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NANOTECHNOLOGY IN HERBAL DRUG DELIVERY SYSTEMS: A REVIEW

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ABSTRACT

Nanotechnology has emerged as a revolutionary approach in pharmaceutical sciences for improving the therapeutic efficacy of herbal medicines. Herbal drugs possess significant pharmacological activities; however, their clinical applications are often limited by poor solubility, low bioavailability, instability, rapid metabolism, and poor target specificity. Nanotechnology-based drug delivery systems such as nanoparticles, liposomes, nanoemulsions, solid lipid nanoparticles, nanostructured lipid carriers, dendrimers, and polymeric micelles have shown great potential in overcoming these limitations. These nanocarriers improve drug solubility, stability, absorption, controlled release, and targeted delivery while reducing toxicity and enhancing therapeutic effectiveness. This review discusses the principles, advantages, types, preparation methods, characterization techniques, applications, challenges, and future perspectives of nanotechnology in herbal drug delivery systems.

KEYWORDS: Nanotechnology, Herbal Drug Delivery, Nanoparticles, Nanoemulsion, Liposomes, Phytomedicine, Targeted Drug Delivery.

INTRODUCTION

Herbal medicines have been used for centuries for the prevention and treatment of various diseases. According to the World Health Organization (WHO), approximately 80% of the world's population relies on traditional herbal medicines for primary healthcare.[1] Herbal products contain numerous bioactive phytoconstituents including alkaloids, flavonoids, polyphenols, terpenoids, glycosides, and tannins that possess diverse pharmacological activities.[2] Despite their therapeutic potential, many herbal drugs suffer from poor aqueous solubility, instability in biological environments, low permeability, rapid degradation, and poor bioavailability, resulting in limited clinical effectiveness.[3,4] Conventional dosage forms often fail to deliver sufficient concentrations of active phytochemicals to the target site.[5] Nanotechnology offers innovative solutions for improving the delivery of herbal medicines. Nanocarriers can protect phytoconstituents from degradation, improve absorption, prolong circulation time, enhance target specificity, and provide controlled drug release.[6,7] Therefore, nanotechnology-based herbal drug delivery systems have gained considerable attention in modern pharmaceutical research.[8]

Nanotechnology

Nanotechnology involves the design, development, characterization, and application of materials with dimensions ranging from 1 to 1000 nanometers. Nanoparticles exhibit unique physicochemical properties such as high surface area, enhanced reactivity, and improved drug loading capacity.[9]

Need for Nanotechnology in Herbal Drug Delivery

Several herbal drugs face challenges including:

- Poor water solubility[10]
- Low oral bioavailability[10]
- Poor membrane permeability[11]
- Rapid metabolism[11]
- Instability during storage[12]
- Lack of site-specific delivery[12]

Nanotechnology helps overcome these limitations and improves therapeutic outcomes.[13]

Types of Nanotechnology-Based Herbal Drug Delivery Systems

Nanoparticles

Nanoparticles are colloidal carriers composed of natural or synthetic polymers. They protect herbal drugs from degradation and improve absorption.[14]

Advantages

- Controlled release
- Improved stability
- Enhanced bioavailability
- Targeted delivery

Disadvantages

- Complex manufacturing
- High production cost

Liposomes

Liposomes are spherical vesicles composed of phospholipid bilayers capable of encapsulating both hydrophilic and lipophilic phytoconstituents.[15]

Advantages

- Biocompatible
- Reduced toxicity
- Improved therapeutic efficacy

Disadvantages

- Stability issues
- Short shelf life

Nanoemulsions

Nanoemulsions are thermodynamically stable systems with droplet sizes typically below 200 nm.[16]

Advantages

- Enhanced solubility
- Improved absorption
- Better patient compliance

Disadvantages

- Surfactant requirement
- Formulation complexity

Solid Lipid Nanoparticles (SLNs)

SLNs consist of solid lipids stabilized by surfactants and are widely used for herbal drug delivery.[17]

Advantages

- Controlled release
- Good stability
- High drug loading

Disadvantages

- Limited drug incorporation
- Lipid crystallization issues

Nanostructured Lipid Carriers (NLCs)

NLCs are second-generation lipid nanoparticles containing both solid and liquid lipids.[18]

Advantages

- Higher drug loading
- Improved stability
- Reduced drug leakage

Disadvantages

- Expensive formulation process

Polymeric Micelles

Polymeric micelles are self-assembled nanostructures formed from amphiphilic polymers.[19]

Advantages

- Solubilization of hydrophobic drugs
- Prolonged circulation

Disadvantages

- Potential instability upon dilution

Dendrimers

Dendrimers are highly branched nanostructures possessing multiple functional groups.[20]

Advantages

- Precise molecular architecture
- High drug loading capacity

Disadvantages

- Toxicity concerns
- Expensive synthesis

Herbal Drugs Formulated Using Nanotechnology

Examples include

Sr.No	Herbal Drug	Nanocarrier System	Therapeutic Use
1.	Curcumin	Polymeric nanoparticles	Anticancer
2.	Quercetin	Liposomes	Antioxidant
3.	Resveratrol	SLNs	Cardioprotection
4.	Berberine	Nanoemulsion	Antidiabetic
5.	Green Tea Extract	NLCs	Antioxidant

6.	Aloe vera	Liposomes	Wound healing
7.	Neem Extract	Nanoparticles	Antimicrobial
8.	Ginger Extract	Nanoemulsion	Antiemetic

Methods of Preparation

Solvent Evaporation Method

Used for polymeric nanoparticles by evaporating organic solvents after emulsification.[21]

High Pressure Homogenization

Widely used for lipid nanoparticles and nanoemulsions.[22]

Ultrasonication Method

Utilizes ultrasonic energy to reduce particle size.[22]

Microemulsion Technique

Produces stable nanocarriers with uniform particle size.[23]

Solvent Diffusion Method

Used for preparation of polymeric nanoparticles.[23]

Thin Film Hydration Method

Commonly employed for liposome preparation.[24]

Evaluation and Characterization

Particle Size Analysis

Determines average nanoparticle diameter.[25]

Zeta Potential

Measures surface charge and predicts stability.[25]

Entrapment Efficiency

Determines percentage of herbal drug encapsulated.[26]

Drug Loading Capacity

Measures amount of drug incorporated into nanocarriers.[26]

Morphological Studies

Performed using SEM and TEM.[27]

In Vitro Drug Release Study

Evaluates release profile of phytoconstituents.[27]

Stability Studies

Assess formulation stability under various conditions.[28]

FTIR Analysis

Identifies drug-excipient interactions.[28]

Differential Scanning Calorimetry (DSC)

Evaluates thermal behaviour.[29]

X-Ray Diffraction (XRD)

Determines crystallinity of formulations.[30]

Applications of Nanotechnology in Herbal Medicine

Cancer Therapy

Improves delivery of anticancer phytochemicals.[31]

Antimicrobial Therapy

Enhances efficacy against resistant microorganisms.[32]

Anti-inflammatory Therapy

Improves delivery of anti-inflammatory phytoconstituents.[33]

Cardiovascular Disorders

Enhances bioavailability of cardioprotective herbal compounds.[34]

Neurodegenerative Diseases

Facilitates blood-brain barrier penetration.[35]

Wound Healing

Improves tissue regeneration and healing.[36]

Challenges

- Scale-up difficulties[37]
- Regulatory concerns[38]
- High production costs[38]
- Long-term toxicity studies required[39]
- Limited clinical trials[39]

Future Perspectives

Future developments in nanotechnology are expected to focus on smart nanocarriers, targeted delivery systems, personalized medicine, theranostics, and AI-assisted nanoformulation design. These advances may significantly improve the therapeutic potential of herbal medicines.[40]

CONCLUSION

Nanotechnology has significantly advanced herbal drug delivery by overcoming challenges associated with poor solubility, low bioavailability, instability, and lack of target specificity. Various nanocarrier systems such as nanoparticles, liposomes, nanoemulsions, SLNs, NLCs, polymeric micelles, and dendrimers have demonstrated promising results in enhancing the therapeutic efficacy of phytoconstituents. Continued research and clinical evaluation will facilitate the development of safe, effective, and commercially viable nanotechnology-based herbal medicines.

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