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Exploring the Frontiers of Green Nanotechnology: Advancing Biomedicine, Herbonanoceuticals, Environment, and Sustainability

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Abstract

Green nanotechnology represents a burgeoning field that holds immense promise in the realm of nutraceuticals and pharmaceuticals. This comprehensive review explores the multifaceted applications of green nanotechnology, offering an extensive analysis of its potential and current achievements in these vital sectors. The utilization of plant extracts and natural compounds as reducing and stabilizing agents for nanoparticles is a key focus of this review. The discussion encompasses various synthesis techniques, shedding light on the innovative developments and methods that researchers employ to harness the full potential of green nanotechnology. The array of applications covered in this review spans applications in drug delivery systems and nanomedicine to imaging and diagnostics and environmental applications. We underscore the significance of maintaining nanoparticle stability and bioavailability throughout their journey within the body, addressing critical issues related to nanotoxicology, in vivo testing, and formulation development. Furthermore, this review emphasizes the pivotal role of green nanotechnology in nutraceuticals and pharmaceuticals by elucidating its contributions to enhanced drug efficacy, reduced side effects, and improved patient outcomes. In conclusion, the blend of green nanotechnology with nutraceuticals and pharmaceuticals offers a remarkable opportunity to revolutionize the healthcare landscape. By harnessing the potential of plant-derived nanoparticles and innovative synthesis methods, researchers and industries alike are poised to unlock new frontiers in drug delivery, diagnostics, and patient care.

Keywords: *Nanomaterial, Herbonanoceuticals, Medicine, Phytotherapeutics, Nanotechnology, Food, Nano-chemicals, Herbal Satellites.*

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Introduction

A recent study in biomedicine has harnessed the potential of an ancient substance from the annals of materials used in the ancient world. Perhaps this breakthrough finds its roots in an age-old practice of delving into ancient texts on vision and development. For more than a decade, food has played a pivotal role in our intellectual pursuits, yet it remains an ever-evolving field of study and is now an integral part of Clinical Research Laboratories.

Numerous herbal remedies and functional foods have proven effective in supporting the treatment of various diseases (Olatunde *et al*., 2020; Walag *et al*., 2020). At present, the new frontier is "nanotechnology" and its application in science, design, and educational curricula (Roco, 2003; Wilson *et al*., 2002). However, the existence of nanoscale materials has been confirmed for thousands of years, as evidenced by ancient manuscripts (Walter *et al*., 2006; Sudhakar, 2009).

Plant-based medicine has held a significant position in healthcare since ancient times, owing to its complementary role and yield in various formulations. Both developed and developing countries have created locally sourced medicines, although their acceptance and yield have been limited. The rapid advancement of nanotechnology has provided robust support for innovative pharmaceutical solutions (Egbuna *et al*., 2018). Nutraceuticals, which encompass foods and diets promoting good health while facilitating nutrient absorption, often face challenges in terms of bioavailability. The application of nanotechnology has shown promise in overcoming these hurdles related to solubility, bioavailability, stability, and transport of food-derived biomaterials. The rapid progress in nutraceutical nanotechnology holds unique potential for delivering a wide array of beneficial nutrients, which can aid in preserving forests and inform treatment strategies for certain non-communicable diseases (Egbuna *et al*., 2022). Research is currently underway on various nanomaterial processing systems in the field of nanotechnology for drug and nutrient delivery to adults (Fabricant *et al*., 2001). Research efforts are also directed towards the integration of nanotechnology, natural treatments, and nutrient supplementation, contributing to the burgeoning fields of nutrition and biomedicine.

Another global biomedical innovation involves incorporating modern technology into metallurgy. Comprehensive reviews of nanomaterial selection for supplements highlight the potential benefits that can be absorbed by the body. This study aims to elucidate the utilization of these substances for incorporating nanomaterials into biomedical applications, sparking a novel concept termed "herbal satellites." Ultimately, this concept involves controlled substances at the nanoscale, enhancing their constituents' participation in maintaining the body's healthy functions. The clinical study of medicinal plants aims to preserve nutrient-rich biomolecules that are expected to promote health and combat diseases. Historical records indicate that plants, along with various other materials, have been used for this purpose since the Paleolithic era some 60,000 years ago (Bardhan *et al*., 2004).

In a recent study by Bernela *et al*. (2023), nanoparticles were employed to enhance the germination of medicinal plants, showcasing their potential for cultivation.

Tracing back through human history, spices have held a pivotal role in global regeneration and development for millennia (Bardhan *et al*., 2004). In the extraction process, natural materials such as pure mulch for flour, pigments, dyes, and various concoctions have been utilized (Yadav *et al*., 2014). These materials were curated for researchers to classify, match, and quantify plant extracts, ultimately unveiling their medicinal properties. Some aspects of this age-old practice are still employed as a starting point (Griggs, 1982). Approximately 119 attributes have been identified in a variety of plants, and these trees are used medicinally worldwide, especially in countries like China, Japan, Egypt, Brazil, and India (Samuelsson, 2004).

The World Health Organization (WHO) has described the traditional dietary system, characterized by home-cooked meals, which prevailed for many years before the advent of modern interventions and the expansion of today's aid programs (WHO, 1991). In non-industrialized countries, reclaimed plants remain a primary source of sustenance for about 80% of individuals, due to their accessibility, nutritional value, cultural significance, origin, and acceptability (Rates, 2001).

Green Nanotechnology in Sustainable Development

Nanotechnology has garnered global attention as a transformative innovation for the 21st century. However, its progress has been hampered by the lack of comprehensive understanding regarding potential risks and a limited framework for analyzing emerging hazards. Despite these challenges, professionals in the field are actively addressing them through effective management, creative problem-solving, dedicated support, and a commitment to professionalism.

One promising approach in this realm is green nanotechnology, a relatively new concept that draws inspiration from the natural world. Green nanotechnology involves harnessing plant-based materials to reduce energy and fuel consumption, offering sustainable alternatives to conventional, non-organic resources. It holds the potential to revolutionize environmental conservation by preserving precious natural resources, optimizing energy usage, and reducing water consumption. Additionally, green nanotechnology can help mitigate ozone depletion and hazardous risks associated with traditional manufacturing processes. In other words, green nanotechnology can be applied in many spheres of human endeavours (Fig. 1).

In the realm of healthcare, green nanotechnology is poised to make a substantial impact on medical diagnosis and drug delivery. Biodegradable and natural nanoparticles are employed to precisely target specific cells, resulting in fewer side effects and enhanced therapeutic efficacy. Moreover, this approach contributes to sustainable energy solutions, such as solar cells and batteries, by improving their efficiency while minimizing their environmental footprint.

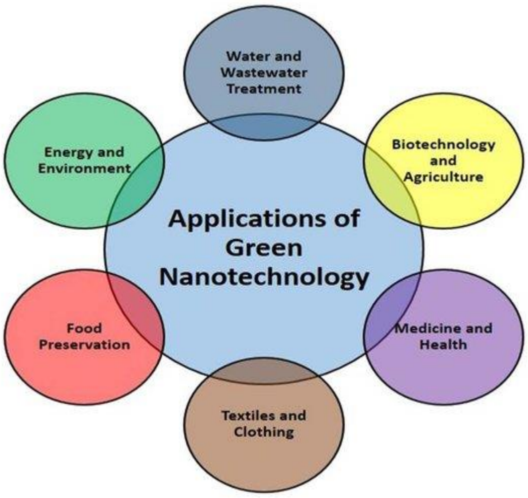

Figure 1: Application of green nanotechnology.
Source: Goutam *et al*. (2020).

Green Nanotechnology in Pharmacy and Medicine

In recent years, green nanotechnology has made significant contributions to the field of medicine by enhancing the delivery of potent and targeted drugs, as noted by Kumar *et al*. (2015). This advancement has played a crucial role in reducing the side effects of medications, thus benefiting patients worldwide. Moreover, there has been a notable resurgence of interest in traditional and natural medicine across many countries. The World Health Organization (WHO) defines traditional remedies as therapeutic interventions with substantial historical and cultural backing, often originating from plants, animals, and minerals. WHO reports indicate that approximately 80% of the population in developing countries turn to traditional medicines for their healthcare needs, as highlighted by Yadav *et al.* (2014). This global renaissance of traditional medicine is driven by growing concerns about the costs associated with allopathic medicine, tracing its roots back to traditional therapeutic interventions, as demonstrated by Batwardhan *et al*. (2004).

Traditional or herbal medicine finds widespread usage in countries like China, Egypt, various parts of Africa, the Americas, and India. Herbal medicine, also known as phytotherapy or botanical medicine, involves the treatment of ailments using herbs or plants, which can be administered orally or applied topically, as established by Griggs in 1982. While ongoing debates surround the unique properties of traditional remedies, many healthcare professionals today recognize the potential therapeutic effects of these natural compounds, as underscored by Sharma *et al*. (2011). The synergy between green nanotechnology and traditional medicine presents a promising avenue for developing innovative, sustainable, and effective healthcare solutions in the future.

Drugs at Home Thrive

One of the oldest forms of medical treatment is herbal therapy. Plant characteristics can be of great significance in human healthcare (Mathur, 2016). The increasing global population, limited access to anti-infective drugs with minimal side effects, and the emergence of complications such as multi-drug resistance from harmful microorganisms have driven the development of herbal remedies for various diseases (Greenwell & Rahman, 2015). Botanical medicine, or phytopharmaceuticals, refers to complex mixtures derived from plant materials and used for medicinal purposes. Nearly half of the effective drugs originate from plants (Kingston, 2011).

Spices and Metals in Medicines

As an alternative treatment option, therapists have gained worldwide recognition. Ayurveda, the traditional Indian system of medicine (including spices and minerals), places a strong emphasis on resources and formulations tailored to specific conditions for treating various ailments (Mathur, 2016). Minerals and vitamins play a very significant role in the body especially for its antioxidant roles (Akram *et al.*, 2020). Plant species used in Ayurveda make up a substantial portion, accounting for up to 6% of all plant species (Greenwell & Rahman, 2015).

During the Samhita period (600-1000 BC), iron was described in Ayurvedic terms as Ayaskrati. Ayurvedic elements like mercury (parada), gold (swarna), silver (ragata), copper (tamra), iron (laoha), tin (vanga), tin (dragon), and zinc (Yasada) are considered non-toxic. The evolution of Rasashastra in the 7th century AD led to the emergence of various definitions of treatment and new Ayurvedic therapies, including Shodana, Jarana, and Marana (Kingston, 2011).

The process of using Rasashastra can transform minerals into genuine medicine, enhancing their absorbability, therapeutic efficacy, and reducing toxicity. Different preparations of basma reduce its size and enhance its therapeutic potential. These preparations involve reducing metals to ash, followed by purification through heating, cooling in specific liquids, and combining with pure substances, especially spices (Mahima *et al*., 2012).

Experimental literature suggests that Ayurvedic preparations involving scales can reduce particle size to the nanometer level (Mathur, 2016). Choudhury (2011) categorized various basmas, including gold, iron, and copper, according to Ayurvedic principles. Techniques such as X-ray diffraction and scanning electron microscopy have been used to detect nano-scale metal deposits. Pavani *et al.* (2013) introduced a life cycle approach to incorporating alternatives using modified bhasmikaran technology (route-bazmas planning). Electron microscopy results coupled with X-ray diffraction revealed the growth of nanoparticles through the Ayurvedic Basmikaran method.

The small size of these nanoparticles is particularly interesting because it allows the minerals and substances that make up the body to interact more effectively. Combining minerals and spices aids in the absorption and transfer of inert chemicals into the human body. This example illustrates how a combination of different elements can yield remarkable results. The question that arises is how to prepare and arrange these minerals to create exceptional medical devices. Currently, there is a growing interest in the use of nanostructures in the field of Ayurveda. Therefore, leveraging nanotechnology to implement these findings represents an exciting step toward defining alternative materials that can deliver outstanding performance.

Green Synthesis of Nanoparticles

Raw materials for nanoparticle synthesis include nutrients, sugars, plant products/natural products and other perishable substances. Plant extracts could serve as effective reducing agents due to their organic strength against metal sources (Iravani, 2011). Polyphenols found in plants are key in this process, as they reduce energy and facilitate the binding of nanoparticles, primarily via -OH groups. Gold nanoparticles, known for their biocompatibility, are widely employed in nanotechnology (Bhattacharya *et al*., 2008).

Gold nanoparticles can be modified through various techniques. Geetha *et al*. (2013) synthesized gold nanoparticles using the flowering period of the *Couroupita guianensis* plant, demonstrating that its assembly is fast and cost-effective. Iram *et al*. (2014) used glucoxylane from *Mimosa pudica* seeds to extract gold nanoparticles without preservatives, revealing that the nanoparticles measure 40 nm in size. Molecular phytotoxicity testing showed no significant adverse effects on radish seed germination. There is an urgent need for biosynthesis of gold nanoparticles utilizing *Pelargonium* leaves, which is non-toxic and specialized for ultrasound-based circular systems using high ultrasound power (Franco-Romano *et al*., 2014). It takes only 3.5 minutes in a water solution to reduce gold salt. The seeds have a shelf life of approximately 8 weeks at 4°C without losing efficacy. Eighty percent of the nanoparticles measure 8-20 nm in size, with a width of 12 ± 3 nm.

Various Fourier-transform infrared spectrometry (FTIR) analyses indicate the presence of biomolecules responsible for reducing gold nanoparticles. Lin *et al*. (2013) employed high-intensity laser absorption/ionization mass spectrometry, FTIR, and thin electrophoresis combined with UV absorption to detect the presence of non-nanostructured substances in gold designs and traditional teas. However, further information on gold particles is lacking due to powerful X-ray diffraction spectroscopy and X-ray data limitations. The precise, rapid, and robust process of surface binding to Raman-scattered gold nanoparticles using *Vitis vinifera* leaf extracts has been discussed. The presence of proteins on the surface of gold nanoparticles was demonstrated through "FTIR." These molecules may have applications in diagnosing and treating malignancies and examining unnecessary biomarkers. Water solvents, such as polyols and hot water proteins, are essential for producing gold, silver, gold oxide, and silver nanoparticles from *Anacardium occidentale* leaves (Calmodia *et al*., 2013). Gold nanoparticles have been embedded into the root canal of *Morinda citrifolia* (Shen *et al*., 2011).

Biosynthesis-targeting nanoparticles have shown that *Chrysopogon zizanioides* extracts contain antibacterial, cell-supporting, and cytotoxic compounds. Arunachalam *et al*. (2013) utilized water-soluble *Memecylon umbellatum* to efficiently produce gold nanoparticles. The paper idea from *Euphorbia hirta* (Zayed *et al*., 2014) was employed to spontaneously produce ecologically friendly gold nanoparticles in the study. Fractionation of *Phoenix dactylifera* leaves into gold nanostructures was achieved by coagulating hydroxyl and carbonyl groups present in carbohydrates, flavonoids, tannins, and phenolic acids (Rajan *et al*., 2014). Carboxylic acid from *Garcinia cambogia's* liquid form is a natural resource suitable for generating chemically robust gold nanoparticles of controlled size and shape (Mohan *et al*., 2013). Kumar *et al*. (2012) used the liquid extract of *Terminalia arjuna* products to demonstrate a simple, rapid, and eco-friendly method for synthesizing gold nanoparticles. Also, gold nanoparticles were synthesized using *Ispaghula* seed pods (*Plantago ovata*). Using an aqueous solution of *Piper pedicellatum* from Tamuli *et al*. (2013), a hazardous reduction in gold and silver salts was found. They hypothesized that the synthetic components of *P. pedicellatum* (catechin, an expensive corrosive substance, astronomical corrosion, and primary corrosive) could act as a thinner, more balanced, and hidden corrosive. The formation and enhancement of gold nanoparticles should be attributed to the different components of the fluid. The gold salt in the gold nanoparticles was reduced due to the glucose in the juice, whereas the fructose stabilized itself. In the process, circular-shaped, hex-shaped, and 3D-shaped nanoparticles were generated. In a stationary centrifugation cycle, this study properly reveals the differential separation of nanoparticles. The ring sits on the bottom of the cylinder as they move during centrifugation, separating the store-like forms as the newest division, even if the polygons stay in this configuration. The liquid was also employed as a reducing agent to bind gold nanoparticles in another investigation (Stalin *et al*., 2012). Natural fruit items were used to mix the various shapes and sizes of gold nanoparticles (citrus fruits, reticulated citrus fruits, and Chinese citrus fruits). The size and condition of nanoparticles were linked to the role of structure-like reagents such as 1.0 mM chloride that disrupt the structure (Njagi *et al*., 2011). The water composition of coconut (*Cochlospermum gossypium*) was used to combine gold, silver, and platinum nanoparticles, and the change was mediated by a real layer (Machado *et al*., 2013). The reduction and alteration of gold nanoparticles was caused by aqueous tannins found in *Terminalia chebula* (Wang *et al*., 2014). Bio-reduction of silver salts using hydrophobic breasts has also been revealed Rajiv *et al*. (2013).

The commercial design of soft magnetic nanoparticles is now a pioneering focus in the supply chain, with minute blood samples, microorganisms, and nutrients being processed into iron nanoparticles using bioavailability technology. Machado *et al*. considered the structure of green algae for iron-valence conversion using plant extracts (oak, pomegranate, and green tea), known for their efficacy against iron depletion (III) and water solution inequalities. Notably, various zinc nanoparticles have not been extensively studied. Nagarajan and ArumugamKuppusamy (2013) synthesized zinc oxide nanoparticles using aquatic plants (*Caulerpa peltata* green, *Hypnea valencia* red, and *Sargassum myriocystum* damaged on the ground). FT-IR spectrophotometry indicated the presence of fucoidan photo and amalgam nanoparticles.

A mixture of copper and zinc oxide nanoparticles was synthesized using *Brassica juncea* L., showing that zinc oxide (ZnO) nanoparticles are of different types (Qu *et al*., 2012). Copper has life-enhancing properties (Srivastava, 2009), and copper-containing materials can be used in cleaning treatments and medical trials (Mikolay *et al*., 2010). Certain portions of the chalice have a toxic effect on living organisms. The natural formation of yellow-valence copper nanoparticles is an astounding feat. Plants can convert a substantial amount of copper from the ground into metallic nanoparticles in and around their roots, often with the help of root endoparasites

(Manceau *et al*., 2008). Copper alloys can be blended with most homemade solutions. ThekkaePadil and Cernik (2013) synthesized copper nanoparticles using Karaya peels, a non-toxic coating. Harne *et al*. showed the durability of copper nanoparticles made from an aqueous solution in *Calotropis procera* L. Properties of metals change significantly at the nanoscale, affecting various parts of the human body (Sengupta *et al*., 2014). The combination of ingredients demonstrates the potency of the composition and, at times, yields reactions different from those of nanoparticles and formed compounds.

In general, raw materials selected for blending have inherent properties that contribute to the effectiveness of the resulting nanoparticles. The fabrication of nanoparticles from these materials enhances their utility. Green nanoparticles are currently being produced, offering anti-inflammatory, antimicrobial, and antidiabetic properties.

Application of Green Nanoparticles in Oncology

Geetha *et al*. (2013) developed gold nanoparticles using *Couroupita guianensis* flower heads and conducted anticancer research through MTT assays, DNA inhibition, apoptosis with DAPI staining, and comet assays for DNA damage (Karuppaiya *et al*., 2013). These 12-nanometer gold nanoparticles were prepared from *Dysosma pleiantha* rhizome extract, and they exhibited translational movement, making them bioavailable against HT-1080 cells (human fibrosarcoma cells). Importantly, the gold content resulting from this process didn't affect the growth of any cells and could hinder the entry of chemo-attractant cells into HT-1080 cells by disrupting the actin polymerization pathway (Mukherjee *et al*., 2013). This green herbal extract, derived from an edible plant, displayed anti-cancer properties against various cell lines, including *Pleurotus florida*, A-549 (human cancer), K-562 (myeloid leukemia), HeLa cell line (human cervical), and MDA-MB cells, without causing toxic effects. It was also tested on Vero cells (kidney cells commonly found in African green monkeys) (Mukherjee *et al*., 2012). The process involved a simple, fast, complete, effective, cost-efficient, and environmentally friendly method of treating gold nanoparticles using *Eclipta alba* water-based extract and demonstrating their resistance to malignant breast cancer (MCF-7 and MDA-MB-231) in conjunction with doxorubicin (Vincatporwar *et al*., 2011).

Compound derivatives employing porphyrins as carriers for the delivery of the anti-cancer drug doxorubicin hydrochloride were found to be effective (Chanda *et al*., 2011). Extensive research has shown that hydrogen storage is responsible for the synthesis of doxorubicin hydrochloride and gold nanoparticles. The concentration of doxorubicin hydrochloride delivered via nanoparticles was found to be six times higher than that of acetic acid (pH 4.5) when working under physiological conditions (pH 7.4). It exhibited greater cytotoxicity in LN-229 stem cells (human glioma cells) compared to local doxorubicin hydrochloride. The use of phytochemically reduced gold nanoparticles in conjunction with cinnamon demonstrated distinct light bands between normal human fibroblasts and damaged cells (PC-3 and MCF-7) and can be employed as a specialist to optimize significant cytotoxic/phototoxic differences.

Drug delivery utilizing green nanoparticles is viable due to their high surface area and composition, making metallic nanoparticles suitable for targeted drug delivery. Too few nanoparticles can enter the drug delivery zone and may clog the material. The particles can be situated on the surface or arranged in a free nanoparticle circle, demonstrating a recommended drug delivery system. Green nanoparticles measuring 40 nanometers are suitable for drug delivery as they are not cytotoxic. Such green nanoparticles can be synthesized from various *Punica granatum*-derived products.

Antimicrobial Concept of Green Nanoparticles

Xylose, a monosaccharide found in various natural sources such as grass, corn, walnuts, and cotton seeds, has been utilized to bind gold nanoparticles, which effectively act as antibacterial agents against gram-positive microorganisms (Badwaik *et al*., 2013).

Furthermore, gold nanoparticles combined with a derivative of *Cinnamomum zeylanicum* have exhibited active antibacterial activity against gram-positive *Escherichia coli* and gram-positive *Staphylococcus aureus*, along with antifungal action against *Aspergillus niger* and *Fusarium oxysporum* (Smitha *et al*., 2013). Gold compounds mixed with terminal shrimp water have shown positive antimicrobial effects against *S. aureus*, while displaying a negative impact on E. coli using a standard pool dispersion method (Bankar *et al*., 2010).

Additionally, nanoparticles combined with banana extracts have demonstrated robust antimicrobial resistance against a wide range of infectious agents and bacterial communities (Mariselvam *et al*., 2014). Silver nanoparticles, derived from methanol concentrate and flower-based ethyl acetate acid, have exhibited antimicrobial activity against various pathogens and human bacteria, including *Klebsiella pneumoniae, Bacillus subtilis, Pseudomonas aeruginosa*, and *Salmonella paratyphi* (Agitha *et al*., 2014).

Moreover, gold nanoparticles derived from the leaves of *Plectranthus amboinicus* have been shown to possess antimicrobial potential (Agitha *et al*., 2014). These findings underscore the promising applications of nanoparticles in combating microbial infections and pathogens.

Different Utilizations of Green Nanoparticles

In addition to their availability in nursing homes, the use of these substances is being investigated. The hematopoietic potential and anti-inflammatory agents for synthesizing gold nanoparticles using fenugreek brain cells were studied. In this study, the variability in the limitations of normal sample measurements was compensated for by treating conventional gold nanoparticles (Ghosh *et al*., 2014). The bond strength of methotrexate-coated nanoparticles was reported in a collective review by Gomes *et al*. (2012). In this esteemed report, Venkatachalam *et al*. (2013) evaluated the antidiabetic properties of gold nanoparticles resulting from the reduced concentration of 2-(3-acetoxy-4,4,14-trimethylandrost-8-en-17-yl) propanoic-containing extract of *Cassia auriculata*. In this study, alloxan (150 mg/kg body weight) was administered to men with diabetes with different indicators (0.25, 0.5, 0.75, and 1.0 mg/kg body weight) for 28 days. Insulin levels increased after treatment with gold nanoparticles with an injection of 0.5 mg/kg of body weight. This indicates the uniqueness of the protein tyrosine phosphatase 1B inhibitor. The complex nanoparticles deposited by *Achillea biebersteinii* flowers have been shown to be resistant to vasculogenic and aortic fluids (Baharara *et al*., 2014). Like iron, beets have a larval regenerating effect. The nanostructure also showed larvicidal activity. Silver nanoparticles introduced using heliotropium plant extracts showed important larvicidal properties against *Aedes aegypti*, *Anopheles stephensi*, and *Culex quinquefasciatus* (Veerakumar *et al*., 2014). Zinc nanoparticles activate uterine parthenium and show high resistance to the effect of parasitic microbes (Cheng *et al*., 2013).

Nanoparticles formed from environmentally friendly materials do not involve hazardous materials and developmental processes. In addition, some green nanoparticles reduce environmental pollution and can be repackaged as a successful tool to support our lives at a high level. The nanoparticles of graphite carbon nitride coated with gold nanoparticles are presented in a green gold photograph showing changes in corrosion properties (Barman *et al*., 2013). In this study, corrosive citrus and ascorbic extracts of red water (*Lycopersicon esculentum*) were obtained, which can be used for the synthesis and activation of gold nanoparticles, as well as for detecting and discovering the presence of methylparathion inhibitors (Pandey *et al*., 2013). Gold nanoparticles are prepared and applied to gingival membranes to extract salts and salt particles (Noh *et al*., 2013). Chondroitin sulfate is recommended to reduce the amount of gold required to produce melamine at lower molar levels (Huang *et al*., 2014). Iron nanoparticles, oolong tea plant extract is suitable for reducing green malachite by up to 75.5%, and they can be filled with green nanomaterials for conventional processing. Kaung *et al*. (2013) prepared iron nanoparticles added to tea tree, oolong tea extract, and tea tree extract, and they have been shown to be effective as an environmentally friendly Fenton monochlorobenzene formulation (Lee *et al*., 2013). An added mixture of iron from green tea leaves is needed to remove monochlorobenzene from the water.

They emphasized that monochlorobenzene disperses beyond the nanoparticles and binds to the hydroxyl boundary. Iron nanoparticles synthesized with eucalyptus leaf extract produced a release of 71.7% of total nitrogen and 84.5% of oxygen requirement (Di Carlo *et al*., 2012). The group of nanoparticles used to reduce salivary corrosive properties showed a clear structure of the influenza virus through hemagglutinin-sialic retention. A close relationship between the influenza B/Victoria strain, B/Yamagata influenza strain, and the exchange of gold nanoparticle crystals was observed. Abnormal level (hemagglutination test titer, 512) of 0.156 volume% was demonstrated early on in this study (Zhang *et al*., 2011). Chitosan-reducing gold nanoparticles are reduced to reveal nasty caffeic acid and could open new lessons in beneficial product design. This is particularly useful in revealing small complex compounds, such as wine, soda, and product properties (Kingston *et al*., 2011). Corrosive tannic materials are used as reducing agents to bind gold nanoparticles and glucose biosensors, which are additionally formed by activating glucose oxidase in chitosan nanocomposites of gold that are coated outside the carbon anode coating. This effect demonstrated the importance of glucose uptake. Again, it is recommended to use gold nanoparticles composed of olefin (phytohormone) nanostructures to prepare nanoparticles that can be readily controlled for their processing and can open up new avenues for the production of devices, optoelectronics, and sensors (Kingston *et al*., 2011). Physiological compatibility of green nanoparticles, according to Williams (2008), relates to the ability of a biomaterial to perform its optimal capacity as a clinical treatment without disturbing unwanted bacteria or causing major effects on the recipient when creating the most appropriate cell or tissue cross-talk in certain situations. This also increases the number of the therapeutic system used. The key to the application of green nanoparticles is their integrity in tissue processing. Large amounts of metal ions harm our bodies. At the nanoscale, it produces fewer toxins than the ionic system. Studies show similarity to Ayurvedic blood. Metal nanoparticles melted by organic mixtures do not require special coatings or additives. Compounding and compressing NRP itself covers newly labeled nanoparticles. In many cases, specialists make plant cutters have a recovery benefit or have a powerful crack that operates over a long period of time. It has been shown that these and other materials can be used in the same way as in the past. The formation of this mixture in metopic nanoparticles allows the reactants to react. Eventually, these combined factors made it less cytotoxic for the study process. Gold nanoparticles added to reduce ascorbate corrosion properties have a low degree of cytotoxicity on human epithelial cells and the human retina (Liong*et al*., 2010). Iron oxide nanoparticles prepared by the use of grape seed proanthocyanidins exhibit high biocompatibility in human mesenchymal stem cells. Nanoparticles have been found to show significant biocompatibility even at high concentrations (500 g/mL) and up to 48 hours of incubation, with no signs of apoptosis or age of the oxygen receptor type (Kingston *et al*., 2011). Then, the products collected from natural sources showed better benefits, better bioavailability, and less risk than the “herbal” concept.

Nanotechnology and Local Medicine

Nanotechnology can be used to disperse fluids more effectively within adult cells, direct them to specific cells or tissues, increase the number of epithelial cells at the end of the endothelium, access larger molecules, and deliver one or at least two drugs with local precision. Drug delivery can be integrated with imaging systems (Liong*et al*., 2008).

The transdermal nanotransmitter gel (NCTG) is a detailed description of the promotion of nanotransmitters, diclofenac diethylamine (DDEA), and curcumin (CRM) for supportive and targeted effects. This NCTG achieves high drug retention and lecithin levels, imparts a wet slope to the vesicles, increases porosity, reduces surfactant wear, and releases more than regular curcumin dispersion gels and gels (Chaudhary *et al*., 2013). Nanotransmitters engineered with DDEA and CRM provide large local areas with the ability to penetrate and achieve high bioavailability (Gugulothu *et al*., 2014). The solid pH of mixed nanoparticles of curcumin and celecoxib is estimated as a potential treatment for benign colitis (Hazzah *et al*., 2015). Curcumin-based solvents (CRM-SLN) have been created with high efficacy and synthetic effectiveness for the treatment of oral mucosal diseases (Dandekar *et al*., 2010). Curcumin-filled hydrogel nanoparticles were extracted from hydroxypropyl methylcellulose (HPMC) and polyvinylpyrrolidone (PVP) and showed significant effects on antimalarial activity (Dandekar *et al*., 2010).

Agundi was applied to the conventional use of Bauhinia tomentosaline supplements and was found to prevent and treat cancer in vitro. Mixed fluorescent AgNPs using *Artemisia annua* in different ways are capable of multiplying these AgNPs. This has been demonstrated by studying the cytotoxicity of human red blood cells and showing high fluorescence and antibacterial activity (Khatoon *et al*., 2015). Gold nanoparticles (AuNPs) were synthesized using *Pistacia integerrima* resin and have therapeutic potential, mainly as antifungal and anti-ulcer agents (Islam *et al*., 2015). The phytosanitary binding of nickel nanoparticles (NiNPs) was detected by *Aegle marmelos* Correa leaf marrow (AMC) (Dilnawaz*et al*., 2013). Cost-effective systems based on nanoparticles (MNPs) for the transmission of curcumin and temozolomides have been successfully developed. In vitro viability of diabetes mellitus (DM) and toxicity was detected in the body using *Syzygium cumini* morning fruit (ASc) and ASc. Nanoparticles (N PASc) were highly anti-inflammatory against bovine LDL deficiency and showed significant effects in vitro (Campos *et al*., 2015). Solid nanoparticles (SLNPs) can be used to increase phenol concentrations. Carnauba has been used to produce efficient lipid nanoparticles (WSLNP promoted by CSLNP) through exercise. There is a high degree of reliability between the adhesion and distribution of phenolic compounds in the small intestine (Li *et al*., 2011). The different epimmones have been described as defining the mechanisms in contrast to Naoxinqing tablets (Ahmed *et al*., 2014). The SNEDDS formula for Modified Quercetin Formula (QT) provides a safe effect unmatched by hepatotoxicity. Differentiation and QT on hepatotoxicity affected by paracetamol did not show risk factors, as described in SNEDDS developed in sefsol and linoleic acid (Zhao *et al*., 2010). SNEDDS is expected to fully utilize Zedoary Turmeric Oil (ZTO) extracted from the rhizomes of Curcuma zedoaria through improved training in water dispersion. Longevity and mutual bioavailability, the stated ZTO-SNEDDS, can complement lipid levels, and the two benefits of extending the formulation are due to the reduction in the required inactive oil content. The Niuhuang Xingxiao Wan (NXW) Chinese Medicine System (MUDDS) was compiled to improve bioavailability and feasibility. NXW was prescribed within four minutes, as did cigar oils, frankincense and myrrh (FMO), musk, and BS. The in vivo anti-tumor test results showed that the adequacy of NXW-MUDDS was higher than that of NXW.

Nanotechnology in Nutraceuticals

In general, nanotechnology is used to create transport mechanisms for food products as well as solubilize active substances. Some areas that have been considered for nanomaterial proteins are discussed here. Food Hydrophobin (HYD) is formulated for the nanoencapsulation of nutrients. To enhance nutrition, it was interesting that they incorporated waterproof materials such as D3 (VD3) Hyd to provide good protection against VD3 spoilage. It has been found that proteins often have aversions to foods and other nutrients (Israeli-Lev *et al*., 2014). Two different steps are confirmed (Whey protein concentrate (WPC) and starch storage center) in some examples (Spray cleaning and electrostatic showers). Another prominent example is found using WPC as an example of the grid. The implementation of this is a promising strategy in the food industry for premium applications (Pérez-Masiá *et al*., 2015). Emulsion Dispersion Systems (EDM) are an excellent option for preparing food nanocapsules. Nanocapsules are prepared by detecting DL-α-tocopheryl and β-carotene acetic acid release.

VD3 binds to several calcium-dependent whey protein (WPI) nanoparticles. Calcium-containing nanoparticles can form small structures, reducing the degradation of VD3 over time. WPI nanoparticles containing VD3 can be used to create clear or inconspicuous products such as natural products, organic compounds, or low-fat foods (Abbasi *et al*., 2014). Structures employing reciprocal processes, FA/nanofabrication hybrids, have been found to have high structural and social additives and can be taken as a second nutrient (Kim *et al*., 2016). The soluble protein-polysaccharide complex provides a transport layer for food and liquids. Complex-lactoglobulin (BLG) in four nutrients: β-carotene, folic acid, curcumin, and ergocalciferol. The modified food solutions were altered under different conditions, addressing the low solubility of aqueous food solutions in nanocomposites. Nanotransmitters have the unique ability to be used therapeutically as an alternative transport system for other lipophilic compounds, effectively increasing the bioavailability of CoQ10 tablets, as demonstrated by significant increases in maximum plasma concentrations in subcultures. The effects of excess water and the ability to absorb oil from insects are examined. The impetus for using nanoemulsions is to expand the availability of lipophilic bio-additives (Cho *et al*., 2014) for feeding biopolymers, proteins, and polysaccharides. They can be used to create various delivery systems suitable for printing, detecting, and improving the performance of oleic lipophilic compounds, nutrients, sweeteners, colors, and foods (Matalani *et al*., 2011). New fortified supplements have been developed to deliver active curcumin and increase hydration. The in vitro lipolysis profile showed that the bioavailability of the nanoemulsions was faster than that of the organelles. Organic nanoemulsions can be used to transport food additives that cannot be added in high concentrations, significantly affecting the nutritional value of the food (Yang *et al*., 2014). Supercharged infusion is permitted to increase A-tocopherol nanoparticles and dispersed NPs, which can be used as supplements and anti-cancer agents in businesses. Lactoferrin (LF) energy can act locally to create release binding compounds. Yang *et al*. (2014) tested epigallocatechin-3-gallate (EGCG). LF-EGCG nanoparticles and microparticles can act as protective agents for EGCG and provide useful instructions for controlling access to other living organisms (Al-Okbi *et al*., 2014). The effect of the essential oil club on the essential substance, eugenol, which is determined by water microemulsions, is combined with the combination of liver fat and dyslipidemia, and high fructose content. Emulsification of eugenol and carbon dioxide leads to a significant increase in hepatic steatosis and dyslipidemia when protection against cardiovascular disease and hepatic steatosis is detected. Using two receptor mechanisms, dilute the DMSO in water and dilute the enzyme mixture of NP dextran to retain the hydrophobic potassium, isoflavone genofein. DMSO methods have been found to increase sensitivity to genistein and dextran concentrations, resulting in higher genistein density and higher nanoparticle levels (Semyonov *et al*., 2014).

Herbal Approach to Developing Nanoparticles

The efficacy of locally grown medicinal plants depends on the overall capability of their adaptive components, as all these constituents work synergistically to enhance therapeutic effects. Bioavailability, systemic treatment, and the need for constant administration or higher doses often become issues with many prescription drugs. This underscores the significance of individualized treatment.

The application of nanotechnology in studying plant compositions and creating nanostructures such as solid lipid nanoparticles (SLNs), polymer nanoparticles (nanospheres and nanocapsules), polyposomes, liposomes, nanoemulsions, and others offers numerous pharmacological advantages. These advantages encompass expanded and improved bioavailability, enhanced drug potency, toxin removal, improved drug performance, prolonged drug delivery, heightened macrophage efficacy, and protection against physical and chemical damage.

In this context, addressing the challenges associated with medicinal plants can be achieved through a drug delivery system (NDDS) designed for locally sourced medications. Such NDDS, including nanocarriers, holds the potential to enhance the effectiveness of these medications, offering a promising avenue for future developments. Embracing nanoscale carriers like NDDS will be crucial in addressing chronic diseases such as diabetes, cancer, asthma, and advancing drug delivery protocols.

Nanoparticles Manufactured from Plant Materials

Gold and silver nanpoarticles

Gold nanoparticles, owing to their unique properties, have found applications in various local treatments, including biomarkers, hyperthermia treatment (Bhattacharya and Mukherjee, 2008), antibacterial agents, genetic systems, and drug delivery procedures. The extraction of gold nanoparticles from plants is a natural biological process that poses no harm to the environment.

Further investigation into these nanoparticles has revealed the formation of various shapes, including modulated, neutral, decaphedral, hexophilic, and hexagonal rods, depending on the pH of the reaction system. Eucalyptus leaves from the *Macrocarpa* species have been found to be effective for gold reduction. The results of this analysis indicate that the nanoparticles have circular dimensions ranging from 20 nm to 80 nm, as obtained from the primary source Rao *et al*. (2016).

Doping with gold (AuNp) and silver (AgNp) nanoparticles using methanolic extracts of *O. dillenii* has shown significant antifungal and antibacterial activity against pathogens such as *S. typhi, B. subtilis, S. aureus, P. aeruginosa, E. coli, A. niger,* and *C. albicans*, with a 10% improvement compared to undoped samples (Ahmed *et al*., 2022).

Copper nanoparticles

Copper (Cu) and copper oxide (CuO) particles are produced using plant extracts. These materials are coated with a high-density composite material, resulting in particle sizes ranging from 40 nm to 100 nm. Additionally, copper nanoparticles have shown potential antibacterial activity against *Escherichia coli* cells (Datta *et al*., 2018).

Extracts and compounds from *Syzygium aromaticum* (clove) and Cunan fruits have been utilized to create 40 nm plates (Bonfacio *et al*., 2014; Sharma and Singh, 2014). Cosmic particles are derived from the latex of *Euphorbia nivulia* stem, which is a common milkweed plant. Chaudhary *et al*. (2023) observed an increase in the antipyretic potential of these extracts after doping with copper nanoparticles. These compounds include peptides and terpenoids found in the latex. Furthermore, these nanoparticles exhibit toxicity towards glandular alveolar basal epithelial cells (Makarov *et al*., 2014).

Palladium and platinium nanoparticles

Palladium nanoparticles were synthesized from *Cinnamomum zeylanicum* (cinnamon) bark extract by Satishkumar *et al*. (2014). The morphology and particle size remained unchanged at 15 nm to 20 nm, despite variations in temperature, concentration, and pH during mixing. *Annona squamosa* (apple custard) peel extract was also used to produce palladium nanoparticles with sizes ranging from 75 nm to 85 nm (Tsoi *et al*., 2012).

Palladium nanoparticles in the range of 20 nm to 60 nm were synthesized using *Camellia sinensis* (tea) and Arabica coffee (espresso) by Melody *et al*. (2011). Additionally, Diospyros (Persimmon) khaki leaf extract was used by Melody *et al*. (2011) to synthesize platinum nanoparticles with diameters ranging from 2 nm to 12 nm. Natural combinations of platinum nanoparticles have also been recently discovered. According to Coccia *et al*. (2006), lignin extracted from red pine (*Pinus resinosa*) has been used to create palladium and platinum nanoparticles.

Nanoparticles of titanium dioxide and zinc oxide

These remarkable elements are combined with oxide nanomaterials derived from various plants. For instance, Roopan *et al*. (2010) arranged TiO2 nanoparticles using *Annona squamosa* leaves, resulting in nanoparticles with sizes ranging from 100 to 150 nm (Brewer *et al*., 2011). *Eclipta prostrata* leaves were found to produce material with diameters ranging from 36 to 68 nm. *Catharanthus roseus* has leaf extractor to synthesize TiO2 nanoparticles ranging from 25 nm to 110 nm. These TiO2 nanoparticles demonstrated activity against *Bovicola ovis* (sheep mites) and *Hippobosca maculata* (louse ingestion). Additionally, the anticancer and antibacterial properties of TiO2 nanoparticles derived from *Psidium guajava* were studied against *Pseudomonas aeruginosa, Staphylococcus aureus, Proteus mirabilis, Aeromonas hydrophila*, and *E. coli*. Furthermore, the effect of nanometer size on the anticancer and antibacterial activities of TiO2 nanoparticles was evaluated (Justin *et al*., 2012).

Indiumoxide (In_2O_3)

Various plant extracts have been utilized to organically synthesize a wide range of metal oxides and metal nanoparticles, including iron oxide, lead, and selenium nanoparticles. For instance, *Aloe vera* leaves have been used to synthesize indium oxide nanoparticles.

Green Reaction of Metal Nanoparticles

Plants have been observed to possess the capability to reduce minerals and aid in the elimination of excess accumulation (Kareem *et al*., 2016). Consequently, their beneficial properties extend to the efficient removal of cationic toxins, which is a significant factor in the synthesis of metal nanoparticles (Hemen *et al*., 2011). These plants contain a plethora of other compounds, including alkaloids, proteins, phenolic acids, polysaccharides, terpenoids, and polyphenols, which play roles in hydrolysis and subsequent reabsorption.

Advantages and Disadvantages of Herbal Remedies

Building specifications are provided with regular installation and are available at an affordable price. This also applies to biomedicine in which medications that have been tested and proven to be effective are also considered for their therapeutic potential with fewer side effects compared to allopathic drugs (Mahima *et al*., 2012). Medicinal plants can be used to treat a variety of conditions. The regenerative capacity of herbal medicine is attributed to the presence of various active compounds such as phenols, terpenoids (sapogenins), alkaloids, steroids, etc. (Mathur, 2016; Egbuna, 2018). Many traditional formulations are compact and unobtrusive due to the presence of hydrophobic phytochemicals. One major challenge in the use of herbal medicines is their low bioavailability, which is often attributed to poor absorption, inadequate distribution, and cost-effectiveness (Gantarat, 2013; Thillaivanan and Samraj, 2014). In general, traditional formulations are administered orally, and their efficacy can be reduced when a large portion of the active compounds is lost during digestion. The bioavailability of many natural products can be affected by factors such as stomach acidity and liver metabolism, leading to suboptimal therapeutic effects (Yadav *et al*., 2011; Ansari *et al*., 2012). Adverse or non-therapeutic effects can occur if the dosage of the herbal medicine is higher than the maximum effective dose (small doses can be very potent). Some phytochemicals have low potency and poor bioavailability, and researchers are actively working to enhance their efficacy and patient compliance through drug delivery systems and controlled release (Park, 2014). With a wide range of herbal remedies available and a growing need to treat chronic diseases, a multidisciplinary approach is required to focus on improving pharmacokinetics, pharmacodynamics, nanotechnology, bioconjugation science, and more (Charman *et al*., 1999). Nano Delivery Systems (NDS) are utilized for herbal remedies. A variety of "Nano Drug Delivery Systems" (NDDS) have been developed primarily for allopathic medicines, particularly for the treatment of malignancies. However, NDDS can also be effectively applied to herbal remedies to enhance their bioavailability, increase potency, prolong action, and overall improve their therapeutic potential (Ansari *et al*., 2012). A systematic approach to drug delivery aims to overcome real challenges, such as crossing the blood-brain barrier (BBB). Proper drug targeting and delivery can significantly impact drug efficacy and patient outcomes. Some common drug delivery routes include oral, transdermal (patches, buccal, sublingual, topical, ocular, and intranasal), and inhalation. Nano Delivery Systems (NDS) provide a way to fine-tune drug delivery to achieve the desired therapeutic effect while minimizing side effects and drug toxicity. NDS utilizes various delivery systems such as liposomes, niosomes, microspheres, encapsulated erythrocytes, transdermal delivery systems (sonophoresis), mucoadhesive delivery systems, supramolecular delivery systems, and osmotic pumps, among others. The use of NDS in herbal medicine is an emerging area of research, addressing the challenges posed by the diverse phytoconstituents present in herbal formulations (Nagavarma *et al*., 2012).

Green Synthesis

There has been an innovative production of Mixed Nutrient Powders (MNPs) with various components, including nutrients, extracts (polysaccharides), phytochemicals from plant species, organisms, biodegradable polymers, and others. Plant extracts are used in the commercial production of MNPs due to the presence of plant compounds that have the potential to reduce metal ions (Iravani, 2011; Shah *et al*., 2015). Polyphenols, including their hydroxyl groups, are prominent plant compounds that can act as reducing agents. Polyphenols can facilitate and stabilize the formation of MNPs. Gold nanoparticles (AuNPs) are particularly well-known in the field of green MNPs due to their excellent bioavailability (Bhattacharya and Mukherjee, 2008). Jaitha *et al*. (2013) described a rapid and eco-friendly method for synthesizing AuNPs using *Couroupita guianensis* flowers. Glucosylanes from *Mimosa pudica* seeds have been utilized to synthesize AuNPs without the need for stabilizers (Iram *et al*., 2014). Rao *et al*. (2016) investigated various therapeutic plant extracts and their volatile compounds for the green synthesis of MNPs, aiming to improve treatment strategies. Plant-derived MNPs exhibit low cytotoxicity, promising biocompatibility, and minimal cellular toxicity. The cytotoxicity of MNPs may be attributed to their high altitude in the atmosphere to achieve effective pharmacological activity, as some MNPs have demonstrated anti-inflammatory properties (Datta *et al*., 2018). However, it is essential to conduct clinical studies to validate the efficacy of homegrown MNP-based medications (Rao *et al*., 2016).

Some MNPs, such as quantum dots, metal oxides, and non-metallic metal NPs, hold promise for pharmaceutical applications (Bonfacio *et al*., 2014; Sharma and Singh, 2014). Several researchers have discovered various plant-associated microorganisms that mediate the green synthesis of MNPs, aiming to produce stable, robust, and non-toxic MNP formulations (Makarov *et al*., 2014). However, certain issues related to the safety of MNP formulations must be addressed and agreed upon before considering their use in therapeutics. Although numerous reports demonstrate the use of MNPs in various therapeutic and biomedical applications, questions remain about their effects on patients (Krug and Wick, 2011). Relevant MNP safety considerations have been discussed in various studies (Tsoi *et al*., 2012; Edmundson *et al*., 2014).

Nanoshells are nanoparticles with dimensions typically within the nanometer range (1-20 nm). Nanoshells consist of a well-defined core covered by a shell or layer containing different materials (Kalele *et al*., 2006). By varying the central core, surface, or shell materials, the properties of these particles can be tuned. Commonly used materials for high-surface-area coatings include silica and polystyrene (Ansari *et al*., 2012; Sachan and Gupta, 2015). Nanoshells are versatile nanoparticles with various applications in biomedicine, particularly in drug delivery systems, and they also find use in in vivo experimental research settings where they provide visual and physical insights. Nanoshells can heat and emit light upon exposure to specific wavelengths, making them useful for various applications (Kalele *et al*., 2006). Drug payloads can be enclosed within the shell, applied to the outer shell surface, or electrostatically deposited on the nanoshell. Upon interaction with the target site, the nanocarrier releases the drug. For drug delivery targeting abnormal tissues or tumors, monoclonal antibodies can be conjugated to the outer surface of nanoshells, allowing for both diagnostic testing and targeted therapy for malignancies (Mamillapalli *et al*., 2016; Singhana *et al*., 2014).

Visions of Nanotechnology in the Future

Nanotechnology has demonstrated its ability to advance drug development and nanocomposites with a wide range of properties, both in vivo and in vitro, especially in drug delivery. While two clinical studies did not significantly impact the efficacy of nanomedicines, a comprehensive understanding of nanotechnology's significance in drug delivery is crucial. Recognizing the limitations of nanoparticles, addressing misconceptions in the field, and rectifying inaccurate exposure are essential for effective interpretation.

To enhance the efficacy of drug delivery, a strategic plan may be necessary to improve nanoparticle compatibility. It's important for nanoparticle practitioners to comprehend that any diagnostic procedure involving nanoparticles, whether FDA-approved or not, requires rigorous evaluation for safety and efficacy through controlled clinical trials.

Doxil® stands out as the first FDA-approved nanoparticle-based drug, receiving approval in 1995. It meets three critical criteria: (1) it delays the reticuloendothelial system's clearance due to its glycol-coated polyethylene nanomaterials, (2) it achieves high and sustained drug concentration through ammonium sulfate-mediated transmembrane transport, facilitating drug retention in tumor tissue, and (3) it contains double the lipid content and exhibits a unique "fluid" state at room temperature (53 °C), composed of phosphatidylcholine and cholesterol.

Despite the FDA's approval of Doxil, nearly two years after its initial approval, availability remains uncertain. This discrepancy highlights the complexities surrounding FDA-approved nanomedicines. The transformation of nanomedicine from a concept to an essential medical tool requires clear identification and a well-defined purpose.

Addressing the challenges of drug delivery with nanotechnology involves understanding the limitations of FDA guidelines and expanding the capabilities of existing nanocomposites (Zou *et al*., 2008).

Conclusion

In conclusion, this review has touched upon a wide range of topics related to nanotechnology, green nanotechnology, and their applications in various fields, including medicine, drug delivery, and environmental conservation. Nanotechnology, with its ability to manipulate matter at the nanoscale, has ushered in a new era of scientific exploration and technological advancement.

Green nanotechnology, in particular, has emerged as an exciting and sustainable approach that harnesses the power of nature to create innovative solutions. By utilizing plant extracts, biodegradable polymers, and other eco-friendly materials, researchers have developed nanoparticles with remarkable properties and potential applications. These green nanoparticles offer exciting prospects in drug delivery, imaging, and environmental remediation.

Throughout our conversation, we have explored the numerous benefits of green nanotechnology, from enhanced drug delivery and reduced environmental impact to improved energy efficiency and resource conservation. However, we have also acknowledged the challenges that come with this cutting-edge technology, including issues related to safety, toxicity, and regulatory compliance. It is imperative that we continue to conduct rigorous research and testing to ensure the safe and effective use of green nanoparticles in various applications.

As we move forward into the 21st century, nanotechnology, and green nanotechnology, in particular, hold the promise of addressing some of the most pressing global challenges, from healthcare and clean energy to environmental sustainability. By fostering interdisciplinary collaboration, responsible innovation, and a commitment to ethical and environmental considerations, we can harness the full potential of nanotechnology for the betterment of society and the planet.

In this rapidly evolving field, staying informed about the latest developments and engaging in thoughtful discussions, as we have done here, will be crucial for navigating the exciting yet complex landscape of nanotechnology and ensuring its responsible and sustainable integration into our lives.

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