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Green Nanochemistry Approaches for Cancer Therapy

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ABSTRACT
Green nanochemistry has become an important sustainable method for producing nanoparticles for cancer therapy. Unlike traditional chemical synthesis that relies on hazardous reagents, green approaches use natural biological resources to reduce and stabilize nanoparticles, making the process safer for both human health and the environment. Several eco-friendly strategies exist, including plant-based synthesis using phytochemicals, microbial synthesis involving bacteria, fungi, and yeast, algal-mediated production using bioactive marine or freshwater algae, and biopolymer-assisted methods that employ materials like chitosan, cellulose, and starch to improve nanoparticle stability and biocompatibility. Nanomaterials generated through these green routes have shown promising applications incontrolled release, imaging, and advanced treatments like photodynamic and photothermal therapy They often exhibit enhanced safety and reduced toxicity compared to chemically produced nanoparticles. However, issues like limited reproducibility, difficulties in large-scale production, and incomplete knowledge of their behavior in the tumor microenvironment remain challenges. Strengthening interdisciplinary efforts among chemists, biologists, and oncologists will be essential for developing reliable, affordable, and sustainable nano-therapeutic platforms for cancer diagnosis and treatment

KEY WORDS: Green Nano chemistry, cancer therapy , Photo thermal therapy, biocompatible nanoparticle, eco-friendly Synthetises, Targeted delivery , Therapeutic efficacy.

I. INTRODUCTION

Green nanochemistry refers to the sustainable and eco-friendly production of nanoparticles using natural, non-toxic, and renewable biological materials. Instead of relying on hazardous chemical reagents, it utilizes plant extracts, microorganisms, algae, and natural polymers to reduce and stabilize nanoparticles. This approach aims to lower environmental pollution, reduce toxicity, save energy, and create biocompatible nanomaterials for applications such as medicine, drug delivery, and cancer treatment.

Green nanochemistry applies the principles of nanoscience to make processes more environmentally sustainable that might otherwise cause harmful effects. It involves the design and synthesis of nanomaterials through eco-friendly approaches and the development of sustainable nanoproducts. The concept of “GREEN” encompasses both safe, non-toxic synthesis methods and utilizing plant extracts to produce nanoparticles biologically rich in chlorophyll [1]. Traditional nanoparticle fabrication often relies on expensive physical processes or hazardous chemicals, leading to concerns regarding their environmental and biological safety. [1, 2].

Although advancements in cancer diagnosis and therapy have been significant, Traditional chemotherapy still faces major challenges, including poor bioavailability, the need for high doses, multidrug resistance, adverse side effects, and limited tumor selectivity. However, early detection can greatly improve treatment success. Targeted therapies aim to overcome these issues by delivering agents that specifically interact with tumor-promoting genes or proteins, aided by nanoscale innovations. Among these, green-synthesized nanoparticles—particularly gold (AuNPs) and silver (AgNPs)—serve as eco-friendly and biocompatible alternatives to traditional drug delivery systems. precise delivery or act as cytotoxic agents that selectively accumulate in tumor sites. Through controlled drug release, green nanochemistry offers a versatile and sustainable approach to cancer therapy, ensuring efficient delivery, better interaction with surrounding tissues, and safe elimination from the body [3].

Uncontrolled cell growth is a hallmark of cancer.

Making the treatment of rapidly proliferating tumors particularly challenging. Conventional treatment options—such as surgery, radiation, and chemotherapy—carry considerable risks, emphasizing the need for safer and more efficient alternatives like targeted drug delivery combined with controlled release systems [4].

Nanotechnology presents a promising strategy for combating cancer, Because of their exceptional biocompatibility, low toxicity, and versatile physical and optical properties, gold nanoparticles, or AuNPs, are attracting a lot of attention.cancer while causing the least amount of damage to healthy tissues by carefully designing and functionalizing these nanoparticles with targeting molecules.. Additionally, their multifunctional use in diagnostic imaging, photothermal therapy, radiosensitization, and combined immunotherapy makes AuNPs highly effective theranostic agents in modern cancer treatment [4]

PRINCIPAL OF GREEN NANOCHEMISTRY APPROACHES FOR CANCER THERAPY

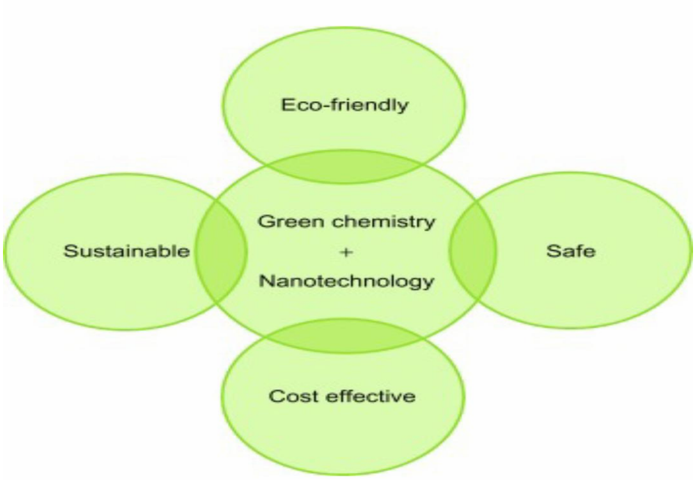

Figure 1: Venn diagram illustrating the key principles of Green Nanochemistry approaches for cancer therapy.

Over the past fifteen years, “green chemistry”has gained significant attention within the broader vision of “sustainable development.” This principle is especially important in chemical industries, which face challenges such as pollution and overexploitation of natural resources. Traditionally, chemistry has been perceived as hazardous, with the term “chemical” often associated with danger and toxicity. Although safety equipment and protocols help reduce risks, their failure in high-risk environments can lead to serious accidents, injuries, or even fatalities. Therefore, creating safe and sustainable chemicals and processes requires minimizing inherent hazards and reducing the chances of accidents and harmful exposure. [5] Applied to nanoparticle synthesis, green chemistry emphasizes three fundamental aspects:

1] Eco friendly sustainable release

The eco-friendly nature, reduced toxicity, cost-effectiveness, higher biocompatibility, and improved control over particle size have made green approaches more favorable for nanomaterial production compared to traditional. A key objective The goal of nanotechnology is to establish efficient and dependable synthesis strategies that can precisely control chemical composition, morphology, and achieve well-dispersed systems suitable for large-scale nanoparticle production. Various sustainable synthesis techniques utilizing Because of their inherent biocompatibility, low toxicity, and affordability. [6]

Eco-friendly solvents, effective reducing agents, and safe stabilizers arekey components in nanoparticle synthesis. A variety and biological methods—are used for their production. While chemical approaches are widely adopted, they are

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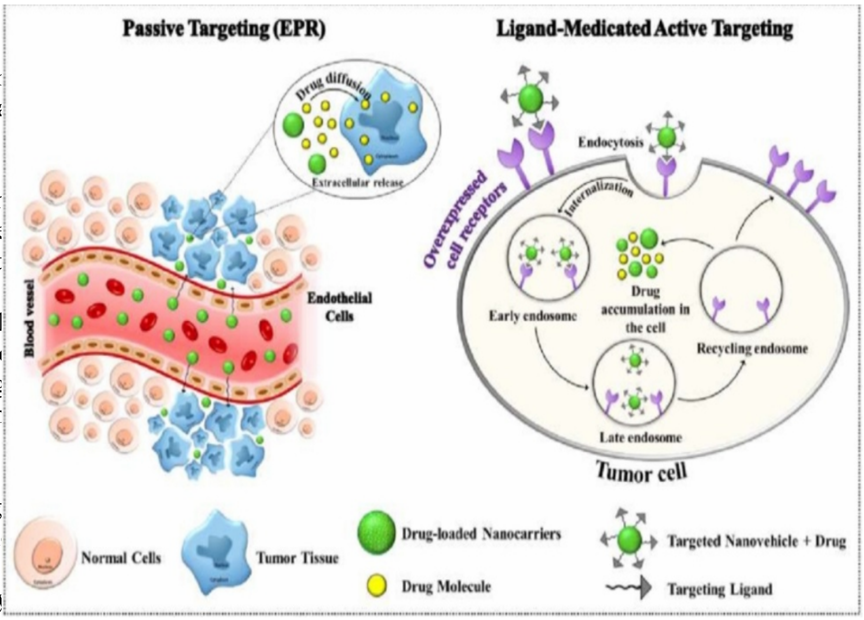
often expensive and rely on hazardous materials that pose environmental threats. In contrast, biosynthetic methods provide a sustainable, biocompatible, and eco-friendly alternative, making use of plants and microorganisms in biomedical application .[6]

2] Reduction of Hazardous chemicals

This principle of green nano chemistry advocates for synthetic methods that use and produce fewer hazardous substances, favoring enzymes instead of toxic chemicals to make the process non-toxic, instance, in a polycarbonate, a l chloride was repla dichloromethane eliminated.[7]

Green nanotechr chemicals by synthe substitutes like wat toxic reagents and through the appl principles, specifi nanomaterials using techniques. To m nanoparticles for remediation and designing for deg steps, and using ren

3] Biocompatibility



Biogenic nanoparticles have been recognized for their strong anticancer potential, though the specific mechanisms behind their effects are not yet completely clarified. Their activity depends largely on the phytochemical composition and how they interact with cancer cells. The binding or coating of phytochemicals on the nanoparticles enhances their functional properties and increases apoptosis (programmed cell death) in cancer cells. These nanoparticles exhibit anticancer behavior mainly through two mechanisms—surface attachment and cellular absorption. may decompose within body fluids after administration, while stable nanoparticles successfully reach and act on the target cancer cells. Although the ions released in biological fluids can also possess anticancer activity, they tend to be less selective toward cancer cells. To improve the stability of unstable nanoparticles, techniques like nano-encapsulation or nano-formulation are employed. Biogenic nanoparticles inhibit cancer cell growth by generating reactive oxygen species (ROS), which damage the cell membrane, degrade membrane proteins, disturb transmembrane electron transport, and lead to apoptosis. Hence, these nanoparticles serve as an effective andbiocompatible approach for reducing toxicity in cancer therapy. [9]

4]Targeted Therapy & Functionalization

Nanocarriers deliver drugs to tumors primarily. Inthe process takes advantage of the physicochemical traits of nanoparticles as well as the unique pathophysiological conditions of cancer. To achieve this, nanoparticle size and surface

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properties must be carefully regulated to prevent rapid elimination through renal clearance or removal by the mononuclear phagocyte system (MPS) thereby extending their circulation time in the bloodstream. Additionally, solid tumors display abnormal angiogenesis, resulting in leaky and irregular blood vessels with poorly organized endothelial junctions.[9]

Figure 2: Schematic representation of nanocarrier-mediated drug delivery to tumors via passive targeting.

5] Sustainable & Scalable Production

This transformation is generally mediated by biomolecules like proteins, enzymes, and metabolites, which have inherent reducing and stabilizing properties. Enzymes, in particular, hold significant promise for biotechnological applications because of their catalytic capabilities and role in complex synthesis. Research also indicates that the interaction of enzymes or their substrates with nanoparticles can enhance catalytic activity on the particle surface. Moreover, enzymes are fundamental to cellular functions as they drive various metabolic reactions.[10]

6] Multifunctionality (Theranostics)

Theranostics represents an innovative approach that combines both therapy and diagnosis within a single platform, aiming to provide precise cancer detection and treatment. This concept is considered a major advancement in overcoming. Nanoparticles serve as excellent carriers for theranostic agents because of their unique physicochemical features, including nanoscale dimensions, modifiable functional properties, ability to achieve active or passive tumor targeting, efficient cellular uptake, and superior optical characteristics. These qualities make them highly suitable for simultaneous imaging and phototherapy. With progress in nanotechnology and medical science, both metallic and biological nanomaterials have greatly contributed to improving cancer treatment and advancing personalized medicine.[11]

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TYPES OF NANOPARTICLES

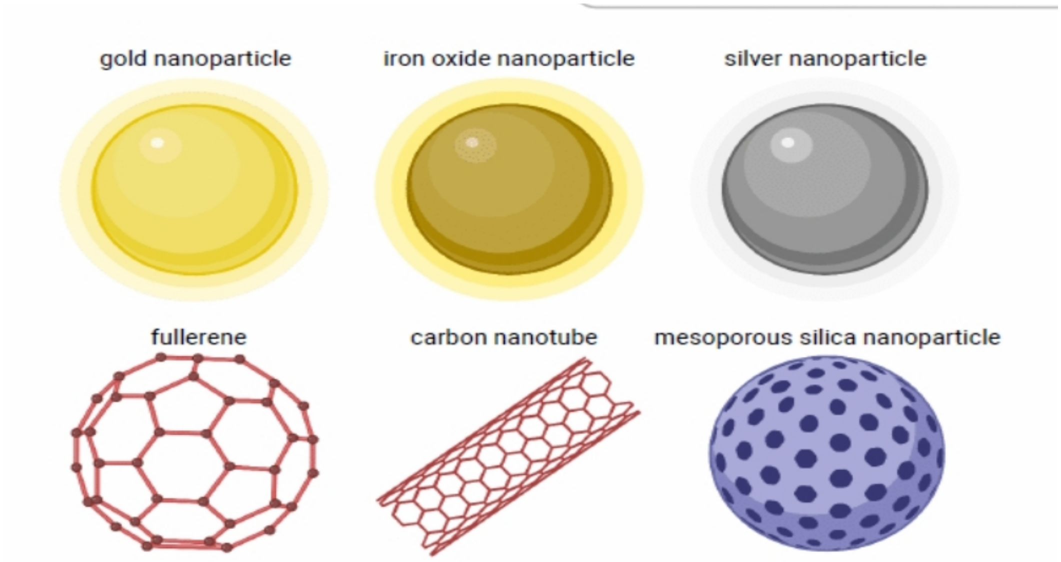

Figure 3: Different types of nanoparticles.

Gold Nanoparticles

Because of their many chemical and physical synthesis methods, gold nanoparticles (AuNPs) have become increasingly important in the biomedical and medical fields. Green synthesis, a cost-effective and environmentally friendly method of producing nanoparticles from phytochemicals and other secondary metabolites derived from plants, has garnered more attention recently. Green-synthesized AuNPs' distinct physicochemical characteristics and therapeutic mechanisms are being studied for the treatment of cancer. A deeper comprehension of these processes may facilitate the creation of more specialized cancer medications and therapies. [12].

Because of its strong resistance to oxidation and chemical inertness, which allow it to retain its structure and luster for extended periods of time without corroding, gold is considered a noble metal. A variety of techniques, including physical, chemical, biological, and green synthesis [13] Their function in tumor targeting has received more attention lately. Gold-based nanoparticles have a lot of promise for treating cancer, particularly if they are made to target specific targets. Additionally, they can increase their antitumor activity.
Through coating or surface functionalization, making them suitable for use in prognosis, bioimaging, diagnostics, and therapeutic interventions [14].

Silver Nanoparticles

From two key angles, silver nanoparticles (AgNPs) offer a promising approach to cancer treatment: they have anticancer properties of their own and can serve as carriers for anticancer medications, providing a dual therapeutic effect. In the latter instance, as was previously mentioned, using delivery systems based on nanoparticles offers a number of benefits over using free anticancer agents. In addition to these advantages, silver has anticancer properties. It is crucial to keep up with the most recent findings about silver nanoparticles in combination with anticancer medications and to evaluate their potential as a therapeutic approach, given the continuous difficulties in attaining successful cancer treatment. Consequently, this review will provide an overview of the results fromCellular tests were documented for every pertinent study in the scientific literature. [15]

The most widely used of these is still chemical reduction, which usually Nevertheless, this method frequently causes toxicity and environmental issues [16, 17]. which materials like microbes, or natural polymers promote nanoparticle formation in mild conditions, has thus gained popularity as a safer and more sustainable alternative [18, 19]. AgNPs are being utilized more and more in biosensing and electrochemical sensing platforms because of their exceptional catalytic and electrical properties [20].Despite having a well-established antimicrobial potential, little is known about the mechanisms underlying how they interact with biological systems.

Microbial cell death may result from these nanoparticles' disruption of essential cellular constituents[21].

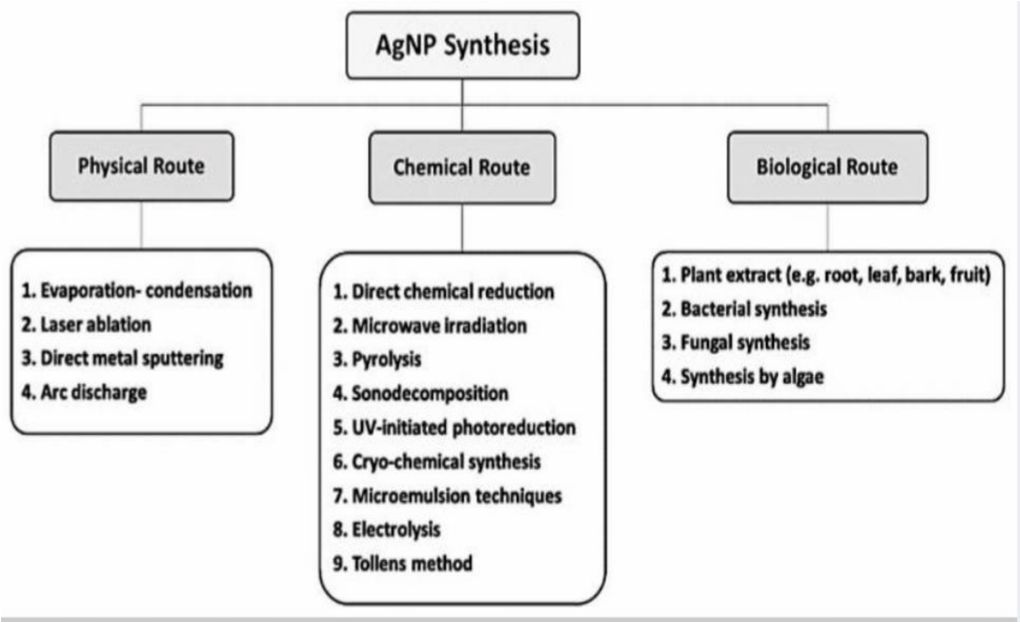

Figure 4:Different routes of AgNPs Synthesis

Copper nanoparticles

Because they contain phytochemicals that including flavonoids, polyphenols, terpenoids, and alkaloids, plants are an invaluable resource for the production of nanoparticles [23]. This method facilitates the combining a copper salt solution with aqueous extracts of leaves, stems, roots, or fruits under carefully regulated [24].

Numerous Bioactive substances found in these plants stabilize the nanoparticles in addition to lowering copper ions [24]. For example, Aloe vera leaf extract's polysaccharides and phenolic compounds effectively transform Cu2+ ions into CuNPs while inhibiting particle aggregation [25].

Plant-mediated synthesis offers several benefits, including a simple preparation process, easy availability of raw materials, and production of biocompatible nanoparticles. Furthermore, bioactive molecules present The synthesized CuNPs' potential for biomedical applications can be increased by the plant extracts' ability to give them therapeutic qualities.[22,23].

SYNTHETISIS OF GREEN NANOPARTICLES IN CANCER THERAPY

Plant mediated synthetisis

Plant-derived nanomaterials (PDNMs) have recently attracted growing interest due to their distinctive characteristics, including rich bioactive compounds that enable improved drug delivery, controlled release, minimized immunogenicity, and enhanced therapeutic outcomes. The green synthesis of nanomaterials, an essential domain of nanotechnology, shows great potential for diverse biomedical applications such as diagnostics, immunotherapy, regenerative medicine, and biosensing. Despite these advantages, in-depth reviews highlighting the remarkable biocompatibility and safety of PDNMs, particularly their involvement in PANoptosis-driven tumor suppression, remain limited.with a focus on the integration of natural resources and nanotechnology as an advanced therapeutic strategy. By shedding light on the underexplored role of PDNMs in regulating PANoptosis-associated inflammatory cell death, this study underscores their synergistic promise in cancer nanotherapy.[26]

Biological approaches generally enable simple and efficient nanoparticle production without requiring high temperatures, toxic chemicals, or stringent conditions, while utilizing eco-friendly and cost-effective resources. Various biological systems, including plants, algae, fungi, and yeast, are employed in nanoparticle fabrication.[27]

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Algae mediated synthetisis

Algae-assisted synthesis offers several benefits compared to plant-based methods, as it enables faster and simpler nanoparticle production under ambient pressure, room temperature, and normal pH conditions in aqueous solutions. Moreover, it is highly scalable, easy to manage, naturally abundant, eco-friendly, and poses minimal risk to both workers and the environment. Algae also have the unique capability to generate These advantages have the potential to significantly boost the advancement of novel algal nanomaterials with distinctive features and applications. Consequently, research on algae-driven biosynthesis of metallic nanoparticles has given rise to a specialized field known as phyco-nanotechnology.[28]

Because of their small size (measured in nanometers), NPs have a large surface area and tissue barrier to reach their target location. Due to their poor solubility, some natural anticancer medications, like camptothecin, may not be used; nanotechnology provides innovative solutions to overcome these challenges. When administered, hydrophobic medications after being encapsulated in them, which makes them soluble.[29]

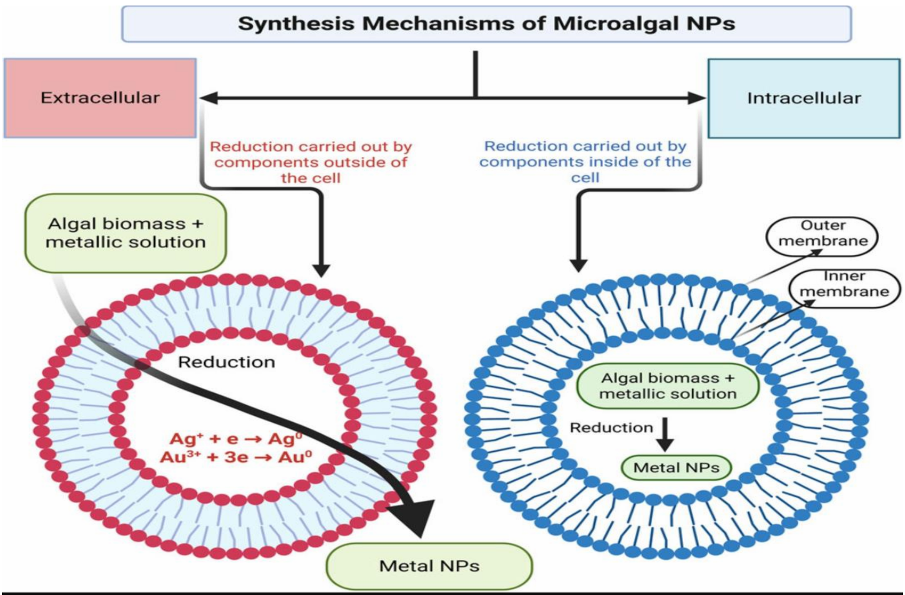

Figure 5: synthesis mechanisms of microbial NPs

3] Biopolymer assisted method

The development of Anticancer agents loaded into nanocarriers (NCs) is revolutionizing treatment methods, offering remarkable advantages over traditional drug delivery systems. These NCs are meticulously designed to protect encapsulated drugs from premature degradation while ensuring their targeted delivery to tumor cells. Their inherent

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biocompatibility enhances therapeutic efficiency and prolongs their circulation time within the body.
highly valued for their non-toxic nature, excellent biocompatibility, and biodegradability. Although synthetic polymers have long supported research in this field, Natural polymers that are becoming more and more popular include capacity to encapsulate medications without undergoing chemical alteration contributes to the preservation of the active ingredients' inherent qualities and therapeutic potential.

Researchers have developed various innovative formulation techniques that produce nanoparticles capable of enhancing therapeutic outcomes against cancer cells. These advancements provide a thorough comprehension of the potential of biopolymers as effective and biocompatible materials for the upcoming nanomedicine generation. [30]

Approaches for cancer therapy in green Nano chemistry

1] Targeted drug delivery

Green nanochemistry–based targeted drug delivery involves using biologically synthesized, eco-friendly nanoparticles to transport anticancer drugs specifically to tumor sites while reducing toxicity to healthy tissues. Natural agents from plants, microbes, algae, and biopolymers act as reducing and stabilizing molecules, forming biocompatible nanoparticles having functional groups suitable for drug loading and ligand attachment. These green nanocarriers promote tumor accumulation by passively targeting with Their natural coatings allow for controlled or stimuli-responsive drug release, improve circulation stability, and reduce side effects. Therefore, green-synthesized nanoparticles present a promising platform for targeted carcinoma treatment that is safer and more effective. [31]

Targeted Systems for delivering drugs areinnovative therapeutic approaches that provide anticancer drugs specifically to tumor sites while limiting harm to surrounding healthy tissues. These systems rely on nanocarriers—such as nanoparticles, liposomes, or polymer-based particles—designed highly expressed cancerous.Within green nanochemistry, such nanocarriers are produced using environmentally friendly biological resources like plant extracts, microbes, or algae, which improves their safety, biocompatibility, and stability. Using both passively aiming through The EPR effect, green-synthesized nanoparticles achieve efficient drug buildup in tumors. This results in a more sustainable approach to cancer treatment, better therapeutic results, and fewer side effects. [31]

2] Photothermal and photodynamic therapy

Among various nanotheranostic techniques, PTT (photothermal therapy) and PDT (photodynamic therapy) are twoare particularly notable for their precise targeting mechanisms. In PTT, light energy is utilized to generate localized heat, leading to In contrast, PDT involves the activation of photosensitizers by light to promote apoptosis within cancerous cell.[32]

By rupturing cell membranes and denaturing proteins, this technique rapidly kills cells by reaching either coagulative levels (55–100°C) or subcoagulative temperatures (43–55°C) with relatively high light intensities.

(Hx) is defined as mild heating between 41 and 43 °C.By inducing heat shock protein expression and altering tumor blood flow and metabolism, Hx alone can improve the efficacy and specificity of other treatments like chemotherapy and radiation therapy, even though it Is not fatal to tumors unless maintained for prolonged periods of time (more than an hour). [32]

Photothermal therapy (PTT) can be applied independently, guided through multimodal imaging, or used in combination with existing treatment approaches to enhance therapeutic outcomes. To date, PTT and its combination therapies have been explored in animal models with lung, bone, and lymph node metastases from various cancers, demonstrating significant therapeutic potential.[32]

Photodynamic therapy (PDT) has become an effective cancer treatment approach, yet its success is limited by the low oxygen levels in tumor tissues. To address this challenge, a biomimetic nanosystem was developed to improve the efficiency of oxygen-dependent PDT. The system is made up of Fe-doped polydiaminopyridine (Fe-PDAP) nanoenzymes that behave like catalase and were co-loaded with indocyanine green (ICG) and metformin (Met). Platelet membranes (PM) were added to the nanoparticles to allow for tumor-specific targeting via biological recognition. Analysis conducted in vivo and in vitro verified that Fe-PDAP nanoenzymes could decompose excess hydrogen peroxide (H O) into oxygen (O) while simultaneously consuming intracellular glutathione (GSH). This dual action elevated reactive oxygen species (ROS) production, thereby amplifying the overall photodynamic therapeutic efficacy.[32]

3] Imaging and Diagnostics

Magnetic nanoparticles (MNPs) are highly promising materials that integrate optical, magnetic, electrical,and mechanical characteristics in a unique, cutting-edge (stimuli-responsive) nanotechnology, which makes them useful instruments for improving tumor treatment. These nanoparticles can be synthesized using various bottom-up approaches, among which biological methods are particularly advantageous. Such eco-friendly strategies utilize renewable resources, require minimal equipment, and are cost-effective—an essential advantage for developing countries aiming to strengthen their anticancer research capabilities.[33]

Furthermore, biosynthesis is a simple and sustainable method that produces nanoparticles with non-toxic, biodegradable cores and coatings, which can positively influence cellular and physiological systems. In this context, plant-derived materials and microbial .These biological extracts contain phytochemicals and enzymes that act as capping and reducing agents during nanoparticle formation.[33]

Both optical and fluorescence imaging

Optical imaging is the visualization of molecular or cellular interactions through the use of light. Depending on the structure and composition of the biological tissue, photons may be absorbed, reflected, or scattered as they pass through it.These optical interactions are analyzed through various imaging methods to generate distinctive spectral patterns. For instance, Raman spectroscopy measures the inelastic scattering of photons, while fluorescence imaging involves light absorption followed by emission.[34]

Fluorescence imaging is an important technique in cancer diagnostics because it can visualize structures at both microscopic and molecular levels with high spatial precision. However, its imaging depth is limited due to light scattering within biological tissues. This limitation can be reduced by using near-infrared (NIR) fluorescent probes, which enable deeper tissue penetration and improved image clarity because of their lower absorption and scattering by soft tissues.[35]

APPLICATIONS OF NANOPARTICLES PRODUCED FROM GREEN SOURCE IN IMAGING AND THERAPY

By combining imaging and therapeutic capabilities into a single nanoplatform, the creation of green-synthesized nanoparticles has revolutionized cancer diagnosis and exceptional biocompatibility,these environmentally friendly nanostructures—which come from natural sources like plant extracts, microorganisms, and biopolymers—are ideal for use in biomedicine.

1. Imaging Applications

Green-synthesized metal and nonmetal nanoparticles are widely employed as contrast enhancers in several diagnostic imaging techniques. Gold (AuNPs), silver (AgNPs), and For magnetic resonance, magnetic nanoparticles (MNPs) are especially usefulcomputed tomography (CT), fluorescence, and photoacoustic imaging. Their LSPR, or localized surface plasmon resonance and intrinsic magnetic characteristics significantly improve image contrast, sensitivity, and tumor detection precision. In addition, Materials based on carbon, like carbon dots (C-dots) and graphene oxide (GO) possess strong and stable fluorescence, enabling real-time cellular imaging and tumor visualization. The application of near-infrared (NIR) probes further enhances imaging resolution and tissue penetration while minimizing background noise.[35]

2. Therapeutic Applications

Targeted transport to malignant tissues through both passive and active mechanisms. Gold and magnetic nanoparticles can convert light or magnetic energy into localized heat, resulting in selective destruction of tumor cells with minimal harm to normal tissues. Similarly, silver nanoparticles and carbon-based nanostructures promote. thereby improving the effectiveness of PDT and inducing cancer cell apoptosis.[34]

3. Theranostic Integrating

Combining therapeutic and imaging capabilities into one green-synthesized nanostructure—an approach referred to as theranostics—marks a significant breakthrough in nanomedicine. These multifunctional systems enable simultaneous tumor identification, drug delivery, and treatment monitoring, leading to better therapeutic results, decreased side effects, and increased precision. [40]

All things considered, green nanotechnology provides an environmentally friendly and sustainable responsible pathway for advancing next-generation cancer diagnostic and therapeutic systems, reducing ecological impact while maintaining high clinical efficiency.

CURRENT CHALLENGES IN GREEN NANOCHEMISTRY APPROACHES FOR CANCER THERAPY

Although green nanochemistry presents a sustainable and eco-friendly cancer treatment option, several obstacles prevent its widespread production and clinical use. These issues are primarily brought on by uncertainties in biosafety, a lack of understanding of biological mechanisms, and uneven synthesis.

Inadequate Mechanism Knowledge

Although green-synthesized nanoparticles have strong anticancer properties, it is still unknown what precise molecular and cellular mechanisms underlie these therapeutic advantages. Their interactions with cellular proteins, DNA, and organelles, as well as their metabolic and excretory pathways, need to be thoroughly studied [36].

Concerns about biosafety and toxicity

Despite their environmentally friendly synthesis, green nanoparticles can still have toxicity, oxidative stress, or genotoxic effects in specific circumstances. The potential accumulation of nanoparticles in vital organs and their long-term biological impacts are still being investigated. Comprehensive in vivo studies and environmental assessments are required to ascertain their safety profiles and biocompatibility [37].

Industrial Limitations and Scale-Up

There are many challenges when bringing green synthesis from the lab to the industrial setting. Variations in biological raw materials and environmental factors make it difficult to maintain nanoparticle stability and uniformity during mass production. Another major challenge is maintaining cost-effective production while satisfying regulatory and quality requirements [38].

Clinical Translation Is Limited

Few green-synthesized nanoparticles have made it to clinical testing or approval, despite the fact that many preclinical studies have shown encouraging results. Their introduction into clinical practice is delayed by complicated approval processes, a lack of standardized toxicity assessments, and inadequate pharmacokinetic data. Successful clinical advancement requires improved cooperation between regulatory agencies and interdisciplinary researchers [39]

II. FUTURE PROSPECTIVE

Green nanochemistry is still showing promise as a sustainable cancer treatment approach, but it will only reach its full potential with targeted study and methodical advancement. In the future, efforts should focus on developing dependable and standardized synthesis processes that guarantee consistent properties of nanoparticles, including stability, homogeneity, and biological activity. Must be accomplished.

Equally crucial is a better comprehension of the interactions between "green"-synthesized nanoparticles and biological systems. Verifying their suitability for clinical use will require looking into their distribution, metabolism, absorption, and long-term safety. Additionally, investigating the ways in which different compounds derived from plants or microorganisms affect their structure and therapeutic efficacy may help direct the development of more potent nanomaterials.

Multifunctional nanosystems that can be used for both diagnosis and treatment can be created by combining green nanotechnology with cutting-edge computational tools, molecular modeling, and real-time imaging. With a single platform, these "theranostic" techniques might enable accurate tumor identification, focused treatment, and ongoing treatment outcome monitoring.

Sustainability ought to continue to be a fundamental idea. Biodegradable materials, low-energy production methods, and renewable natural precursors can reduce environmental impact while maintaining biological efficiency. Furthermore, ensuring economical production will enable healthcare systems in both developed and developing nations to use these nanotechnologies.

In conclusion, interdisciplinary cooperation between engineers, scientists, andand clinicians is essential to the future of green nanochemistry in cancer treatment. These environmentally friendly nanosystems could develop into workable and secure ways to enhance cancer diagnosis and treatment globally with continued innovation and improvement.

III. CONCLUSION

Green nanochemistry is a cutting-edge and ecologically friendly approach to improving cancer treatment. Utilizing natural resources like microorganisms and plant extracts reduces ecological hazards while improving the safety and biocompatibility of nanoparticles. With promising results in preclinical and laboratory models Nonetheless, the field continues to face challenges, such as uneven synthesis techniques, inadequate toxicity evaluation, and difficulties with large-scale production. Translating this technology into clinical use will require overcoming these obstacles through interdisciplinary cooperation, increased biological understanding, and better production methods. Ultimately, there is a lot of potential for creating safer, more efficient, and environmentally friendly cancer treatments through the combination of green nanotechnology and precision medicine.

To overcome these challenges, it will require consistent effort to enhance synthesis techniques, carry out thorough biocompatibility analyses, and encourage collaboration among scientists from different disciplines. With more research and development, green nanochemistry may one day transform cancer treatment into a safer, more efficient, and environmentally friendly medical approach.

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