International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 07 Issue 01 January 2024
DOI: 10.47191/ijcsrr/V7-i1-45, Impact Factor: 6.789
IJCSRR @ 2024
www.ijcsrr.org

A Green approach of Ag and Au Nanoparticles, Properties and its Applications: A Review

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ABSTRACT: The emergence of nanotechnology has transformed antimicrobial and cancer treatment methodologies employed by clinicians. Conventional approaches, such as, radiotherapy, hormonal therapy and chemotherapy, now have a contemporary counterpart in nano therapy, presenting a potential alternative. This innovative treatment paradigm holds promise due to its minimal side effects in comparison to traditional methods. Notably, metallic nanoparticles synthesized through green chemistry utilizing biological entities, contribute to the mitigation of side effects while augmenting the metal's efficiency against cancer cells. These environmentally friendly nanoparticles have become integral in research, demonstrating significant antimicrobial and cytotoxicity activities across diverse cancer cell lines. In this review concentrates on metal nanoparticles, specially silver and gold, synthesized via green chemistry approach. The aim is to explore their impact on inducing cancer cell death, delving into the associated molecular pathways. The primary objective of this review is to discern strategies for expediting the clinical applications of silver and gold nanoparticles based therapeutic systems. The overarching goal is to reduce normal tissue toxicity consequently elevating the overall efficacy of the treatment. Anticipated advancement in nano-medicines are poised to revolutionize future cancer treatment modalities, ushering in a paradigm shift characterized by minimal side effects and enhanced therapeutic outcomes.

KEY WORDS: Application of nanoparticles, Cancer cell line, Gold nanoparticles, Silver nanoparticles, Therapeutic uses.

1. INTRODUCTION

Richard Feynman's (1960) contemplation of the elegance of nanomaterials, encapsulated in the aphorism "there is plenty of room at the bottom", resonates with the transformative potential that the realm of miniaturization brings to scientific and technological landscapes. This speculation has indeed materialized, ushering in innovative avenues for the synthesis and characterization of nanomaterials and their consequential integration into societal frameworks. [1,2]. The burgeoning scientific fascination with nanoparticles (NPs) stems from their unique role as conduits bridging the chasm between bulk constituents and atomic or molecular assemblies. Numerous extensively studied bulk materials unveil intriguing properties at the nanoscale, where NPs distinguished by their high aspect ratio, exhibit enhanced reactivity and effectiveness relative to their high aspect ratio exhibit enhanced reactivity and effectiveness to their macroscopic counterparts.

Over time, researchers demonstrated remarkable proficiency in crafting nano-sized counterparts for composites, alongside pioneering nano-based materials. The manifold applications of nanotechnology encompass high-resolution imaging, myriad nano-sized sensors for environmental monitoring, a plethora of optoelectronics strategies and innovative nano-sized engineered solar applications [3]. The nanoscale domain, intrinsic to nanotechnology, harbors evidence of nanostructures dating back to the inception of the life. The imperative for nanotechnology has been urged, fueled by the escalating demand for nanostructured materials in diverse fields including catalysis [4]. Over the past centuries, material scientist has unearthed carbon-based nanomaterials and minerals elemental blends that exhibit superior optoelectronics and dimensional characteristics compared to their conventional counterparts. Organics nanoparticles such as liposomes[5], fullerenes[6], dendrimers and polymeric micelles[7], coexist alongside inorganic of magnetic, noble metal and semiconductor materials.

Notably, metallic nanoparticles have captured the attention of researchers due to their unique properties that remain elusive in isolated molecules. The development of metallic nanoparticles represents a dynamic arena in both theoretical and applied research within the realm of nanotechnology [8,9].

In this review focuses on contemporary research endeavors that center on the green synthesis of inorganic nanoparticles which holds a distinct advantage over conventional methods employing environmentally harmful chemical agents. The article delves into traditional synthetic techniques, shedding light on recent strides in eco-friendly approaches to manufacturing metal, metal oxide and other pivotal nanoparticles. Furthermore, it explores the mechanism underlying nanoparticles formation along with the factors dictating surface morphology, dispersity and other pertinent properties of these biogenically synthesized nanoparticles. The report culminates in a discussion of the current landscapes and future prospects of nanoparticles production through various sustainable methodologies.

In essence, the surging demand for nanomaterials across diverse applications, ranging from biomedical to bioenergy endeavor, is primarily attributed to their diminutive size, which confers substantial surface area for accommodation molecules if interest in scientific applications, notably drug delivery systems for various medical conditions.

2. METHODS INVOLVED IN SYNTHESIS OF NANOPARTICLES

2.1.1 Chemical reduction method:

One of the quintessential techniques employed in nanoparticles synthesis is the chemical reduction method. This process, characterized by its simplicity and versatility, relies on the judicious reduction of metal ions to nanoparticles in a controlled chemical milieu. Reducing agents such as hydrazine or sodium borohydride acts as alchemists, orchestrating the transformation from ions to nanoparticles. The delicate balance of reaction conditions facilitates the nucleation and subsequent controlled growth of nanoparticles [10,11].

2.1.2 Sol-gel method:

The Sol-gel method, an epitome of chemical finesse, involves the conversion of precursors solutions into a gel-like state, followed by controlled drying to from nanoparticles. This meticulous process enables the manipulation of nanoparticles size, morphology and distribution by modulating the precursor compositions and drying conditions. The resulting materials find applications in catalysis, optics and biomedical sciences attesting to the versatility of this method [12].

2.1.3 Poly Synthesis:

Ploy synthesis emerges as a sophisticated avenue for nanoparticles fabrications, capitalizing on polyfunctional alcohols as both solvent and reducing agent. The chemical orchestra unfolds in a high-temperature environment, guiding the reduction of metal precursors to nanoparticles with exquisite control over size and shape. This method's prowess lies in its ability to yields monodisperse nanoparticles, an essential attribute for applications demanding homogeneity [13,14].

2.1.4 Hydrothermal and Solvothermal Synthesis:

The hydrothermal and solvothermal methods harness high- temperature and high- pressure conditions to induce the formations of nanoparticles. These controlled environments expedite the nucleation and growth processes, ensuring the creation of nanoparticles with distinct properties. This approach is particularly pertinent in the synthesis of advanced materials, such as metal oxides and sulfides, with tailored physicochemical characteristics [15].

2.2 Physical Vapor Deposition:

Among these arsenal of physical methods, Physical Vapor Deposition (PVD) stands as an exemplar of controlled nanoparticles synthesis. This technique involves the transformation of a solid material into vapor, followed by its condensation onto a substrate from nanoparticles. The beauty of PVD lies in its ability to produce nanoparticles with remarkable uniformity and precisely tailored characteristics. Evaporation, sputtering and lase ablation are common variants of PVD, each offering unique advantages in nanoparticles fabrications [16,17].

2.2.1 Mechanical Milling method:

In the realm of mechanical methods, ball milling stands as a robust physical approach to nanoparticle synthesis. This process involves the mechanical grinding of solid materials to produce finely divided particles. The energy imparted during the milling process induces particle fracture and leads to the creation of nanoparticles with tailored properties. Ball milling finds extensive applications in material science and nanocomposite fabrications [18,19].

2.3 Green synthesis method:

Green synthesis of nanoparticles pivots on the utilization of natural sources such as plant extracts, microorganism or other eco-friendly entities as reducing and stabilizing agents. The methodology adheres to the principles of sustainability, circumventing the use of hazardous chemicals and energy-intensive processes. Harnessing the inherent reducing potential of biological entities, green synthesis stands as a testament to the elegance of nature-inspired nanotechnology [20-22].

2.3.1 Environment sustainability:

Green synthesized nanoparticles exhibit heightened biocompatibility owing to the inherent nature of the biological reducing agents involved [23]. This facet is particularly crucial in biomedical applications, where conventional synthesis methods may introduce cytotoxicity concerns. Green-synthesized nanoparticles, in contrast, offer a safer and more biologically compatible alternative [24].

2.3.2 Cost-Efficiency:

The simplicity of green synthesis methods contributes to cost efficiency. Eliminating the need for elaborate instrumentation and expensive reagents, green synthesis democratizes nanoparticles fabrication, making it accessible even in resource-constrained settings [25].

3. METALLIC NANOPARTICLE

3.1 Silver nanoparticles:

Metal nanoparticles exhibit notable physicochemical characteristics, including a high specific surface area and a significant fraction of surface atoms, owing to their unique properties. This uniqueness encompasses catalytic activity, optical activity and electronic properties, antibacterial effects, and magnetic characteristics [26]. The distinctive features of nanoscale materials have positioned them as innovative antimicrobial agents, capitalizing on their elevated surface area to volume ratio and distinct chemical and physical attributes. In recent years, the exploration of metallic nanoparticles has burgeoned as a focal point in material science research. Crystalline nanosilver, in particular has garnered considerable attention for its superior applicability in biomolecule detection, antibacterial functions, electronics and diagnostic applications within healthcare systems [27,28].

The high reactivity of AgNPs imparts a potent biocidal effects against a wide array of bacteria, fungi and even some virus. This biocidal prowess opens avenues for diverse applications, such as gel-like composite implants for filling tubular bone defects and surgical interventions utilizing nanoparticles and films with polyethylene glycol and glycerin to cover damaged skin area [29]. However, while AgNPs exhibit antibacterial efficacy, their impact on eukaryotic cells cannot be overlooked. Even minimal doses of nanoparticles possess the potential to induce DNA damage, chromosomal aberrations and subsequent cell cycle arrest. As we delve further into the multifaceted realm of metal nanoparticles, a nuanced understanding of their biocidal and eukaryotic effects becomes imperative for responsible and targeted applications in diverse fields [30].

3.2 Gold nanoparticles:

The unique attribute of gold nanoparticles (AuNPs) can be attributed to their diminutive size. These particles, significantly smaller the wavelength of light, absorb light in the blue-green spectrum (450 nm) and reflect red light (700 nm), resulting the distinctive ruby red color [31, 32]. Michael Faraday's pivotal discovery marked the inception of modern nanotechnology with researchers flocking to this fertile filed for exploration. The AuNPs have proven particularly valuable in surface- enhanced Raman scattering (SERS), serving as substrate for detecting various elements within living cells [33].

The mechanism SERS involves two significant amplifications: electromagnetic enhancement, where the resonance of light filed and electron oscillation amplify the local electric field at the nanoparticles surface and short-range chemical enhancement. arising from charge-transfer interactions altering molecular polarizability [34]. Gold nanoparticles have emerged as stellar candidate for delivering diverse payloads to specific sites. These payloads span from small drug molecules to large biomolecules like DNA, RNA and proteins. Some drug molecules can directly bond with gold nanoparticles through physical absorption or ionic covalent bonding, obviating the need for modification [35,36].

Given the voluminous and continually evolving information in this file, this review synthesizes generalized data from recent years, encapsulating the most promising application of gold nanoparticles in drug delivery [37]. The multifaceted capabilities of gold nanoparticles continue to unfold, promising groundbreaking advancements in medical and technological landscapes [38].

4. PROPERTIES OF NANOPARTICLES

4.1 Optical

The optical properties of these nanoparticles are intricately linked to their size and shape [39]. The phenomenon of plasmon resonance is highly sensitive to nanoparticles dimensions, with shifts in resonance frequencies corresponding to alterations in size. The size-dependent behavior is particularly pronounced in Au and Ag nanoparticles providing a tunable platform for manipulating their optical response [40]. The optical properties of AgNPs and AuNPs unveil a mesmerizing transcends the ordinary. The unique characteristics of these nanoparticles rooted in their plasmonic behavior, pave the way for a myriad of applications in fields ranging medicine to electronics. At the heart of the optical prowess of Au and AgNPs lies their ability to support localized surface plasmon resonance (LSPR). When exposed to light, these nanoparticles resonate at specific frequencies, dictating their color and influencing their optical behavior [41].

In the case of AuNPs, this resonance often manifests as vibrant reds due to absorption in the blue-green region (~520 nm), while AgNPs showcase hues ranging from yellow to brown due to absorption in the blue (~420 nm). The optical characteristics of Au and AgNPs find applications in the realms of sensing and imaging [42,43]. Their distinct plasmonic signatures enable the detection of molecular interactions, making them vital components in biosensors. Additionally, their strong scattering and absorption properties make them excellent contrast agents in imaging techniques like dark-filed microscopy and surface- enhanced Raman spectroscopy (SERS) [44].

From their vibrant hues to their applications in sensing, imaging and biomedicine, these nanoparticles captive the imagination of researchers and engineers alike. As we navigate the intricate nuances of their optical behavior, the potential for ground breaking advancements in diverse scientific disciplines continues to unfold, promising a future illuminated by the brilliance of nanotechnology.

4.2 Mechanical

Beyond their mesmerizing optical characteristics, Ag and AuNPs unveil a fascinating realm of mechanical properties that underscores their resilience and potential applications. In the labyrinth of the nanoscale, the mechanical behaviors of these noble metal nanoparticles become key elements in diverse scientific and technological landscapes. The mechanical robustness of Ag and AuNPs belies their diminutive size. Despite their microscopic dimensions, these nanoparticles exhibit surprising strength, a testament to the cohesive forces within their atomic structure. Their inherent stability becomes a pivotal factor in applications where mechanical integrity is paramount [45,46].

The mechanical properties of Ag and AuNPs find applications in the burgeoning fields of nanomechanics. Researchers leverage the strength and stability of these nanoparticles to construct nanoscale devices, sensors and materials. The ability to manipulate these mechanical characteristics at the nanoscale holds promise for innovations in nanoelectromechanical systems (NEMS) and other emerging technologies. One of the intriguing facets of the mechanical properties of Ag and AuNPs is their size dependences. As these nanoparticles shrink to the nanoscale, quantum effects become prominent, influencing their mechanical behaviors. The relationship between size and strength opens avenues for tailoring nanoparticles with specific mechanical attributes for varied applications [47-49].

While the mechanical properties of Ag and AuNPs offer a wealth of opportunities, challenges such as potential deformation under stress and the influence of surface modifications on mechanical integrity warrant careful consideration. Researchers are actively exploring strategies to address these challenges, seeking to refine enhance the mechanical characteristics of these applications.

4.3 Magnetic properties

Nanoparticles, when scaled down to the nano-size range exhibit intriguing magnetic phenomena owing to quantum effects. In this miniature realm, the confinement of electronics imparts distinct magnetic characteristics, defying the conventional behavior observed in bulk materials. The quantum quarks within nanoparticles become pivotal in understanding and manipulating their magnetic properties [50].

In realm of electronics, magnetic nanoparticles bring forth a new paradigm. The integration of these nanoparticles into electronic devices offers avenues for the development of more efficient and compact information storage solutions. Spintronics [51], a burgeoning field at the crossroads of magnetism and electronics, explores the potential of utilizing the spin of electrons in magnetic nanoparticles for novel computing architectures.

The current landscape witnesses a surge in research exploring the magnetic properties of nanoparticles for emerging technological trends. Magneto-optical devices, magnetic sensors and advancements in spin-based technologies are in the horizon. The quest to unravel the full potential of nano-magnetic technological involves navigating the intricate interplay of magnetic forces within nanoparticles [52].

Despite the promising prospects, challenges such as maintaining stability, preventing agglomeration and understanding the dynamics of nanoparticles interactions with their environment remain. Future directions in research seek to address these challenges, aiming to harness the magnetic properties of nanoparticles with enhanced control and precision.

5. SYNTHESIS METALLIC NANOPARTICLES FROM VARIOUS PARTS OF THE PLANTS

5.1 Leaf:

Nanoparticles synthesis using leaf extract aligns seamlessly with the principles of green chemistry. The method eliminates the need for hazardous chemicals, reducing the environmental footprint and minimizing potential harm to researchers. Leaf extracts serves as bio-reducing agents, facilitating the conversion of metal ions into nanoparticles in a benign and sustainable manner [53].

The synthesis of nanoparticles encapsulates the elegance of green chemistry, where nature's bounty serves as a reservoir of reducing agents. As researchers delve deeper into refining this mothed, the potential applications across industries continue to burgeon, promising a future where the synthesis of nanoparticles seamlessly integrates with the sustainable ethos of our natural surroundings [54].

5.2 Stem Bark:

The synthesis of nanoparticles using stem bark extract represents an innovative convergence of biological resource and nanotechnology. Rooted in green chemistry principles, this method harnesses the rich repository of bioactive compounds inherent in stem bark to facilitate the controlled production of nanoparticles. In this exploration, we unravel the intricacies of this eco-friendly synthesis approach [55].

Utilizing stem bark extract for nanoparticles synthesis aligns seamlessly with the ethos of green chemistry. Stem bark extract, rich in natural compounds, impacts biocompatibility to the synthesized nanoparticles, enhancing their applicability in biomedical and biotechnological domains. By replacing traditional chemical reagents with plant-derived extracts, the method champions sustainability. Minimizing environmental impact and priorities the safety of researchers involved in the process [56].

5.3 Flower:

The synthesis of nanoparticles utilizing flower extract introduces a botanical elegance to nanotechnology. Synthesizing nanoparticles with flower extracts embodies the of green chemistry. Eschewing conventional synthetic methods laden with harsh chemicals, this approach relies on the inherent reducing agents present in the flower extracts [57]. The process unfolds as a gentle, environmentally conscious ballet, harmonizing with the principles of sustainability.

Flower extracts serve as botanical alchemists, brimming with bioactive compounds like polyphenols, flavonoids and terpenoids [58]. These compounds endowed with reducing potential orchestrate the reducing of metal ions into nanoparticles. The intricate dance of molecules within the petals navigates the fine balance between reduction and stabilizing. The flower extracts boasts a diverse array of nanoparticles, embracing metallic hues such as gold, silver and platinum [59]. Petal-based reduction imparts level of precision allowing for control over nanoparticles size, shape and surface morphology. Each flower species contributes its unique signature to the nanoparticles bouquet.

5.4 Roots:

Harnessing the power of extracts for nanoparticles synthesis embodies the principles of green chemistry. The roots, laden with phytochemicals such as phenolic, terpenoids an alkaloids serve as potent bio-reducing agents [60]. This green alchemy transforms metal ions into nanoparticles, echoing the ethos of environmental responsibility and safety. Plant roots act as nature's laboratories, rich in compounds that exhibit dual functionality reducing metal ions and stabilizing the ensuing nanoparticles. This intricate synergy of biomolecules guides the synthesis process, offering a route characterized by mild conditions and minimal ecological impact [61].

The use of root extract facilitates the synthesis of a diverse array of nanoparticles, including but not limited to silver, gold and selenium. The variability lies not only in the metallic composition but also in the size, shape and surface properties of the nanoparticles, demonstrating the adaptability of root-driven synthesis [62].

5.5 Reduction mechanism:

The synthesis process involves the extraction of bioactive compounds, such as phenols[63], flavonoids[64], and enzymes from plant leaves[65]. These compounds act as a reducing agents [66] imparting electrons to metal ions, leading to their reduction and subsequent nanoparticles formations. The versatility of leaf extract allows for the synthesis of various metallic nanoparticles, including silver [67], gold and copper [68].

6. ANTIMICROBIAL ACTIVITIES OF BIO-SYNTHESIZED METAL NANOPARTICLES

The antimicrobial activities of nanoparticles synthesized through green methods represents a groundbreaking intersection of nanotechnology and eco-friendly approaches. This shift towards sustainable synthesis methodologies not only aligns with green chemistry principles but also introduces potent antimicrobial agents with far-reaching applications in infection control. The green synthesis of nanoparticles employs natural extracts such as plant based compounds or microbial products, as reducing and stabilizing agents [69].

This approach not only eliminates the need for harmful chemicals but also imparts unique properties to the nanoparticles, setting the stage for their remarkable antimicrobial efficacy. Green synthesized nanoparticles exert their antimicrobial effect through multifaceted mechanism. Additionally, the nanoparticle may induce oxidative stress within microbial cells, leading to damage in vital structure and impending their growth [70]

The antimicrobial prowess of these nanoparticles finds immediate applications in the medical field. They are explored for wound dressing [71], where the controlled release of nanoparticles inhibits bacterial growth and promotes healing [72]. Furthermore, their potential use in medical implants and devices adds an extra layer of infection preventions. Challenges in standardizing green synthesis protocols and optimizing nanoparticle stability persist [73]. However, ongoing research endeavors focus on overcoming these hurdles, seeking to refine the antimicrobial properties of nanoparticles and expand their applications.

7. ANTICANCER ACTIVITY OF METAL NANOPARTICLES

The anticancer activities of these nanoparticles originate from the reduction of metal ions using plant extracts, microbial products or other biocompatible sources [74]. This synthesis methodology not only sidesteps the use of harmful chemicals but also imbues the nanoparticles with inherent biological activity, setting the stage for their applications in cancer therapy. The anticancer activities of these nanoparticles unfold through targeted and multifaceted mechanism [75]. Their small size facilities efficient cellular uptake, enabling them to selectively target cancer cells. Once inside, they may induce apoptosis, disrupt cellular signaling pathways or inhibit angiogenesis, collectively impending the growth and proliferation of cancerous tissues [76,77].

Green-synthesized nanoparticles often serve as versatile platform for drug delivery. By encapsulating anticancer drugs, they enhance the drug's efficacy, promote targeted delivery and reduce systemic toxicity. This synergistic combination of nanoparticles and therapeutic agents presents a formidable approach in combating cancer [78]. The adaptability of green synthesis allows for the incorporation of diverse plant extracts and microbial products, paving the way for personalized medicine approaches. Tailoring nanoparticles to specific patient profiles and tumor holds immense promise for precision medicine in cancer treatment [79].

Challenges in optimizing synthesis protocols, ensuring nanoparticles stability and understanding their long-term effects persists. Ongoing research focuses on overcoming these challenges, exploring new green synthesis avenues and refining nanoparticles formulations for enhanced anti-cancer activities. As research continues to unravel the intricacies of these eco-friendly warriors, their potential to revolutionize cancer treatment becomes increasingly evident.

8. INDUSTRIAL APPLICATION OF METAL NANOPARTICLES

The burgeoning field of nanotechnology has propelled the utilization of metal nanoparticles to the forefront of industrial innovation. Among these, gold and silver nanoparticles, with their unique physicochemical properties, stand as luminaries, opening new vistas across various sectors. This essay delves into the diverse industrial applications of gold and silver nanoparticles, exploring their extraordinary contributions to catalysis, electronics, medicine, and beyond.

Metal nanoparticles exhibit remarkable properties that render them indispensable in diverse industrial applications. In the realm of catalysis, these nanoscale entities function as exceptionally potent catalysts, augmenting reaction kinetics and selectivity in pivotal industrial processes such as petrochemical refinement and environmental remediation [80]. The integration of metal nanoparticles into electronic materials has revolutionized the landscape of conductivity, fostering the creation of avant-garde electronic components and devices. Furthermore, their pivotal role in the healthcare sector cannot be understated, as metal nanoparticles are instrumental in the formulation of cutting-edge drug delivery systems, diagnostic imaging modalities, and antimicrobial coatings.

This ubiquity across industries, spanning from energy to materials science, underscores the pivotal role of metal nanoparticles in propelling technological innovation and sustainable solutions [81,82].

Their high surface area-to-volume ratio and inherent catalytic activity have been harnessed in refining processes within the petrochemical industry. Gold nanoparticles, in particular, exhibit remarkable catalytic prowess in facilitating oxidation and reduction reactions, enhancing efficiency and selectivity in intricate chemical transformations. This application has revolutionized the landscape of industrial catalysis, fostering cleaner and more sustainable processes [83,84].

The realm of electronics has witnessed a paradigm shift with the integration of gold and silver nanoparticles. These nanoscale wonders confer superior electrical conductivity and enhanced stability when incorporated into conductive materials [85]. Gold nanoparticles, owing to their inert nature, are particularly prized in the fabrication of advanced electronic components. Silver nanoparticles, with their excellent conductivity, are instrumental in the development of highly efficient and miniaturized electronic devices [86]. The marriage of metal nanoparticles with electronics has paved the way for the creation of cutting-edge technologies, underpinning the evolution of smart devices and high-performance computing [87,88].

In the realm of healthcare, gold and silver nanoparticles have become indispensable assets, contributing to transformative advancements in diagnostics and therapeutics. Gold nanoparticles, with their unique optical properties, are employed in diagnostic imaging techniques such as photoacoustic imaging and surface-enhanced Raman scattering (SERS). These applications facilitate precise and early disease detection. Furthermore, both gold and silver nanoparticles serve as carriers in drug delivery systems, enhancing the efficacy and targeted delivery of therapeutic agents. Their biocompatibility and tunable surface properties make them ideal candidates for revolutionizing medical treatments [89-91].

CONCLUSION

The synthesis of silver and gold nanoparticles using plant extracts offers several advantages, including economic feasibility, energy efficiency, cost-effectiveness the promotion of healthier workplaces and communities and the safeguarding of human health and the environment. This approach results in induced waste production and the creation of safer products. Green synthesized silver nanoparticles stand at the forefront of nanotechnology, showcasing unparalleled applications. Utilizing plant in nanoparticle-synthesis proves advantages over other biological entities, circumventing time-consuming processes associated with employing microbes and maintaining their cultures, which may diminish their potential for nanoparticles synthesis, therefore, the use of plant extract for synthesis is poised to make a profound impact in the coming decades.

A significant challenge lies in the variation in chemical compositions of plant extracts from the same species collected across different parts of the world, potentially yielding disparate results in various laboratories. This variability poses a major drawback in the synthesis of silver and gold using plant extracts as both reducing and stabilizing agents, emphasizing the need for resolution. The inherent bio-molecules within plant extracts play a dual role, acting as reducing and stabilizing agents during the Ag and Au nanoparticles synthesis process. The advantages plant-mediated synthesis over physical and chemical procedure are noteworthy. It not only aligns with eco-friendly practices but also proves to be cost-effective. As we delve deeper into green nanotechnology, the synthesis AgNPs and AuNPs through plant-mediated processes holds the potential to redefine environmentally conscious nanomaterial production for various applications.

Moving forward, our research will dedicate its efforts to synthesizing diverse types of green nanoparticles for application spanning pharmaceuticals, medicine, environment, aquaculture and agriculture. The findings from this study provides valuable insights that will guide the trajectory of future research endeavors in the development of green nanoparticles, particularly in the realm of environmental and biomedical advancement.

Institutional Review Board Statement: Not applicable. Informed Consent Statement: Not applicable. Data Availability Statement: Not applicable. Conflicts of Interest: The authors declare no conflict of interest. Sample Availability: Not applicable.

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Cite this Article: J Thomas Joseph Prakash, Saravana Kumar Deivanathan (2024). A Green approach of Ag and Au Nanoparticles, Properties and its Applications: A Review. International Journal of Current Science Research and Review, 7(1), 481-491