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COLLOIDAL SILVER NANOPARTICLES STABILIZED WITH CALLISIA REPENS PLANT EXTRACT IN DEVELOPMENT OF NEW FORMULATION FOR BURN AND WOUND INFECTION

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Abstract:
Nanotechnology has been widely studied for its use in creating colloidal silver nanoparticles (AgNPs), which have gained considerable interest for their exceptional antibacterial and anti-inflammatory effects. Silver nanoparticles (AgNPs) are synthesised by a range of processes, including physical, chemical, and biological procedures. Out of these methods, the green synthesis technique has become popular since it uses plant extracts and has advantages such as being environmentally friendly, cost-effective, and capable of producing nanoparticles that are very stable and biologically active. The Rhodiolarosea plant, renowned for its medicinal benefits, is an exceptional resource for the environmentally friendly production of silver nanoparticles (AgNPs). These nanoparticles have strong anti-inflammatory properties, making them excellent candidates for the treatment of disorders like burn wounds, where inflammation and infection are significant issues. The compact dimensions and expansive surface area of AgNPs enable them to easily infiltrate microbial cells, hence augmenting their antibacterial potency and diminishing inflammation. Moreover, the bioactive constituents included in Rhodiolarosea extract enhance the stability and efficacy of the synthesised nanoparticles. Characterisation methods, including UV-Vis spectroscopy, TEM, SEM, and XRD, provide evidence of the effective synthesis and favourable characteristics of AgNPs. Preclinical studies have showed encouraging results in the use of AgNPs integrated into ointments for treating burn wounds. These studies have shown a substantial decrease in inflammation and improved wound healing. Further investigation and refinement of eco-friendly synthesis techniques for AgNPs have significant prospects in the development of cutting-edge, secure, and efficient therapeutic agents in the healthcare sector.

Keywords: Colloidal silver nanoparticles, Synthesis of nanoparticles, Green synthesis, Application

Introduction:

The use of nanotechnology in research and development departments for the creation of nanoscale goods is increasing. Nanotechnology has the capability to manufacture a wide variety of items that may be employed in a diverse range of scientific fields. The phrases "creation," "exploitation," and "synthesis" are often used in the context of nanotechnology, which primarily deals with materials that have dimensions smaller than 1 mm. The term "Nano" is derived from the Greek word "nanos", which translates to "dwarf, tiny, or very small". Nanotechnologies are often categorised into three groups: wet, dry, and computational. Aquatic nanotechnology is linked to biological entities such as enzymes, tissues, membranes, and other cellular constituents. Dry nanotechnology is closely linked to the field of physical chemistry and is mostly focused on the manufacturing of inorganic materials, such as silicon and carbon [1]. Computational nanotechnology involves the use of computer simulations to study structures that are on the scale of nanometres. The ideal functioning of these three aspects (wet, dry, and computational) is interdependent, as seen in Figure 1. Nanotechnology facilitates cooperation by providing a platform for numerous sectors, including electronics, pesticides, medicine, and parasitology. Nanobiotechnology is an illustrative instance where the investigation and advancement integrate many scientific domains, such as nanotechnology, biotechnology, material science, physics, and chemistry [2]

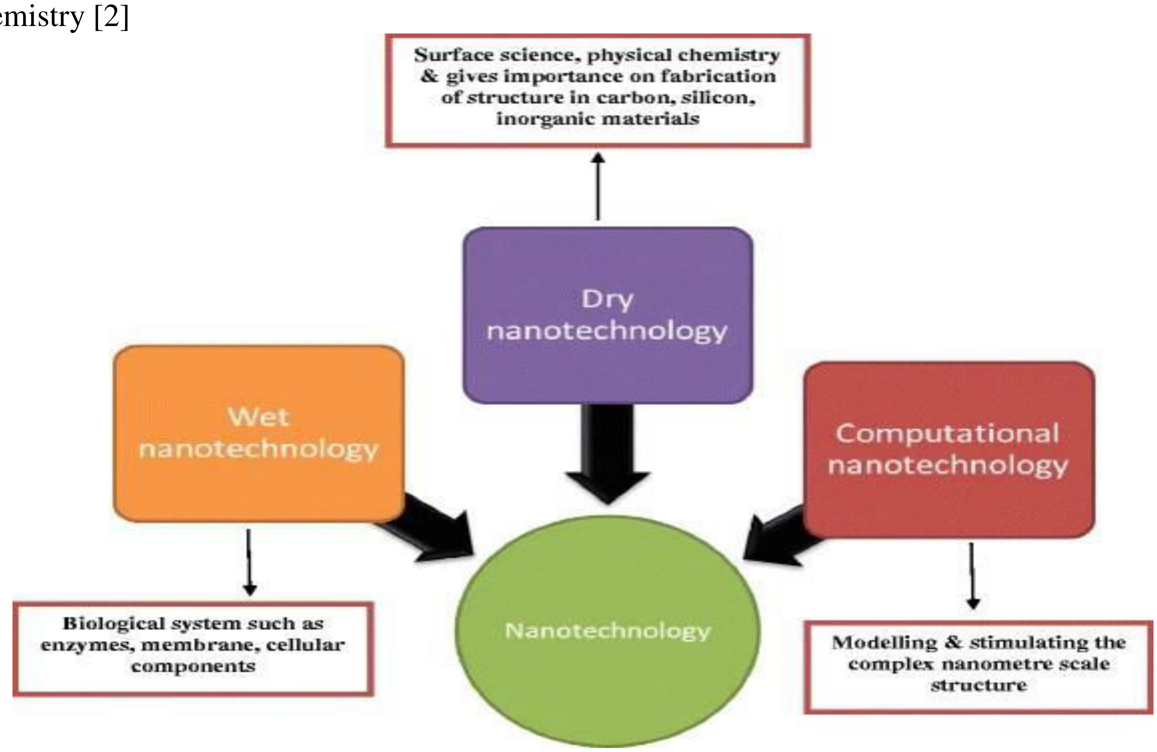

Figure 1: Different type of nanotechnology

Potential exists for the creation of nanoparticles via the cooperation of several natural science fields, which possess antibacterial, antioxidant, and anticancer characteristics. Nanotechnologies have the potential to provide innovative tools for assessing and creating more advanced, secure, and efficient medication compositions [3].

Burn damage is a prominent public health issue since it causes serious harm to the patient and leads to higher expenses for dressing, medicine, and surgery. Burn wounds may be categorised into four degrees based on the extent of tissue damage. Third or fourth-degree burn injuries are classified as serious and need prompt surgical intervention. An additional significant consequence of burn injuries is wound infection, which is recognised as a primary factor contributing to death. The traditional approach to wound healing is the transplantation of healthy tissue as replacements for the damaged skin at the injury site. Nevertheless, the scarcity of donor sites, the elevated danger of infection, and the inclination for scarring and contraction have sparked an increasing interest in investigating therapeutic substances that possess antibacterial and anti-inflammatory effects [4].

Silver nanoparticles (AgNPs) are renowned for their broad spectrum of activity against microorganisms, their ability to inhibit malignant cell growth, and their capacity to reduce inflammation. The antibacterial activity of the substance is primarily attributed to its tiny size, large surface area, and rapid dispersion rate. These characteristics enable it to effectively penetrate microbial cells and have a long-lasting influence. The production of nanoparticles may be classified into physical, chemical, and biological techniques [5]. The biological technique has many advantages over conventional physical and chemical procedures. It is non-toxic, cost-effective, ecologically friendly, and utilises natural capping and reducing agents. The biological approach utilises bacteria, fungus, algae, or plants to produce nanoparticles. The use of plants has garnered significant interest owing to their lack of reliance on the maintenance and cultivation of microbes. Moreover, the plant species possess unique bioactive chemicals. The production of nanoparticles using plants may include using extracts derived from various plant parts such as flowers, stems, leaves, peels, latex, or roots [6]. Furthermore, secondary plant metabolites with antioxidant properties may be better suited for use in the biomedical domain. Medicinal plants include abundant amounts of polyphenols, flavonoids, tannins, coumarins, alkaloids, and other compounds. These bioactive substances have been shown to decrease and maintain the stability of nanoparticles. AgNPs synthesis using medicinal plants, including Caryaillinoinensis, Carduuscrispus, Lysilomaacapulcensis, Caesalpiniapulcherrima, Piper chaba, Menthaaquatica, Carallumatuberculata, Aeglemarmelos, Nigella sativa, Annonamuricata, Brillantaisiapatula, Crossopteryxfebrifuga, and Sennasiamea, has been documented in various reports. The process of plant-assisted nanoparticle synthesis begins with the reduction of metal ions from their bivalent state to a zerovalent state, facilitated by the presence of metal salts and plant extract [7]. The nanoparticles are created by the merging of the metal atoms that have been reduced. This work involves the synthesis of silver nanoparticles (AgNP) using an extract derived from the roots of Rhodiolarosea. Rhodiolarosea, often referred to as golden root, belongs to the Crassulaceae plant family, which is renowned for its therapeutic qualities [8]. Rhodiolarosea has several therapeutic properties including anti-diabetic, anti-cancer, anti-aging, cardio-protective, and neuroprotective action. This herb has been used in traditional Asian medicine. The study focused on examining the biologically active substances found in Rhodiolarosea, including alkanols, benzyl, phenols, phenylethanes, gallic acid, phenylpropanoids, flavonoids, monoterpenoids, triterpenes, and others. The objective of this work was to create an ointment using AgNPs and examine its impact on a mouse model with burn wounds. Initially, we created silver nanoparticles (AgNP) using Rhodiolarosea and then analysed many characteristics of the nanoparticles, including their synthesis rate, yield, stability, crystallite size, and shape. Subsequently, we assessed the antibacterial and antioxidant efficacy of AgNP. Ultimately, we developed an ointment containing AgNPs and examined its ability to reduce inflammation in a mouse model with burn wounds [9].

Method used in colloidal nanoparticles synthesis:

Nanoparticles, with distinctive characteristics as a result of their dimensions, dispersion, and structure, are essential constituents of nanotechnology. In the late 1970s, R.O. Becker et al. used silver particles as a means of addressing infections produced by microorganisms in the treatment of orthopaedic illnesses, leading to expedited bone healing. Currently, a wide range of physical, chemical, biological, and hybrid techniques are used to create different types of nanoparticles. Historically, the production of nanoparticles has been accomplished by two methods: physical and chemical. The methods used include ion sputtering, solvothermal synthesis, reduction, and sol-gel procedures. Nanoparticle production techniques may be categorised as either bottom-up or top-down approaches [10]. Chemical approaches include the process of reducing chemicals, using electrochemical techniques, and reducing photochemicals. The plant-based synthesis of nanoparticles is much more rapid, secure, and less burdensome. It operates at lower temperatures and necessitates just modest and ecologically benign constituents. The increasing demand for ecologically friendly goods has led to a greater focus on plant-based nanoparticles [11]. Furthermore, the utilisation of plants for synthesising nanoparticles has several benefits, including the usage of cleaner solvents, less reliance on hazardous reagents, less harsh reaction conditions, practicality, and their versatility in medical, surgical, and pharmaceutical applications. In addition, the physical conditions necessary for their synthesis, such as pressure, energy, temperature, and the materials involved, are insignificant [12].

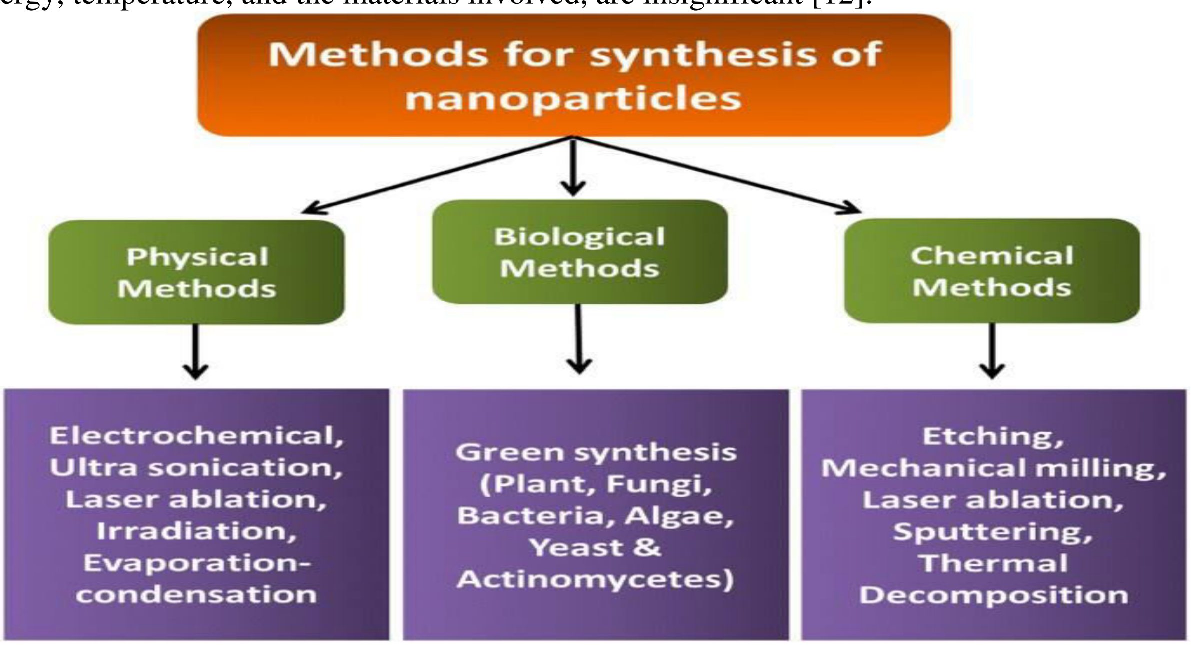

Figure 2: Different methods used in synthesis of nanoparticles.

Synthesis of silver nanoparticles:

Table 1: Plants used in green synthesis of silver nanoparticles.

Sr. No.	Plants	Plantparts	Size(nm)	Shape	References
1	Calotropisgigantea	Latex	5–30	Spherical	[13]
2	Mukiamaderaspatana	Leaf	13–34	Spherical	[14]
3	Musabalbisiana	Leaf	50	Spherical	[15]

4	Alstoniascholaris	Bark	50	Spherical	[16]
5	Prosopisfarcta	Leaf	10.8	Spherical	[17]
6	Grewiaflaviscences	Leaf	50–70	Spherical	[18]
7	Rosmarinusofficinalis	Leaf	10–33	Spherical	[19]
8	Caricapapaya	Leaf	50–250	Spherical	[20]
9	Plukenetiavolubilis	Leaf	4–25	Optical	[21]
10	Cucurbitamaxima	Petals	19	Crystalline	[22]
11	Moringaoleifera	Leaf	11	Rectangle	[23]
12	Acoruscalamus	Rhizome	19	Spherical	[24]
13	Aristolochiaindica	Leaf	30–55	Sphericalor cubical	[25]
14	Euphorbiahelioscopia	Leaf	2–14	Spherical	[26]
15	Daturametel	Leaf	40–60	Spherical	[27]
16	Momordicacymbalaria	Fruit	15.5	Spherical	[28]
17	Hypneamusciformis	Leaf	40–65	Spherical	[29]
18	Potentillafulgens	Root	10–15	Spherical	[30]
19	Annonamuricata	Leaf	20–53	Spherical	[31]
20	Justiciaadhatoda	Leaf	5–50	Spherical	[32]
21	Hemidesmusindicus	Leaf	25.24	Spherical	[33]
22	Emblicaofficinalis	Leaf	15	Spherical	[34]
23	Averrhoacarambola	Leaf	14	Spherical	[35]
24	Helicteresisora	Root	30–40	Crystalline	[36]
25	Saracaindica	Leaf	23	Spherical	[37]
26	Abutilonindicum	Leaf	106	Crystalline	[38]
27	Ficuscarica	Leaf	21	Crystalline	[39]
28	Sinapisarvensis	Seed	14	Spherical	[40]
29	ZiziphusJujuba	Leaf	20–30	Crystalline	[41]
30	Tephrosiatinctoria	Stem	73	Spherical	[42]
31	Nelumbonucifera	Root	16.7	Polydispersed	[43]
32	Aervalanata	Leaf	18.62	Spherical	[44]
33	Myrmecodiapendan	Wholepl	10–20	Spherical	[45]

		ant			
34	Piperlongum	Fruit	46	Spherical	[46]
35	Enteromorphaflexuosa	Seaweed	2–32	Circular	[47]
36	Lansiumdomesticum	Fruit	10–30	Spherical	[48]
37	Onosmadichroantha	Root	5–65	Spherical	[49]
38	Crataegusdouglasii	Fruit	29.28	Spherical	[50]
39	Vitexnegundo	Leaf	≥20	Cubic	[51]
40	Clerodendrumserratum	Leaf	5–30	Spherical	[52]
41	Lycopersiconesculentum	Fruit	10–40	Spherical	[53]
42	Skimmialaureola	Leaf	46	Hexagonal	[54]
43	Prunusyedoensis	Leaf	20–70	Circular,smooth edges	[55]
44	Cocosnucifera	Coir	22	Spherical	[56]
45	Eucalyptus chapmaniana	Leaf	60	Spherical	[57]

Utilising plants for nanoparticle synthesis has several advantages compared to other biological synthesis techniques, since it eliminates the need for cell culture upkeep and facilitates the large-scale production of nanoparticles. Utilising extracts from individual leaves instead of whole plants for extracellular nanoparticle manufacturing may result in a more cost-effective procedure owing to simplified downstream processing. Sastry and his team are credited with being the first to develop nanoparticle synthesis utilising plant extracts [58].

The use of plant extracts containing phytochemical agents for the production of AgNPs by green synthesis has garnered significant attention. This eco-friendly technique is both biocompatible and cost-effective, and it also has the capacity to sustain greater synthesis. The production of AgNPs using several environmentally friendly chemico-physical methods, as well as by diverse microorganisms, has been extensively studied. Chemical synthesis of AgNPs necessitates three essential components: (1) a silver salt such as AgNO3, (2) a reducing agent like NaBH4, and (3) a stabilising or capping agent such as polyvinyl alcohol. These components are crucial for regulating the size of nanoparticles and avoiding their aggregation. Silver nanoparticles (AgNPs) are used in several fields including wound-healing, eye disease treatment, DNA processing, and medicines. They also find uses in electronics, optics, catalysis, and Raman scattering. Lokini et al. demonstrated that AgNPs had the ability to disrupt the outer membrane and cause the plasma membrane to rupture, resulting in a decrease in intracellular ATP levels [59]. Silver has a higher tendency to interact with biomolecules in the cell that include sulphur or phosphorus. As a result, proteins in the cell membrane or inside cells that contain sulphur, as well as components in DNA that contain phosphorus, are more likely to be favoured locations for binding AgNPs. Using plants for the synthesis of nanoparticles has many benefits, such as their widespread availability, safe handling, and the existence of a diverse range of metabolites that may assist in the reduction of silver. The duration needed to decrease 90% of silver ions is around 2 to 4 hours. Gericke and

Pinches observed that the manipulation of crucial parameters, such as pH, temperature, substrate concentration, and duration of substrate exposure, may regulate the size of particles formed inside cells [50].

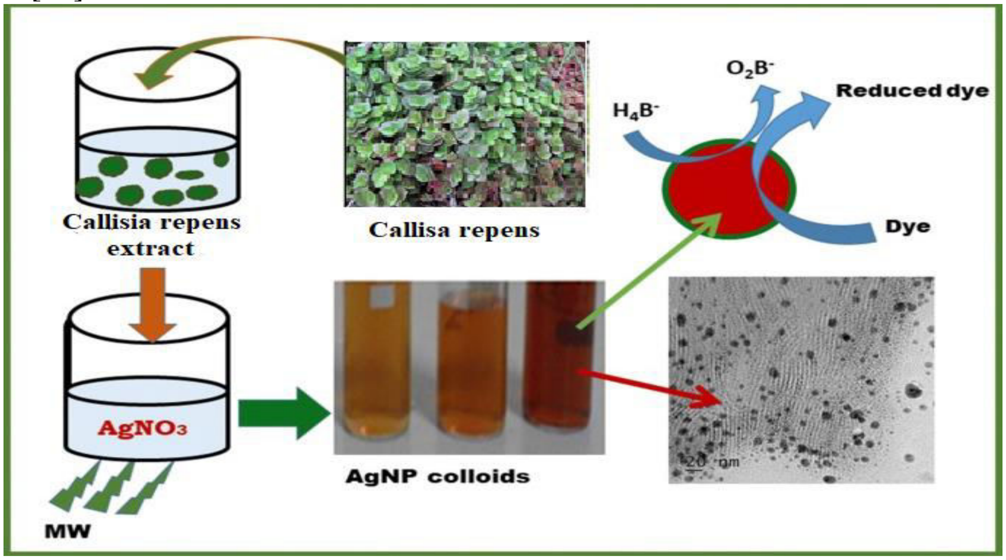

Figure 3: Green synthesis of colloidal silver nanoparticles.

Physical method used in colloidal silver nanoparticles:

Metal nanoparticles are typically produced by evaporation condensation in physical processes. This may be achieved by using a tube furnace operating at atmospheric pressure. The source material located in a boat positioned near the furnace is transformed into a gaseous state and carried away by a carrier gas. Prior to this, nanoparticles composed of several materials, including Ag, Au, PbS, and fullerene, were generated by the evaporation/condensation method. Nevertheless, the use of a tube furnace for generating AgNPs has many disadvantages. This is due to the fact that a tube furnace takes a substantial amount of space, consumes a significant amount of energy, hence increasing the ambient temperature around the source material, and necessitates a considerable amount of time to attain thermal stability. A conventional tube boiler typically consumes several kilowatts of electricity and takes many tens of minutes to reach a steady working temperature during the preheating process. Moreover, silver nanoparticles have been produced by the use of laser ablation on metallic bulk materials in a liquid solution. An benefit of laser ablation, in comparison to other traditional methods for creating metal colloids, is the lack of chemical reagents in the solutions. Thus, this approach may be used to manufacture pure colloids that are beneficial for further applications. To summarise, the physical production of AgNPs typically involves the use of physical energy to create AgNPs that have a rather uniform size distribution. The physical method allows for the production of a significant amount of AgNPs samples in a single operation. This process is quite effective for producing AgNPs powder. Nevertheless, it is essential to take into account the initial expenses associated with the acquisition of equipment [61].

Chemical method used in colloidal silver nanoparticles:

In addition to the aforementioned methods, chemical reduction is often used due to its ease and minimal equipment requirements. Regulating the expansion of metal nanoparticles is necessary in order to get nanoparticles that are tiny in size, have a spherical form, and possess a limited diameter distribution. Chemical reactions may be used to manufacture silver nanoparticles at a cheap cost and with a high yield, which is well recognised. This paper provides an overview of several chemical synthesis processes used for the creation of silver nanoparticles. Typically, the chemical production of AgNPs in a solution involves three primary components: metal precursors, reducing agents, and stabilizing/capping agents [62]. The process of creating colloidal solutions by the reduction of silver salts consists of two distinct phases: nucleation and subsequent development. Furthermore, it is evident that the dimensions and morphology of the produced AgNPs are significantly influenced by these phases. In addition, in order to achieve the production of monodisperse AgNPs with a consistent size distribution, it is necessary for all nuclei to form simultaneously. In this scenario, it is probable that all the nuclei will possess same or comparable dimensions, resulting in uniform further development. By manipulating reaction parameters such as temperature, pH, precursors, reduction agents (e.g. NaBH4, ethylene glycol, glucose), and stabilising agents (e.g. PVA, PVP, sodium oleate), one may regulate both the initial nucleation and the subsequent development of initial nuclei [63].

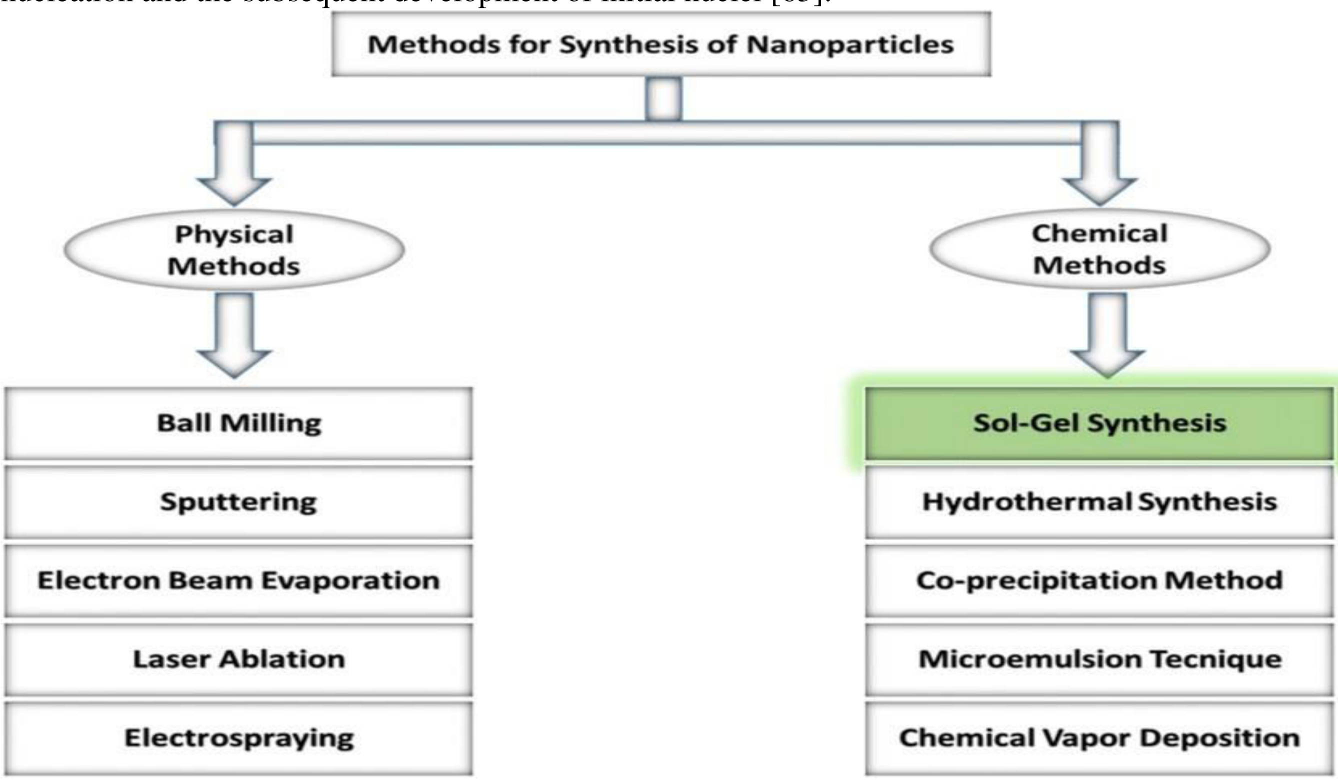

Figure 4: Physical and chemical method used in synthesis of silver nanoparticles.

Characterization of colloidal silver nanoparticles:

Characterising AgNPs is crucial for comprehending and managing the manufacture and utilisation of nanoparticles. Multiple methodologies are used to ascertain distinct criteria. The morphology of AgNPs is determined by the use of transmission and scanning electron microscopy (TEM, SEM). The Zetasizer Nano Series analyser may be used to measure the size distribution of AgNPs. Energy dispersive X-ray spectroscopy (EDS) observations are conducted using an emission scanning electron microscope that is equipped with an EDS apparatus. AgNPs are characterised using X-ray photoelectron spectroscopy (XPS), X-ray diffractometry (XRD), Fourier transform infrared spectroscopy (FTIR), and UV-Vis spectroscopy. UV-Vis spectroscopy is used to validate the synthesis of AgNPs by detecting the Plasmon resonance. Furthermore, XRD is used to ascertain the degree of crystallinity. The Loresta-GP MCP-T610 resistivity meter is used to measure the volume resistivity in order to assess the electrical conductivity. In our recent investigations, we discovered an optical absorption peak of AgNPs owing to surface plasmon resonance in the synthesised AgNPs, as shown by the findings of UVVis measurement [64]. The EDS analysis indicates that the peak seen at around 3 keV is specific to AgNPs. No contaminants, save for trace quantities of carbon and oxygen, are detected, suggesting that the chemicals employed have been completely removed. Due to the water-solubility of the chemicals utilised in this research, the end product, which is not soluble in water, can be readily isolated from the mixture of reactions [65]. XPS analysis is conducted to ascertain the elemental composition of AgNPs. The Ag (3d3/2) and Ag (3d5/2) binding energies for AgNPs are measured to be 374 eV and 368 eV, respectively. The peaks seen at 368.3 eV in the reported binding energy of Ag0 (3d5/2) confirm the presence of AgNPs.

Application of colloidal silver nanoparticles:

Antibacterial activity:

The threat posed by the potential outbreak of antibiotic-resistant microbes is growing globally and demands the introduction and production of novel more advanced platforms for the study and development of more potent antimicrobial agents against multidrug-resistant strains The antimicrobial activity of AgNPs is widely recognized, though their activity can change with physical characteristics of the nanoparticle, such as its shape, mass, size, and composition, and conditions of its synthesis, such as by pH, ions, and macromolecules Their shapes can be relevant to their antibacterial activity .Compared to larger AgNPs, smaller AgNPs have a greater binding surface and show more bactericidal activity. Variation in the thickness and molecular composition of the membrane structures of gram-positive and gram-negative bacteria account for the difference in their sensitivities to AgNPs. Bactericidal activity is presumably due to changes in the structure of the bacterial cell wall as a result of interactions with embedded AgNPs, leading to increased membrane permeability and consequently death. AgNPs also interact with sulfur- and phosphorus-rich biomaterials, which include intracellular components, such as proteins or DNA, and extracellular components such as membrane proteins. These components influence the respiration, division, and ultimately survival of cells. Upon compromising the bacterial cell wall, silver ions (as part of AgNPs) can enter into cells, leading to the accumulation of damaged DNA and effect on protein synthesis [66].

Anticancer activity:

Silver nanoparticles (AgNPs) are effective in treating cancer due to their ability to interfere with the mitochondrial respiratory chain, leading to the production of reactive oxygen species (ROS) and inhibition of ATP synthesis, which may cause DNA damage. The cytotoxicity of AgNPs synthesised using extracts from Sesbaniagrandiflora leaves was proven against MCF-7 cancer cells. Observations of MCF-7 cells treated with AgNPs revealed morphological changes such as membrane damage, reduced cell proliferation, cytoplasmic condensation, and cell clumping. In contrast, control cells remained unaffected. Furthermore, MCF-7 tumour cells exhibited apoptotic characteristics, including cell shrinkage and nuclear condensation and fragmentation, 48 hours after being treated with a concentration of 20 μg/mL of AgNPs. Silver nanoparticles (AgNPs) produced using extracts from S. grandiflora caused the production of free radicals, leading to oxidative damage and apoptosis mediated by caspase [67].

The AgNPs synthesised using extracts from Guignardiamangiferae shown strong antifungal efficacy against plant pathogenic fungi. The IC50 values of AgNPs against Vero, HeLa, and MCF-7 cells were 63.37, 27.54, and 23.84 μg/mL, respectively, during a 24-hour incubation period. Therefore, the silver nanoparticles (AgNPs) produced using G. mangiferae extracts exhibit excellent biocompatibility, making them suitable for a broad range of biomedical/pharmaceutical and agricultural uses. These nanoparticles have great promise and should be further investigated as viable options in these fields. Silver nanoparticles (AgNPs) were produced utilising extracts derived from several plant sources, including Cucurbita maxima (petals), Moringaoleifera (leaves), and Acoruscalamus (rhizome). Out of the three nanoparticles that were created, the ones made using A. calamus rhizome extracts showed improved antibacterial and anticancer properties. These properties were assessed using MTT assays against epidermoid A431 carcinoma cells. The antibacterial and anticancer properties of AgNPs synthesised using A. calamus rhizome extracts were shown to be superior to those prepared using petal and leaf extracts. Both synthesised and unsynthesized AgNPs caused DNA fragmentation at all doses. Cells treated with AgNPs synthesised using extracts from Phytolaccadecandra, Hydrastiscanadensis, Gelsemiumsempervirens, and Thujaoccidentalis showed DNA laddering, indicating the apoptotic effects of the nanoparticles in comparison to untreated cells. AgNPs synthesised using P. decandra and G. sempervirens extracts had a higher efficacy in inducing DNA laddering compared to AgNPs synthesised using H. canadensis and T. occidentalis extracts [68].

The IC50 values of silver nanoparticles (AgNPs) produced using extracts from Potentillafulgens were 4.91 µg/mL and 8.23 µg/mL in MCF-7 and U-87 cell lines, respectively. Moreover, the cytotoxic properties of nanoparticles were assessed on both malignant and normal cells using the trypan blue test and flow cytometric analysis. Nanoparticles have the ability to hinder or destroy cancer cells, unlike their impact on healthy cells. The silver nanoparticles (AgNPs) produced using extracts from Coleus amboinicus were shown to be harmful to EAC cell lines. The AgNPs caused cytotoxicity of 50% and 70% at concentrations of 30 and 50 µg/mL, respectively, demonstrating a cytotoxicity that is dependent on the concentration. The alcoholic floral extracts of Nyctanthes arbor-tristis may be used to synthesise AgNPs, which have applications in molecular imaging and medication administration. AgNPs exhibited no toxicity towards L929 cells, even at the highest dosage tested (250 µg/mL). The in vitro anticancer efficacy of silver nanoparticles (AgNPs) produced from unripe fruits of Solanumtrilobatum was assessed against MCF-7, a human breast cancer cell line. This evaluation used MTT tests, analysis of nuclear morphological properties, and RT-PCR and western blot studies. The treatment of MCF-7 cells with either AgNPs or cisplatin resulted in a reduction in Bcl-2 expression and an increase in Bax expression. This suggests that the mechanism of cell death mediated by AgNPs involves the mitochondria [69].

Mitochondria serve as vital hubs for signalling; their integrity may be impaired by different regulators of apoptosis. AgNPs may generate reactive oxygen species (ROS) that rely on mitochondria to activate intrinsic caspase-dependent apoptotic pathways, ultimately resulting in cell death. The use of Rosa indica extracts in the synthesis of nanoparticles shows promise for several therapeutic anticancer applications. The silver nanoparticles (AgNPs) produced from the green petals of R. indica function as agents that eliminate free radicals and trigger programmed cell death (apoptosis) in HCT-15 cells, while also promoting the production of reactive oxygen species (ROS) [70].

Anti-oxidants activity:

Colloidal silver nanoparticles exhibit potent antioxidant activity, primarily attributed to their unique physicochemical properties and high surface area-to-volume ratio, which enhance their interaction with free radicals. These nanoparticles can effectively scavenge reactive oxygen species (ROS) and inhibit lipid peroxidation, thereby protecting cells from oxidative stress-induced damage. The antioxidant activity of colloidal silver nanoparticles is also linked to their ability to catalyze electron transfer reactions, stabilizing reactive molecules and preventing cellular and molecular damage. This potential makes them promising candidates for therapeutic applications aimed at mitigating oxidative stress-related conditions, including inflammation, aging, and various chronic diseases [71].

Antidiabetic Activity of AgNPs

Colloidal silver nanoparticles demonstrate significant antidiabetic activity, which is attributed to their ability to enhance insulin sensitivity and promote glucose uptake in cells. These nanoparticles have been shown to modulate key enzymes involved in carbohydrate metabolism, such as alpha-glucosidase and alpha-amylase, thereby reducing postprandial blood glucose levels. Additionally, colloidal silver nanoparticles exhibit anti-inflammatory properties that help mitigate the chronic inflammation often associated with diabetes. By protecting pancreatic beta-cells from oxidative damage and apoptosis, they contribute to the preservation of insulin secretion. The multifunctional nature of colloidal silver nanoparticles, including their antioxidant and anti-inflammatory effects, positions them as promising agents in the management and treatment of diabetes mellitus [72].

Anti-inflammatory Activity:

Colloidal silver nanoparticles exhibit potent anti-inflammatory activity, which is largely attributed to their ability to modulate immune responses and reduce the production of pro-inflammatory cytokines. These nanoparticles can effectively inhibit the activation of key inflammatory pathways, such as the nuclear factor-kappa B (NF-κB) pathway, thereby suppressing the expression of inflammatory mediators like tumor necrosis factor-alpha (TNF-α), interleukin-6 (IL-6), and nitric oxide. Additionally, colloidal silver nanoparticles demonstrate a capacity to attenuate the infiltration of inflammatory cells to sites of tissue injury or infection, further mitigating inflammation. Their antioxidant properties also play a crucial role in reducing oxidative stress, which often exacerbates inflammatory responses. Consequently, colloidal silver nanoparticles hold promise as therapeutic agents in treating various inflammatory conditions, including arthritis, inflammatory bowel disease, and skin inflammations [73].

Conclusion:

The growing use of nanotechnology in research and development has substantial promise in several scientific domains, particularly in the production of items at the nanoscale. The production and use of nanoparticles, namely silver nanoparticles (AgNPs), have shown encouraging antibacterial, antioxidant, and anticancer characteristics. The use of plant extracts for the production of AgNPs by green synthesis has many benefits, such as being environmentally friendly, cost-effective, and containing bioactive components that improve the stability and efficiency of the nanoparticles.

This work focusses on the production of silver nanoparticles (AgNPs) utilising the roots of Rhodiolarosea, a plant recognised for its medicinal benefits. The nanoparticles were characterised to determine their size, shape, stability, and crystallinity, which confirmed their suitability for use in biological applications. AgNPs, when added to an ointment, showed significant anti-inflammatory properties in a mouse model with burn wounds. This suggests that there is potential for the development of therapeutic therapies for burn injuries.

Combining nanotechnology with conventional medicine, namely via plant-based synthesis processes, offers a sustainable and effective strategy for creating cutting-edge therapeutic molecules. AgNPs possess distinctive characteristics, including their diminutive size, expansive surface area, and capacity to infiltrate microbial cells, rendering them well-suited for tackling diverse medical obstacles, such as wound infections and cancer therapy. The advancement of research in nanotechnology has immense promise to transform medical treatments and enhance patient outcomes.

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