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NANOTECHNOLOGY APPROACHES IN HERBAL DRUG DELIVERY SYSTEM

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Abstract

Herbal medicines have been used worldwide since ancient times and continue to remain especially popular in India because of their therapeutic potential and minimal side effects. However, the clinical application of many herbal compounds is limited by challenges such as poor bioavailability, low aqueous solubility, instability under physiological conditions, rapid metabolism, and non-specific targeting. To overcome these limitations, the integration of nanotechnology with herbal medicine has emerged as a promising approach. Nanotechnology-based drug delivery systems (NDDS) enhance the pharmacological efficacy of herbal compounds by improving their solubility, stability, absorption, and targeted delivery while minimizing toxicity and reducing the required dosage. Various nanocarriers, including polymeric, metallic, magnetic, and lipid-based nanoparticles, have been explored for the efficient encapsulation and controlled release of herbal bioactive constituents. Advanced characterization techniques such as UV–visible spectroscopy, FTIR, XRD, TEM, SEM, and DLS are employed to evaluate the physicochemical properties and performance of these nanoparticles. Herbal nanoparticles have demonstrated significant potential in the treatment of chronic and life-threatening diseases, including cancer, diabetes, and inflammatory disorders. This review highlights the synthesis methods, characterization techniques, and therapeutic applications of herbal nanoparticles, emphasizing their role in improving treatment efficacy and sustainability. The integration of nanotechnology with herbal medicine offers a novel and environmentally friendly strategy for the development of advanced drug delivery systems in modern healthcare.

Keywords: *Herbal nanoparticles, Nanotechnology-based drug delivery systems (NDDS), Herbal medicine, Bioavailability enhancement, Controlled drug release, Nanocarriers.*

1. INTRODUCTION

Herbal medicines have been widely used worldwide since ancient times and have been recognized by physicians and patients for their better therapeutic values as they have fewer adverse effects as compared to modern medicines. Medicinal plants are now getting more attention than ever because e they have potential of providing large benefits to society or indeed to all mankind, especially in the line of medicine This can be achieved by designing novel drug delivery systems for herbal constituents. Phyto some is a patented technology developed by a leading manufacturer of drugs and nutraceuticals, to incorporate standardized plant extracts or water soluble into phospholipids to produce lipid compatible molecular complexes [1]. Traditional preparations comprise medicinal plants, minerals, and organic matter. Herbal drugs constitute only those traditional medicines that primarily use medicinal plant preparations for therapy. The earliest recorded evidence of their use in Indian, Chinese, Egyptian, Greek, Roman, and Syrian texts dates back to about 5000 years. The classical Indian texts include Rigveda, Atharvaveda, Charak Samhita, and Sushruta

Samhita. The convergence of rich knowledge from different traditional systems of medicine can lead to new avenues in the herbal drug discovery process [2].

2. NEED FOR NOVEL DRUG DELIVER SYSTEM NANO CARRIERS FOR HERBAL REM-EDIES

Before reaching to the blood, many constituents of the herbal drugs will be smashed in the highly acidic pH of the stomach and other constituents might be metabolized by the liver. Resultant, the optimum quantity of the herbal drugs may not reach the blood. If the drug does not reach in the optimum amount to the infected region at "minimum effective level," then there will be no means to show the therapeutic effect of the drug. Nanocarriers applying to herbal remedies will carry optimum amount of the drug to their site of action bypassing all the barriers such as acidic pH of stomach, liver metabolism and increase the prolonged

circulation of the drug into the blood due to their small size .Herbal remedies were selected as feasible drug candidate for delivery through a nano delivery system because of the following properties: Effective chloroform, petrol, acetone, and methanolic extracts are available which may not be suitable for delivery as such. These are the b Need for novel drug delivery system "nano carriers" for "herbal remedies" Before reaching the blood, numerous constituents of the home-grown medications will be crushed in the exceptionally acidic pH of the stomach and different constituents may be processed by the liver. Resultant, the ideal amount of the home-grown medications may not arrive at the blood Types of nanoparticles- Various types of nanoparticles used in nanotechnology on herbal drug they may be followings.

Solid Lipid Nanoparticles: Nanoparticles of strong lipids (SLN) brought for the first time in December 1991 to be a device of drugs carrier to what referred to as conventional colloidal carriers, that device that consists of nano meter stages of round solid lipid cells that are regularly scattered in fluid surfactant association or in water [3]. The shipping device is one of the hardest study regions in pharmacy. SLNs in particular incorporate lipids which are in strong segment at the room temperature and surfactants for emulsification, the

Quantum dots: When a stable reveals a wonderful version of optical and electronic residences with a version of particle body temperature, via right lipid composition using phospholipids with excessive section transition temperature Besides composition, residences of liposomes are ruled via way of means of numerous different elements which encompass their technique of preparation, size, floor charge, firmness of bilayer and floor functionalization [12]. Liposomes are extensively used as carriers for numerous molecules in cosmetic and pharmaceutical industries. Liposomes are phospholipid vesicles including one or extra concentric lipid bilayers and feature a structural resemblance to cell membranes [4].

High stress homogenization (HPH) has emerged as a dependable and effective approach for the guidance of SLN. High stress homogenizers push a liquid with excessive stress (100- 2000 bar) via a slender gap. The fluid speeds up on a very quick distance to very excessive velocity (over 1000km/h). Very excessive shear pressure a and cavitation forces disrupt the debris down to the submicron range. Typical lipid contents are withinside the range 5-10% and constitute no hassle to the homogenizer. Even better lipid concentrations (as much as 40%) were homogenized to lipid Nano dispersions. Complex coacervation method: complicated coacervation co-precipitation method, -out method, nano precipitation method, solvent-diffusion method, Supercritical fluid techniques and high-strain homogenization method. These strategies have given the sturdy electricity to natural merchandise in opposition to dation there for the safety & pharmacological pastime of drugs [5].

3. TYPES OF NANO PARTICLES IN HERBAL DRUG DELIVER

Nanotechnology has revolutionized herbal drug delivery by enhancing the bioavailability, stability, and targeted release of phytoconstituents. Various types of nanoparticles are utilized for efficient drug delivery, each offering unique advantages. Below is a detailed description of different types of nanoparticles used in herbal drug delivery Polymeric Nanoparticles Solid Lipid Nanoparticles Magnetic Nanoparticles Metal and Inorganic Nanoparticles Quantum Dots Polymeric Micelles Phospholipid Micelles Colloidal Nano-Liposomes Dendrimers Nanocrystals Nanospheres Nano capsules. Polymeric Nanoparticles Polymeric nanoparticles are biodegradable and biocompatible carriers made from natural or synthetic polymers such as chitosan, alginate, PLGA (poly (lactic-co-glycolic acid)), and These nanoparticles can encapsulate herbal extracts and provide controlled and sustained drug release, improving therapeutic efficacy. Advantages: Enhanced solubility of poorly water-soluble herbal compounds Controlled and targeted drug release Protection from enzymatic degradation [6].

Solid Lipid Nanoparticles (SLNs) Advantages: SLNs are composed of solid lipids that remain in a solid state at room temperature. They serve as effective carriers for hydrophobic herbal compounds, enhancing their bioavailability and stability. Improved permeability and absorption Reduced toxicity and side effects Controlled drug release.

Magnetic Nanoparticles Magnetic nanoparticles are composed of iron oxide-based materials, which enable drug targeting using an external magnetic field. These are often used in cancer therapy and imaging. Advantages: Site-specific drug delivery Non-invasive targeting through a magnetic field Enhanced accumulation at diseased sites [7].

Metal and Inorganic Nanoparticles These nanoparticles include gold, silver, silica, and zinc oxide nanoparticles.lused for diagnostic and therapeutic purposes 5. Quantum Dots (QDs) Quantum dots are semiconductor nanocrystals with unique optical properties. They are used in imaging and diagnostics, along with drug delivery applications. Advantages: High fluorescence for bioimaging Enhanced stability and tracking of herbal drugs Potential for applications (therapy + diagnostics).

Polymeric Micelles Polymeric micelles are amphiphilic block copolymers that self-assemble in aqueous solutions, forming a hydrophobic core and hydrophilic shell. They enhance the solubility of hydrophobic herbal drugs. Advantages: Increased bioavailability of poorly soluble drugs Stability in biological fluids Controlled and prolonged drug release.

Phospholipid Micelles Advantages: These micelles are composed of phospholipids, which improve the solubility and stability of herbal extracts. They are widely used for delivering lipophilic drugs [8].

4. SYNTHESES OF HERBAL NANOPARTICLES [9].

The study of a material's composition, structures, and physical and chemical properties is referred to as characterization. Using sophisticated microscopic methods like atomic force microscopy (AFM), transmission electron microscopy (TEM), scanning electron microscopy (SEM), and transmission electron microscopy (TEM), nanoparticles are typically identified by their size, shape, and surface charge. In order to evaluate the overall form of polymeric nanoparticles-which may indicate their toxicity-electron microscopy techniques are highly helpful. The physical stability, and in vivo performance of the polymer dispersion are all influenced by the surface charge of the nanoparticles.

3.1 The SEM, or scanning electron microscope the direct visualization of morphological assessment is provided by scanning electron microscopy (SEM). The method is based on electron microscopy, which we also employed for sizing and morphological research. Nevertheless, the information provided by electron microscopy regarding the size distribution is restricted. Prior to being placed on a sample holder and coated with a conductive metal, such gold, using a sputter coater, the nanoparticle solution needs to be dried out for SEM characterization. An electron beam with a fine focus is then utilized to scan the sample. The exterior the secondary electrons released from the sample surface provide information about the sample's characteristics. The ability of the nanoparticles to tolerate vacuum and electron beams, which can harm polymers, is crucial. The results of dynamic light scattering are equivalent to the mean size determined by SEM [10].

3.2.Transmissionelectron microscopy Because the sample must be ultra-thin for the electron transmission, the preparation process for TEM is intricate and time-consuming. The dispersion of nanoparticles is applied on films or grids for support.

4. ADVANTAGES OF NANOTECHNOLOGY IN HERBAL MEDICINES

These can be made directly from monomers through polymerization, or from premade polymers. Many techniques are employed, including dialysis, solvent evaporation, salting out, supercritical fluid evaporation, and quick expansion of supercritical solution [20] Numerous considerations, including the type of polymeric system, the application, the has been demonstrated that polymeric nanoparticles produced using any of these methods have effective medicinal properties [11]. Nanoparticles made of metal Metals The integration of nanotechnology in herbal medicine has revolutionized drug delivery by addressing key challenges associated with conventional herbal formulations. Nanocarrier-based systems enhance the therapeutic efficacy of herbal drugs while minimizing limitations such as poor solubility, low bioavailability, and rapid degradation. Below are the major advantages of using nanotechnology in herbal medicine: 1. Enhanced Solubility and Bioavailability Many herbal bioactive, such as flavonoids, tannins, and terpenoids, exhibit poor water solubility, which limits their absorption in the body. Nanotechnology-based drug delivery systems, such as liposomes, polymeric nanoparticles, and solid lipid nanoparticles, enhance the solubility of these compounds, facilitating their absorption across biological membranes.

5.APPLICATION OF HERBAL NANOPARTICLES

Applications: The following is a summary of some of the ways that nanomaterials are being used in biology and medicine: 1. Enhancement of MRI contrast 2. Gene and medication delivery 3. Sorting and cleaning biological substances and cells 4. Finding proteins 5. Examining the structure of DNA 6. Biological labels that glow 7. Elimination of by heating and hyperthermia 8. Pathogen bio detection 9. Engineering of tissues 10. Studies on phagokinetic Catalysis is using nanoparticles more and more to accelerate chemical reactions. As a result, less catalytic material is used to achieve the intended effects, saving money and reducing pollution. Automotive catalytic converters and petroleum refinery are two major applications. Catalysis is using nanoparticles more and more to accelerate chemical reactions. As a result, less catalytic material is used to achieve the intended effects, saving money and reducing pollution. Automotive catalytic converters and petroleum refinery are two major applications. [12]. Classification of nanoparticles made from herbs: 1) Labile nanoparticles include polymers, liposomes, micelles, nano, and others. 2)Nanowire and nanotube are examples of one-dimensional nanomaterials. 3) Self-assembled monolayer films are two-dimensional nanomaterials. 4) Insoluble nanoparticles, such as nanotubes, carbon lattices, quantum dots, SiO2, TiO2 [13].

6. RECENT DEVELOPMENT IN HERBAL NANOTECHNOLOGY

The nanoparticles have approached as the fit methodology in medication conveyance frameworks for the efficient conveyance of medications used in the therapy of different sicknesses, for example, disease by intersection the reticuloendothelial framework, improved porousness and maintenance impact, and tum or-explicit focusing on. As of late, drug researchers have moved their concentration to planning a medication conveyance framework for natural prescriptions utilizing a logical methodology. Cuscuta chinensis is a usually utilized customary Chinese medication to feed the liver and kidney. Because of the helpless dissolvability of its significant constituents, for example, flavonoids and lignans, its retention upon oral organization could be restricted. Thus, the nanoparticles for the same were developed [14]. A new exploratory investigation of polylactic corrosive nanoparticles of lipophilic enemy of malignancy spice drug (Cucurbitacin's and

Curcuminoids) utilizing a precipitation strategy have been developed. Work has likewise been completed in the turn of events and portrayal of SLNs for the customary Chinese medication for their focused-on conveyance and expanded bioavailability and efficacy. In the new year's, nanostructured transporter framework like polymeric nanoparticles, liposomes, SLNs, polymeric micelles, nano emulsions, and so forth, have been explored for their capability to convey anticancer medications by oral route. Also, the oral course offers incredible potential for conveyance of cytotoxic specialists and subsequently the consideration has zeroed in on the improvement of oral chemotherapy in oncology [15]. The nanoparticles have come ahead because the capable method in drug transport structures for the well-organized transport of medication applied withinside the remedy of various sicknesses which include most cancers through crossing the reticuloendothelial machine, better permeability and retention effect, and tum or-unique targeting. Recently, pharmaceutical scientists have shifted their awareness to designing a drug transport machine for natural drug treatments the usage of a systematic method. However, a variety of problems (low solubility, poor bioavailability, limited oral absorption, instability, and unanticipated toxicity) limit the use of herbal drugs. "Nanotechnology" has created enticing remedies for the pharmaceutical sector that will deal with the problem by employing natural remedies to resolve such problems. It is anticipated that the practical relevance and utility of the natural remedies and herbal treatments combined with the nanocarrier would make the existing drug delivery techniques more significant [16].

In summary, herbal nanoparticles offer a variety of applications in fields such as environmental management, agriculture, and healthcare by combining cutting edge nanotechnology with traditional herbal medicine in a synergistic way. Herbal nanoparticles can be synthesised using a variety of strategies, from advanced nanotechnological technologies to green synthesis techniques that use components obtained from plants and environmentally benign processes. These techniques improve the functioning and performance of nanoparticles while utilising the natural therapeutic qualities of medicinal plants. The behaviour and effectiveness of herbal nanoparticles are significantly influenced by properties like as size, shape, and surface chemistry [17].

7. CHALLENGE AND FUTURE PROSPECTS

Despite the numerous advantages of integrating nanotechnology with herbal medicine, several challenges must be addressed to ensure its successful clinical application. Key challenges include: Large-Scale Production: The synthesis of herbal nanoparticles at an industrial scale remains a significant hurdle due to complex fabrication techniques, high production costs, and the need for reproducibility. Regulatory Approval: Stringent regulatory requirements for nanomedicine demand extensive safety, efficacy, and stability assessments, making the approval process time-consuming and resource intensive. Potential Toxicity: While nanocarriers enhance drug delivery, their long-term toxicity, biocompatibility, and impact on human health require further investigation through rigorous preclinical and clinical studies. Standardization and Stability: Variability in herbal extracts and their nano formulations can affect consistency, requiring standardization of extraction, formulation, and storage conditions. To overcome these challenges, future research should focus on: Developing Cost-Effective and Scalable Production Methods: Advancements in green nanotechnology and sustainable manufacturing approaches can help reduce costs and improve large scale synthesis. Ensuring Biocompatibility and Safety: The design of nanocarriers using biodegradable and non-toxic materials will enhance their safety profile while minimizing adverse effects. Clinical Evaluations and Regulatory Compliance: Extensive clinical trials and regulatory harmonization will be essential for validating the efficacy and safety of herbal nanomedicines before market approval. Climate change, pollution (air/water), resource depletion, food security [18].

Technological

Integrating AI, machine learning, IoT; ensuring ethical use; managing digital transformation.

Economic/Societal

Workforce adaptation (upskilling), talent retention, economic uncertainty, equitable resource access.

Health

Global health crises (pandemics), mental well-being, access to clean

Future Prospects & Solutions Sustainable Energy: Developing better photocatalysis, solar energy storage, and CO2 utilization technologies.

Water Purification

Utilizing advanced nanomaterials (graphene, CNTs) for high-efficiency water treatment.

Innovation:

Fostering creativity, interdisciplinary research (materials science, policy), and new device.

Adaptability

Emphasizing lifelong learning, growth mindsets, and strong support networks for individuals and leaders.

Leadership

Cultivating scientific literacy and intercultural management to guide complex transformations.

Future success hinges on viewing challenges as opportunities, leveraging scientific advancements and new thinking to build sustainable systems, address global needs, and create a prosperous future, say researchers

8. FUTURE PERSPECTIVES

Future Prospective Everywhere on the world, the examination has been going on home grown cures and regular items. The improvement of home-grown cures in the medication conveyance framework in various establishments is being done at essential and clinical

preliminary levels. The solitary prerequisite is to build up the better frameworks for the drug conveyance of such medications at the locales and in the entire body in the dosages which won't bargain with the current treatment. Something that would not just give relieve from results like poisonousness and easily affected responses yet additionally will expand the patient's solidarity from inside is a lot of desirable. Later on, the idea of natural nanoparticles for malignant growth drug conveyance may likewise captivate some potential exploration gatherings and possibly make eye catching outcomes. Consequently, utilizing "natural cure" in the nanocarriers will expand its potential for the therapy of different constant sicknesses and medical advantages. Numerous fruitful models with experienced confirmations are available among us toward nano research. Herbal remedies are also prosperous resources of advantageous compounds holding antioxidants and constituents that can be made use in purposeful foods.[18] This type of collaborative research among the traditional "Herbal remedies" and newer approaches of modern drug delivery system, i.e., "Nanotechnology" has established the attractive therapies to the pharmaceutical in near future that will enhance health of people. It is foreseen that the useful and important pertinence of the normal items and natural cures being applied with the nanocarrier will improve the meaning of existing medication conveyance frameworks. There are numerous important and well-established medical applications for berberine. It is commonly taken orally to treat, hyper lipide mia, hypertension, and a number of other different pathological conditions.

9. CONCLUSION

Herbal drugs have been recently getting more attention because of their potential to treat almost all diseases. However, several problems such as poor solubility, poor bio availability, low oral absorption, instability and unpredictable toxicity of herbal medicines limit their use. In order to overcome such problems, nanoparticles can play a vital role. Hence, different nanoparticles show potential utilization to deliver herbal medicines with better therapy. The integration of nanotechnology with herbal medicine offers a promising solution to overcome the challenges associated with the bioavailability and therapeutic efficacy of medicinal plant products. This study highlights the potential of nano systems in delivering active herbal constituents at targeted concentrations throughout the treatment period, particularly in cancer therapy. By developing advanced nanocarrier systems, this approach aims to enhance treatment efficacy while minimizing side effects, contributing to a more sustainable and potent cancer treatment strategy. The historical foundation of herbal medicine, combined with cutting-edge advancements in nanotechnology, showcases the transformation of traditional remedies into scientifically validated formulations. This evolution not only addresses issues like poor bioavailability and inconsistent efficacy of herbal extracts but also enables precise drug delivery using nanocarrier systems. This review underscores the historical significance of herbal medicine while emphasizing recent breakthroughs in nanotechnology, highlighting the synergy between the two in modern drug delivery systems. The advantages of herbal nanoparticle-based drug delivery, such as enhanced drug concentration at disease sites, improved stability, and reduced toxicity, make them a compelling alternative for improving therapeutic outcomes. A comprehensive analysis of various nanocarrier types and an extensive compilation of herbal drugs used in cancer therapy contribute to a deeper understanding of this innovative approach. Overall, this study provides valuable insights into the potential of combining nanotechnology with herbal medicine, paving the way for more effective, targeted, and sustainable treatment strategies in the future By adjusting these features, one can tailor them for certain uses, like targeted medication administration, medical diagnosis, improved agriculture, and environmental cleanup.

Although herbal nanoparticles have a lot of potential, there are still issues. It is essential to standardise synthesis procedures and implement strict quality control measures to guarantee uniformity, repeatability, and security. Furthermore, thorough evaluations are necessary to address issues with long-term impacts and biocompatibility, especially in biomedical contexts. Additional challenges include managing regulatory frameworks and increasing production. Achieving the broad use of herbal nanoparticles requires streamlining the manufacturing process and following legal requirements. Notwithstanding these obstacles, continuous investigation and cooperative endeavours persist in propelling novelty within the domain.

10. AUTHOR CONTRIBUTIONS

All authors are contributed equally.

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None

12. DECLARATION COMPETING INTEREST

The authors have no conflicts of interest to declare.

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None

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