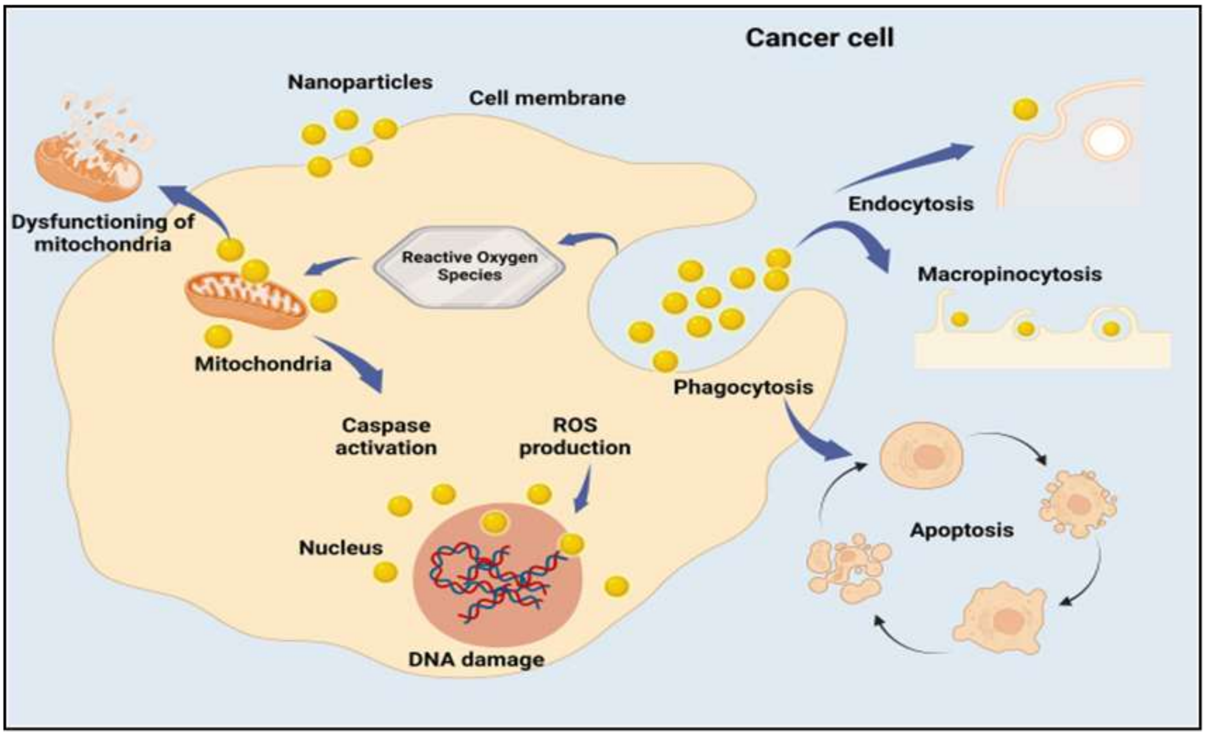

Figure 6 Mechanism of Antitumor Activity

3.1.1. Mechanism of Antitumor Activity:

- Oxidative Stress and Reactive Oxygen Species (ROS) Production: AgNPs can generate ROS, which damages cellular components, including DNA, proteins, and lipids, leading to cancer cell death.
- DNA Damage and Apoptosis: AgNPs can induce DNA damage, activate pro-apoptotic proteins and inhibit anti-apoptotic proteins, triggering programmed cell death.
- Anti-Angiogenic Effects: AgNPs can inhibit angiogenesis (formation of new blood vessels) by reducing vascular endothelial growth factor (VEGF) expression, thereby starving tumors of oxygen and nutrients.
- Disruption of Mitochondrial Function: AgNPs can disrupt mitochondrial membrane potential, leading to ATP depletion, and initiating apoptosis.
- Cell Membrane Distruction: AgNPs disrupt cell membrane by endocytosis process.

3.2. Antioxidant Activity

Anti-oxidants represent a form of opposition to oxidants. Antioxidants are natural or synthetic substances that may prevent or delay damage of cell caused by oxidants (ROS, RNS, free radicals, other unstable molecules). In order for the substance to be considered as an anti-oxidant, it must be active at low concentration (phenolic anti-oxidants often loose activity at high concentration and act as pro-oxidant), its amount needs to be satisfactory high to deactivate the target molecule, it must react with oxygen or nitrogen free radicals, and the final product of the reaction should be less toxic than removed radical. There is no universal antioxidant, as different antioxidants react with different reactive species by various mechanisms, at various locations and protect specific molecular targets [40]. Silver nanoparticles (AgNPs) have gained significant attention for their potential as antioxidant agents due to their unique properties. Here's a detailed explanation of the mechanism of action of AgNPs as antioxidant agents:

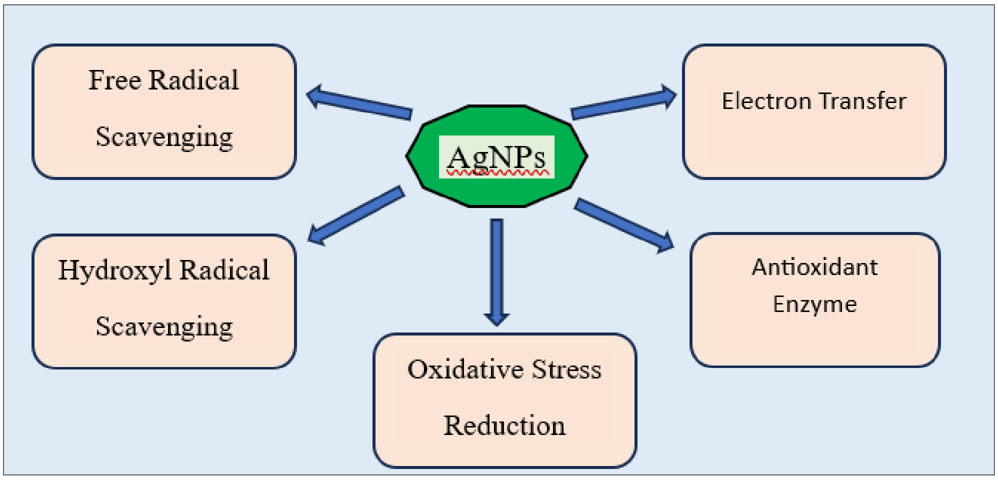

Figure 7 Mechanism of Antioxidant Activity

3.2.1. Mechanisms of Antioxidant Activity:

- Free Radical Scavenging: AgNPs can neutralize free radicals, such as reactive oxygen species (ROS), by donating electrons. This process terminates the free radical chain reaction, thereby preventing oxidative damage.
- Electron Transfer: AgNPs can transfer electrons to ROS, reducing their reactivity and preventing oxidative stress.
- Hydroxyl Radical Scavenging: AgNPs can specifically scavenge hydroxyl radicals (•OH), which are highly reactive and damaging to biomolecules.
- Anti-oxidant Enzyme Mimicry: AgNPs can mimic the activity of anti-oxidant enzymes, such as superoxide dismutase (SOD), catalase, and glutathione peroxidase.
- Oxidative Stress Reduction: AgNPs can reduce oxidative stress by decreasing the levels of lipid peroxidation, protein oxidation, and DNA damage.

3.3. Antimicrobial Activity

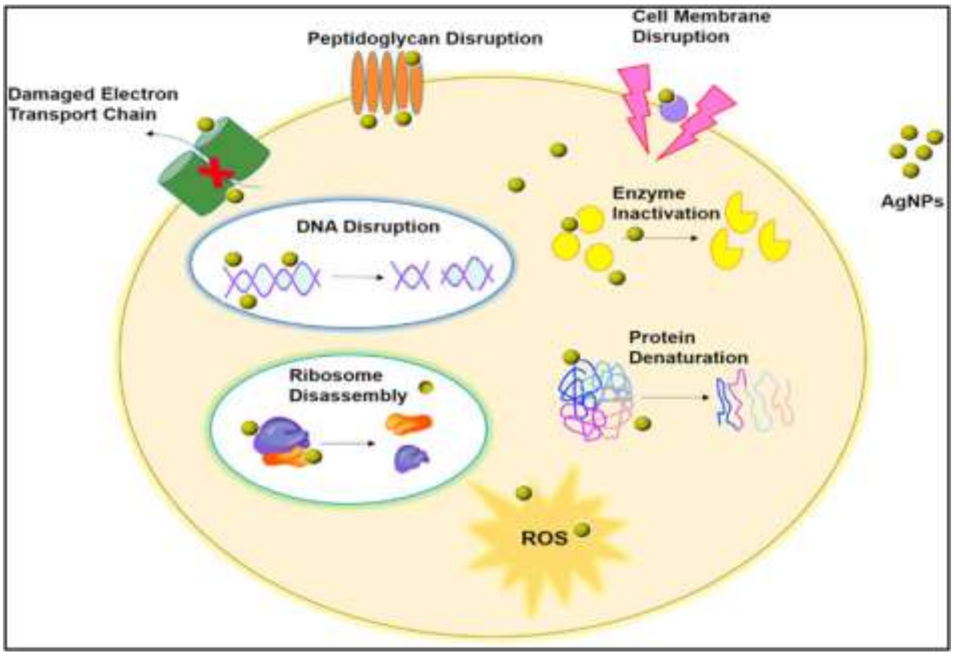

Figure 8 Mechanism of Antimicrobial Activity

The increasing use of NPs in medicine has led to a growing number of studies exploring potential antimicobial mechanisms of NPs. For example, metal NPs (silver nanoparticles) can change the metabolic activity of bacteria. This capacity represents a huge advantage in terms of eliminating bacteria to cure diseases. The ability of NPs to enter biofilms also provides a practical method to inhibit biofilm formation based on the Ag-inhibited expression of genes. NPs need to be in contact with bacterial cells to achieve their anti-bacterial function. NPs then cross the bacterial membrane and gather along the metabolic pathway, influencing the shape and function of the cell membrane. Thereafter, NPs interact with the bacterial cell's basic components, such as DNA, lysosomes, ribosomes, and enzymes, leading to oxidative stress, changes in cell membrane permeability, enzyme inhibition, protein deactivation, and changes in gene expression [41]. Silver nanoparticles (AgNPs) have gained significant attention as potent anti-microbial agents due to their broad-spectrum efficacy against various microorganisms, including bacteria, viruses, and fungi. The mechanism of action of AgNPs as anti-microbial agents involves multiple pathways, which are summarized below.

3.3.1. Mechanisms of Antimicrobial Activity

- Cell Membrane Disruption: AgNPs interact with the bacterial cell membrane, causing disruption and damage, leading to changes in membrane permeability and eventual cell lysis.
- Oxidative Stress (ROS): AgNPs generate reactive oxygen species (ROS), which damage cellular components, including DNA, proteins, and lipids, ultimately leading to cell death.
- DNA Disruption: AgNPs bind to bacterial DNA, inhibiting replication and transcription, and causing mutations.
- Protein Denaturation: AgNPs interact with essential proteins, causing denaturation and loss of function.
- Ribosome Disassembly: AgNPs inhibit nutrient uptake, starving the microorganism.
- Damage Electron Transport Chain: AgNPs interfere with bacterial signaling pathways, disrupting normal cellular processes.
- Peptidoglycan Disruption: AgNPs penetrate in the peptidoglycan layer causing structural changes and disruption.
- Enzyme Inactivation: AgNPs interact with thiols group of proteins, which deactivate their enzymatic function.

4. Conclusion

This study presents a simple and eco-friendly method for producing silver nanoparticles using vegetable waste extracts. This approach is efficient, cost-effective, and sustainable, making it an attractive alternative to traditional methods. Using potato peels and coriander stems, we successfully synthesized silver nanoparticles with unique properties, including anti-tumor, anti-microbial and anti-oxidant activities. These nanoparticles were crystalline, spherical, and agglomerated, with sizes ranging from 65-70 nm. Our findings suggest that these green-synthesized silver nanoparticles offer a low-cost, safe, and non-hazardous solution for various therapeutic applications. This study highlights the potential of using vegetable waste extracts as a sustainable raw material for nanoparticle synthesis, aligning with the growing demand for eco-friendly alternatives in the pharmaceutical industry. Overall, our approach opens new avenues for utilizing vegetable waste extracts in nanoparticle synthesis, providing the way for the development of multifunctional nanoparticles for various medical applications.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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