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THE PHARMACEUTICAL APPLICATION IN HERBAL NANOPARTICLES

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ABSTRACT
Herbal medicines have long been central to ancient healing systems such as Ayurvedic medicine, the Siddha therapeutic tradition, and the heritage healthcare system of China, offering therapeutic benefits with comparatively fewer side effects. Advances in nanotechnology have provided innovative strategies to overcome these challenges by incorporating herbal bioactives into nanometric therapeutic delivery platforms, including polymer-based nanocarriers and solid-lipid nanostructures,metallic and ceramic nanoparticles, and green-synthesized nanocarriers. These systems enhance solubility, protect unstable phytoconstituents, prolong circulation time, and enable targeted and controlled release. Various preparation techniques—such as green synthesis, coacervation, salting-out, solvent diffusion-emulsification, supercritical fluid processing, and high-pressure homogenization—offer versatile approaches for developing efficient nanocarriers. Characterization tools such as SEM, TEM, DLS, AFM, BET analysis, and particle-size analyzers ensure accurate evaluation of nanoparticle properties critical

KEYWORDS: Herbal nanoparticles; Nanotechnology; (NDDS); (SLNs); Green synthesis; Characterization techniques; Targeted drug delivery; Phytopharmaceuticals; Inorganic and organic nanoparticles.

INTRODUCTION
One of India's oldest medical systems is Ayurveda.[1] Herbal medicines have gained recognition among clinicians and patients because of their potential therapeutic benefits and their comparatively lower side effects than conventional drugs. They can also enhance the bioavailability of medications.[4]

Formulating herbal drugs is challenging because the active constituents are often complex, unstable, or present in low concentrations. In traditional In conventional formulations, only a limited amount of the given medication arrives at the intended site, whereas the majority disperses throughout the body according to its physical–chemical and biological characteristics.[5,6] Advanced herbal-based therapeutic platforms are designed to provide site-specific transport of active agents, improve solubility and absorption, reduce dosing frequency, and enhance drug elimination profiles.[7] Among These systems, nanoparticles are considered highly effective. They allow herbal drugs to be directed toward specific organs, improving safety, therapeutic action, and targeted deliver. Nanotechnology broadly involves designing and manipulating materials at the molecular and atomic scale. Although typically defined by extremely small dimensions, the term is commonly applied to structures measuring up to several hundred nanometers. At this scale, atoms and molecules behave differently, resulting in unique and sometimes unexpected properties. Research in nanotechnology and nanoscience has expanded rapidly in recent years across many sectors. It provides new opportunities for developing materials for medical use, particularly where traditional technologies may have limitations.[8]

Properties of Nanoparticle

Nanoparticles function as an important bridge Among atom-level or molecule-level structures and bulk substances, their extensive surface-per-volume measure creates a strong driving force for diffusion, particularly at elevated temperatures. Consequently, processes such as sintering can occur at lower temperatures and within shorter time periods compared to coarse particles.. The pronounced interaction between nanoparticle surfaces and surrounding solvents also enables the formation of stable suspensions, preventing particles from settling or floating despite density differences. Moreover, nanoparticles often demonstrate unique optical behaviors, as their small size allows electrons to become confined, giving rise to quantum effects.

Role of Nanoparticle

- Medications can be formulated into extremely small particles, increasing their surface area and allowing them to dissolve more rapidly in the bloodstream.
- These systems enable precise, site-specific delivery of drugs.
- Nanoparticles enhance drug transport across epithelial and endothelial barriers.
- They ensure that therapeutic agents reach the intended target site more effectively.
- They allow the combination of two different therapeutic approaches or drugs within a single system. Overall, nanoparticles offer several advantages over conventional novel drug delivery systems (NDDS).[22]

Type of Nanoparticle

(1). Inorganic Nanoparticle

The characteristics, benefits, limitations, and uses of different categories of inorganic nanoparticlessuch as metal, ceramic, magnetic particles, and nanoshells have been well established. Inorganic nanoparticles are generally much smaller than their organic counterparts, offering enhanced loading efficiency.[17]

(2). Organic Nanoparticle

Benefits and limitations of several classes organic nanoparticles such as polymer-based systems, dendrimers, carbon nanotubes, quantum dots, and liposomes have been reviewed in detail.[18]

(3). Ceramic Nanoparticle

Ceramic nanoparticles, which are inorganic carriers characterized by their porous structure, have recently gained attention as promising drug delivery platforms. Examples like silicon dioxide, titanium dioxide, and aluminum oxide demonstrate promise in oncology treatment. Their lack of biodegradability presents a major drawback, as these materials can accumulate in the body and potentially lead to adverse effect.[30]

(4). Metallic Nanoparticle

Iron oxide nanoparticles, generally ranging from 15 to 60 nm, along with other metallic Nanostructures are often made of superparamagnetic materials and can be coated with substances such as phospholipids or dextran to enhance their stability and prevent clumpin.[31]

(5). Polymeric Nanoparticle

Nano-sized particles act as colloidal transport systems, spanning from ten up to a thousand nanometers, possessing traditional herbal formulations, they provide several advantages—including enhanced absorption, reduced dosing requirements, improved therapeutic efficacy, increased bioavailability, and better solubility of herbal compounds.
To overcome the challenges associated with triptolide's limited solubility and toxicity.[25,26,27,28]

(6). Solid Lipid Nanoparticle

They typically incorporate highly purified triglycerides as their core lipid component.[33]

Method of preparation Nanoparticle

(1). Green synthesis of Nanoparticle

Various approaches—physical, chemical, and biosynthetic—have been employed to produce nanoparticles. Among these, the biosynthetic method is considered a green, biocompatible, and sustainable technique, making use of plants and microorganisms for biomedical applications (Razavi et al. 2015). By contrast, many conventional chemical synthesis routes are expensive and rely on hazardous or toxic reagents, which contribute to significant environmental concerns (Nath and Banerjee 2013.[22]

Plants in green nanomaterial development

Employing these organisms for nanoparticle production provides a sustainable and green alternative for generating nanoparticles with unique characteristics. In this method, both unicellular and multicellular organisms are capable of participating in the synthesis process (Mohanpuria et al. 2008).[33]

Techniques of Nanoparticle

(1) Oppositely charged polymer phase separation method

1. Creation of three distinct non-miscible layers
2. Encapsulation of the core material by a liquid polymer layer.
3. Subsequent hardening or solidification of this polymer coating.[8,12,13]

(2). Method of co-precipitation

This approach for producing nanosized core–shell particles is a modified form of the complex coacervation technique. Studies have shown that this method enhances the dispersion stability of drugs that exhibit low water solubility.[8,12,14]

(3). Salting-out Technique

Well-documented tendency to separate from aqueous media through electrolyte-induced salting-out. A key stage in the process is the migration of acetone out of the droplets. If excessive water is added during dilution, this diffusion may lead to interfacial disturbances, ultimately promoting polymer aggregation into nanoparticles.[8,12,14]

(4). The Diffusion-emulsification method of solvents

The method involves preparing an o/w emulsion in which the oil phase consists of polymers like PLGA and an oil component dissolved in an organic solvent. This oil phase is blended with the stabilizer-containing aqueous phase using a high-shear mixer to form the emulsion. Subsequent addition of water promotes the diffusion of the organic solvent, leading to the formation of nanoparticles.[8,12,14]

Example of herbal drug Nanoparticle Formulation

(1). Artemissia Anua

Common name: Wormwood or Sweet sagewort

Biological source: Leaves and flowering tops of Artemisia vulgaris.

Family: Asteraceae.

Chemical constituents: Mugwort contains key components such as thujone, cineole, volatile oils, acrid resins, and tannins. It also includes flavonoids, triterpenes, and coumarin derivatives.

Uses: It exhibits strong antimalarial activity overcomes these limitations, artemisinin has been formulated into nanoparticle-coated forms. After encapsulation, the nanocapsules showed improved dispersion in water and enhanced hydrophilicity of artemisinin crystals.[36]

(2). Berberine

Common name: Barberry

Biological source: a naturally occurring nitrogenous bioactive compound of the isoquinoline class, can be extracted from the roots, underground stems, and bark of various therapeutic plants, such as the barberry.Berberis plant family.

Chemical constituents: Berberine is a tetra-substituted nitrogenous molecule that belongs to the protoberberine category of benzyl isoquinoline natural compounds. It occurs in

Uses: Berberine has demonstrated significant anti-cancer activity and has been shown to act effectively against human leukemia, colon cancer, esophageal cancer, and malignant brain tumor cell lines. For sustained drug delivery, various berberine-loaded nanoparticles have been developed using methods like emulsion techniques and ionic gelation.[37, 38]

(3). Curcumine

Common name: Turmeric, Curcuma, Curcuma aromatica.

Biological source: Turmeric contains curcumin, a potent phytochemical that is a hydrophobic polyphenolic compound (diferuloylmethane).

Family: Zingiberaceae.

Chemical constituents: The main constituents include ar-turmerone (20.20%), β-sesquiphellandrene (5.20%), and curcumenol (5.11%). Curcumin has been identified through IR, ^{1}H NMR, and ^{13}C NMR analyses.

Uses: Curcumin’s therapeutic potential is restricted because it undergoes rapid metabolism, has a short half-life, is poorly soluble in water, and is quickly eliminated from the body, resulting in low oral bioavailability [41].

(4). Quercetin

Common name: Citrus bioflavonoid, Quercitol, Flavin.

Biological source: is a plant-derived Natural phenolic compound isolated from the naturally dried stem and bark tissues of Pagoda tree.

Family: Fabaceae.

Chemical constituents: It has a naturally bitter taste and is commonly incorporated into dietary supplements, beverages, and food products.

Uses: Its strong antioxidant, anti-inflammatory, antiviral, and cardioprotective activities contribute to its broad therapeutic potential.

Application

Herbal nanoparticles are applied across numerous as well as their ability to improve therapeutic effectiveness [30].

Cosmetics and Personal Care

These nanoparticles are incorporated into various skincare preparations and haircare formulations to enhance effectiveness and stability.

Agriculture and Food Industry

Their use extends to improving the efficiency of fertilizers and pesticides, along with contributing to better food preservation methods.

Environmental Applications

They play a role in processes like water purification and soil cleanup, supporting environmental sustainability.

Marketed formulation

By January 2022, numerous herbal nanoparticle-based products had entered global markets. Their specific formulations and regional availability can differ depending on local regulations and ongoing advancements in research. Common examples of commercialized options include:

1. Curcumin-based nanoparticle formulations.
2. Green tea polyphenol nanoparticle products.
3. Nanoparticles containing various herbal extracts.
4. Herbal nanoparticle systems developed for cancer treatment.
5. Herbal nanoparticles incorporated into cosmeceutical products.

Future prospect

The merging of nanotechnology with herbal medicine is advancing quickly, offering significant potential for creating safer, more potent, and scientifically authenticated phytopharmaceutical products. Future research is expected to refine nanoparticle-based delivery systems to address long-standing challenges in herbal therapeutics, including low bioavailability, chemical instability, and non-targeted distribution within the body. One of the key directions ahead involves improving the standardization and quality assurance of herbal nanoparticle formulations. Developing consistent criteria for selecting plant materials, extraction techniques, formulation methods, and characterization procedures will be essential to ensure reproducibility and meet regulatory requirements. Progress in analytical tools—such as nanoscale metabolomics and advanced imaging—will play a major role in supporting this standardization.

Another promising frontier is the creation of target-specific and stimuli-responsive nanocarriers. These intelligent systems, which react to triggers such as pH changes, enzymes, heat, or magnetic fields, can deliver herbal activities precisely to diseased tissues while reducing unwanted side effects. The rise of multifunctional and hybrid nanoparticles, capable of providing both therapeutic and diagnostic benefits, may further expand opportunities in herbal nano-theranostics.

There is also substantial potential in green, sustainable nanoparticle synthesis using botanical extracts, microbial systems, and non-toxic solvents. Such eco-friendly approaches not only minimize environmental harm but also improve the safety and compatibility of the resulting nanocarriers. The integration of nanotechnology with personalized and genomic medicine could further enhance the future of herbal therapy. By understanding individual responses to herbal compounds and nanoscale carriers, personalized treatment strategies can be developed for improved therapeutic outcomes. Additionally, broader in vivo research, well-controlled clinical studies, and long-term toxicity assessments will be essential before these systems can be widely implemented.

In summary, the advancement of herbal nanoparticles will rely on harmonizing traditional medicinal knowledge with cutting-edge nanoscience and modern regulatory frameworks. With sustained interdisciplinary research, herbal nanoformulations are likely to evolve into standardized, scientifically validated therapeutic tools in global healthcare.

CONCLUSZION

Nanoscience has developed into a revolutionary strategy for the medicinal use of plant-based compounds.medicines addressing long-standing limitations associated with conventional herbal fBy decreasing the particle dimensions to the nanometer scale and designing sophisticated transport platforms, nano-sized particles greatly enhance dissolution, chemical stability, absorption efficiency, and site-specific transport of therapeutic agents. of phytoconstituents. Techniques such as green synthesis and high-pressure homogenization provide eco-friendly and scalable methods for nanoparticle production, while modern characterization tools ensure precise control over their physicochemical attributes. The integration of herbal compounds into nanoparticles not only enhances therapeutic efficiency but also minimizes toxicity and dosing frequency, making these systems highly suitable for future clinical use. Continued research, standardization, and regulatory validation will further strengthen the potential of herbal nanomedicine as a bridge between traditional healing and modern pharmaceutical technology.

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