NANOTECHNOLOGY BASED HERBAL DRUG DELIVERY – A REVIEW

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Abstract:

Herbal medicines, long embraced globally and especially in India, are advanced for their effectiveness and minimal side effects. To optimize these treatments, the development of advanced drug delivery systems is crucial to tackle the issues like poor bioavailability. Integrating nanoscience, such as Nanoparticle Drug Delivery Systems (NDDS), with traditional medicine have that enhanced potential of herbal remedies, particularly in combating chronic ailments. Various nanoparticle synthesis methods, including polymer, magnetic, and metallic nanoparticles, are being explored. Advanced technologies aid in characterizing nanoparticles, evaluating their properties, and assessing toxicity. By utilizing various nano-carriers, nanotechnology helps to overcome the limitations in herbal compounds, leads in enhancing their efficiency. This review discusses recent advancements and future prospects in this innovative approach to healthcare.

INTRODUCTION:

Ayurveda, the traditional medical science from India, highly connects with herbal medicines due to their therapeutic potential and lower side effects compared to other medicinal approaches. (1) However, their wider acceptance was impeded for a long time due to challenges in proving their scientific validity and difficulties in processing. (2) Recently, modern phytopharmaceutical research has stepped in to bridge this gap by focusing on developing advanced drug delivery systems. These systems, such as nanoparticles, microemulsions, and solid dispersion, aim to overcome the hurdles of bioavailability and targeted delivery for herbal formulations (4) Despite the intricate nature of active constituents in herbs, these novel drug delivery systems strive to enhance the efficiency of herbal medicines by increasing their solubility and absorption while reducing their elimination, thereby improving the therapeutic effectiveness and safety. (4)

Nanotechnology, operating at the atomic and molecular levels, is crucial in advancing herbal medicine delivery. Nanoparticles enable precise targeting of herbal medicines to specific organs, optimizing delivery and enhancing medicinal impact. This rapidly growing field offers new possibilities for medical applications, overcoming traditional limitations. By manipulating matter on an incredibly small scale, nanotechnology revolutionizes drug delivery systems, particularly for herbal medicines, improving their efficacy. This approach promises breakthroughs in medical treatments, heralding a new era of advanced therapeutic interventions. (7,8)

Researchers around the world have looked at how plants are used in traditional medicine, based on what people commonly use them for, as well as on scientific studies. They are interested in how these plants could be helpful in making new medicines. About half of the drugs approved from 1981 to 2006 were made from natural substances, either directly or indirectly.

The complexity of the chemicals in plant extracts is really important when making medicines because the medicine needs to release the active ingredient. So, the way the medicine is made needs to make sure the active ingredient can dissolve well, not break down too quickly, not be harmful, and not taste bad. At the same time, it needs to control how the body absorbs and responds to the active ingredient.

Scientists have already figured out what some of the chemicals in medicinal plants do and how they work in the body. But many of these chemicals dissolve well in water but don't get absorbed well because they can't cross through cell membranes or are too big. This means they might not work as well as we would like them to. Some studies have shown that plant medicines work well in lab tests, but then don't work the same way in real-life tests. Also, some important substances aren't used often because they don't work well with other ingredients in the medicine, or they have bad qualities. (55,56,57)

Various nanotechnological methods, including polymeric nanoparticles, solid lipid nanoparticles (SLNs), liquid crystal (LC) systems, precursor systems for liquid crystals (PSLCs), liposomes, and microemulsions, have been developed to overcome these challenges. These approaches enable the incorporation of substances with diverse properties into a single formulation and can even alter a substance's characteristics and behavior within a biological setting. These advancements in technology have transformed drug delivery, providing novel systems that not only enhance the efficacy of active ingredients but also allow for the reintroduction of previously discarded components that were deemed unsuitable for formulation. Additionally, these innovative delivery systems offer the potential to enhance new substances by increasing their selectivity and effectiveness, shielding them from thermal or photo-induced degradation, reducing adverse effects, and regulating the release of active compounds prior to their market introduction or therapeutic use, making them highly appealing for pharmaceutical applications. (55,56,57,58)

In tandem with the strides made in drug development over recent decades, there arises an urgent necessity for advancements in nanoscience and nanotechnology pertaining to the utilization of nanoscale materials, which, until now, have primarily garnered attention within the cosmetics industry. Scientific progressions hold the potential to revolutionize and augment solutions to the challenges encountered in formulation preparation. Moreover, in addition to enhancing the solubility and stability of active ingredients, nanostructures have the capability to prolong the action of a formulation and effectively amalgamate active substances with varying degrees of hydrophilicity/lipophilicity. Furthermore, this technology can be harnessed to target the distribution of a drug substance towards specific tissues or organs. (59,60,61,62)

The pharmaceutical sector has shown a growing interest in advancements in nanotechnology due to their potential benefits, including modified release systems and the ability to create new formulations that were previously unattainable due to various factors associated with the active ingredients. (63)

While nanotechnology offers numerous advantages across various medical fields, it's crucial to acknowledge some of its drawbacks. Clinical researchers have highlighted several negative factors, including high expenses, challenges in scaling up processes, and the potential risks associated with the inhalation of nanoparticles, which could lead to severe lung diseases and disrupt homeostasis, potentially resulting in fatalities. (64,65)

The application of nanotechnology to plant extracts has garnered significant attention in literature due to its potential benefits. Nanostructured systems have the capability to enhance the efficacy of plant extracts, facilitate sustained release of active ingredients, reduce required dosage, minimize side effects, and enhance overall activity. (66,67)

Bhattacharya and Ghosh utilized lipid-based systems to incorporate green tea and ginseng extracts, aiming to boost the absorption of their active components. (68) Kesarwani and Gupta's review highlighted numerous studies that utilized nanostructured systems to enhance the properties of plant extracts. (69)

Su et al. developed nanoparticles using Radix salvia miltiorrhiza extract and observed a notable enhancement in its bioavailability. Sinico et al. created liposomes with Artemisia arborescens extract, facilitating the penetration of active components through cellular barriers. (70) Rajendran et al. synthesized nanoparticles from a methanolic extract of Ocimum sanctum and found that the encapsulated extract exhibited superior antimicrobial activity compared to its free-form counterpart against various bacteria like Escherichia coli, Bacillus subtilis, Pseudomonas aeruginosa, and Staphylococcus aureus. (67)

Employing diverse drug delivery systems rooted in nanotechnology, including polymeric nanoparticles, solid lipid nanoparticles (SLNs), liquid crystal (LC) systems, precursor systems for liquid crystals (PSLCs), liposomes, and microemulsions, presents a compelling strategy to enhance the most favorable attributes of a formulation. Moreover, the utilization of nanoscale particles holds promise for ensuring efficacy and overcoming challenges associated with the utilization of medicinal plants. (71)

Evolution of Medicinal Plant Use: Bridging Traditional Wisdom with Modern Formulations and Innovative Drug Delivery Systems

Throughout history, natural products, particularly plants, have been pivotal in treating various human illnesses. The inception and evolution of modern medicine draw heavily from the principles embedded in traditional therapies across diverse regions such as ancient China, Egypt, Africa, America, and India, where medicinal plant usage predates recorded history. The advent of chemical analysis in the early 1800s initiated the extraction and modification of herbal components. Despite this progress, herbal medicines faced obstacles in becoming advanced formulations due to challenges like insufficient scientific validation and complexities in standardization, extraction, and identification of individual constituents within intricate polyherbal systems. Yet, contemporary phytopharmaceutical research has bridged these gaps, allowing the development of innovative formulations like nanoparticles, microemulsions, solid dispersions, liposomes, SLNs, among others. Specifically, advancements like nano micellar systems, nanotubes, and colloidal nanogels have been tailored for curcumin's application, both independently and alongside other chemotherapy agents like paclitaxel. (9,10,11)

Challenges in Herbal Drug Delivery and the Role of Nanoparticles

Herbal drugs encounter significant obstacles before reaching the bloodstream; many constituents can break down in the highly acidic stomach environment, while others might undergo liver metabolism. Consequently, the optimal quantity of these drugs may not effectively reach the bloodstream, compromising their therapeutic potential. Without attaining the minimum effective level at the infected site, the drug's therapeutic impact remains elusive. Nanocarriers integrated into herbal remedies offer a solution by transporting the ideal drug amount to their targeted action sites, circumventing barriers like stomach acidity, liver metabolism, and prolonging drug circulation in the bloodstream due to their diminutive size. (12)

The selection of herbal remedies as viable candidates for nano delivery systems stems from several inherent properties:

1. Availability of effective chloroform, petrol, acetone, and methanolic extracts, unsuitable for direct delivery.

2. Herbal drugs typically constitute bulk formulations, motivating the intention to reduce dosage.

3. Current formulations in the market lack specificity in targeting various chronic diseases.

4. Associated side effects exist with currently available formulations.

5. Patient adherence dwindles due to the large doses and limited effectiveness of existing formulations. (12,7)

Importance of Nanotechnology

Nanotechnology holds significant potential for advancing medical treatments by creating products with novel and enhanced properties. One key application is the development of nanocarriers, which serve to protect drug payloads from degradation and improve their bioavailability. Additionally, nanocarriers can reduce both therapeutic doses and side effects of medications, while enabling targeted therapy and controlled release of phytomedicine—a branch of medicine utilizing plant-based remedies.

Nanotechnology serves as a bridge between biological and physical sciences by employing nanostructures and nanophases across various scientific fields, particularly in nanomedicine and nano-based drug delivery systems, where nanoparticles are of significant interest. Nanomaterials, defined as materials with sizes ranging between 1 and 100 nm, play a pivotal role in advancing the frontiers of nanomedicine, spanning from biosensors and microfluidics to drug delivery and tissue engineering.

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The emergence of nanomedicines has garnered significant attention, as nanostructures can serve as delivery agents by encapsulating drugs or attaching therapeutic agents, enabling precise delivery to target tissues with controlled release. Nanomedicine represents a burgeoning field that applies the principles and techniques of nanoscience to medical biology and disease prevention and treatment. It encompasses the utilization of nano dimensional materials, including nanorobots, nano sensors for diagnosis, delivery, and sensing purposes, as well as active materials in living cells. (72,73,74,75)The Different nanostructures are represented in Figure no:1

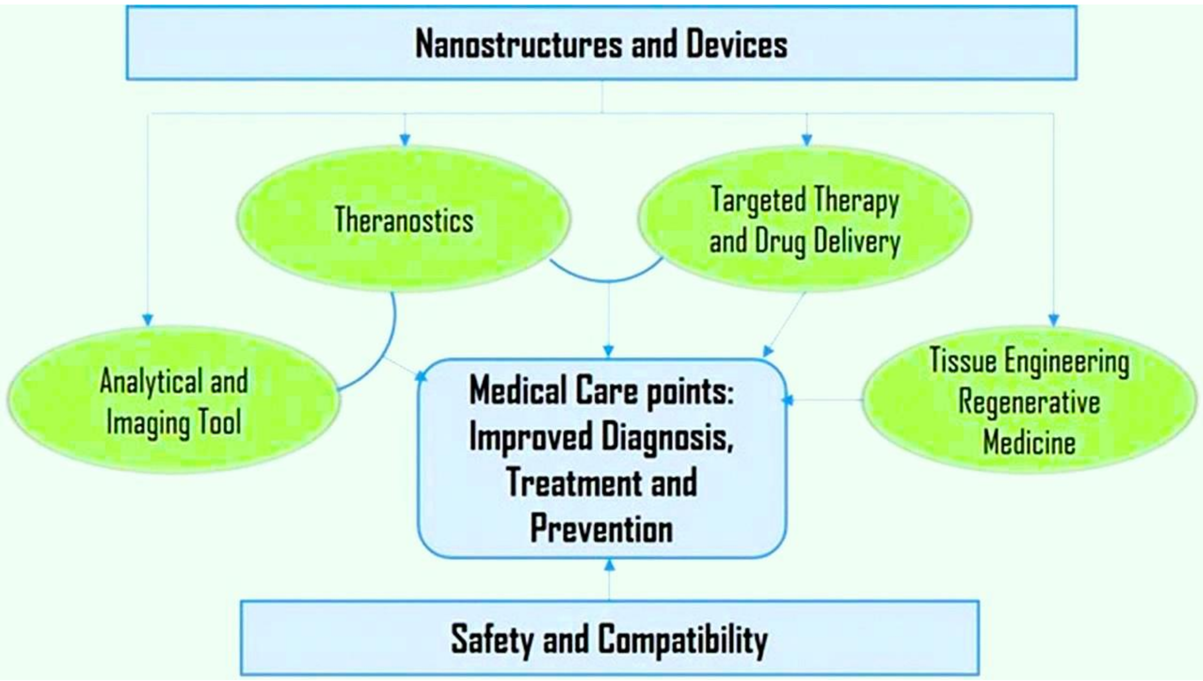

Figure :1

The initial generation of nanoparticle-based therapies introduced lipid systems such as liposomes and micelles, which have since received FDA approval. These lipid carriers can incorporate inorganic nanoparticles like gold or magnetic nanoparticles, expanding their utility in drug delivery, imaging, and therapeutic applications. Additionally, nanostructures have been shown to protect drugs from degradation in the gastrointestinal tract and facilitate the delivery of poorly water-soluble drugs to their intended targets. Nanodrugs exhibit increased oral bioavailability due to their ability to utilize absorptive endocytosis mechanisms for uptake.

Nanostructures remain in the bloodstream for longer periods, allowing for the gradual release of combined drugs at a specified dosage. This leads to fewer fluctuations in plasma levels and reduced side effects. Due to their small size, nanostructures can easily penetrate tissue systems, facilitating drug uptake by cells and ensuring efficient delivery to targeted areas. Compared to larger particles, nanostructures are taken up by cells more readily, enabling direct interaction with diseased cells for improved efficacy and minimal side effects.

Polymer-based nanoparticles are constructed from polymers and are known for their versatility in drug delivery applications. They can be tailored to control drug release kinetics, improve stability, and enhance targeting capabilities.

Inorganic nanoparticles, on the other hand, are composed of non-organic materials such as metals or metal oxides. They offer unique properties such as high surface area and tunable surface chemistry, which can be exploited for drug delivery purposes.

When it comes to drug delivery using nanomaterials, the choice of nanoparticle depends on the physical and chemical properties of the drugs being delivered. The combination of nanoscience with bioactive natural compounds has become increasingly attractive and is growing rapidly. This approach offers several advantages, especially in delivering natural products for treating cancer and other diseases. Natural compounds have been extensively studied for their various activities, such as inducing tumor-suppressing autophagy and acting as antimicrobial agents. For example, curcumin and caffeine induce autophagy, while cinnamaldehyde, carvacrol, curcumin, and eugenol exhibit antimicrobial effects. (76) By incorporating nanoparticles, the properties of these natural compounds, such as bioavailability, targeting, and controlled release, can be enhanced. For instance, encapsulating thymoquinone, a bioactive compound from Nigella sativa, in lipid nanocarriers resulted in a sixfold increase in bioavailability compared to free thymoquinone, protecting it from the gastrointestinal environment and improving its therapeutic effects. (79)

Various metallic, organic, inorganic, and polymeric nanostructures, including dendrimers, micelles, and liposomes, are commonly used in designing target-specific drug delivery systems. These nanoparticles are particularly useful for drugs with poor solubility and low absorption. However, the effectiveness of these nanostructures as drug delivery vehicles depends on factors such as size, shape, and other biophysical and chemical characteristics. (80) Polymeric nanomaterials, with diameters ranging from 10 to 1000 nm, are ideal for efficient delivery due to their high biocompatibility and biodegradability. Synthetic polymers like polyvinyl alcohol, poly-L-lactic acid, polyethylene glycol, and poly (lactic-co-glycolic acid), as well as natural polymers like alginate and chitosan, are commonly used in fabricating nanoparticles. These polymeric nanoparticles can be classified into nanospheres and nano capsules, both of which are excellent drug delivery systems. Similarly, compact lipid nanostructures and phospholipids, such as liposomes and micelles, are highly effective in targeted drug delivery. (81,82,83,84)

The selection of an optimal nano-drug delivery system is primarily based on the biophysical and biochemical properties of the drugs intended for treatment. However, it's essential to address issues such as nanoparticle toxicity when considering the use of nanomedicine. Recently, nanoparticles have been increasingly utilized in combination with natural products to mitigate toxicity concerns. Utilizing green nanoparticles for drug delivery can help to minimize medication side effects. Furthermore, adjustments in the size, shape, hydrophobicity, and surface characteristics of nanostructures can further enhance the bioactivity of these nanomaterials.

Various classes of nanocarriers have been explored for drug delivery in phytomedicine, including lipid-based nanoparticles (NPs), polymer-based NPs, and inorganic NPs. These different types of nanocarriers offer unique advantages and characteristics, making them suitable for specific applications within phytomedicine.

Lipid-based nanoparticles are composed of lipids and have gained attention for their ability to encapsulate drugs efficiently and deliver them to target sites. They offer advantages such as biocompatibility and the ability to incorporate both hydrophilic and hydrophobic drugs.

A schematic representation of common nanocarriers illustrates in Figure:2 their structures and functionalities, providing a visual aid for understanding their roles in drug delivery within phytomedicine. This comprehensive exploration of nanocarriers underscores their importance in advancing the efficacy and safety of phytomedicine treatments.

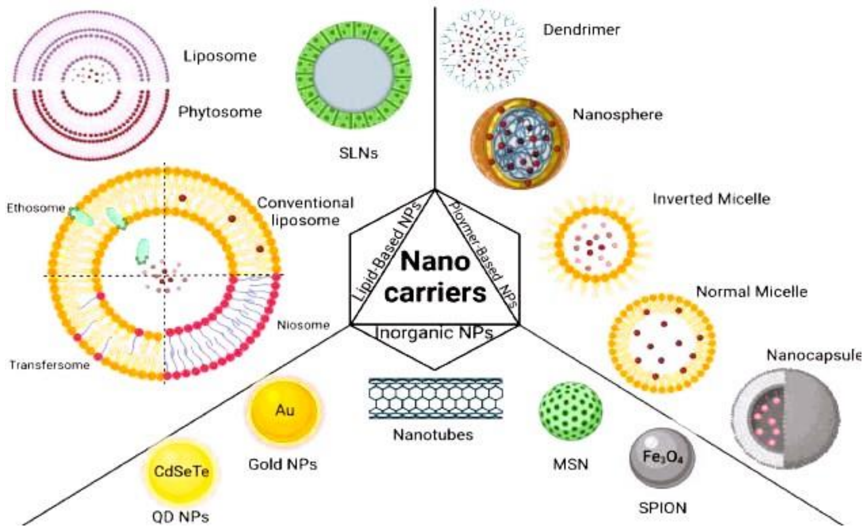

Figure :2 Schematic representation of common nanocarriers

Lipid based Nanocarriers for Herbal Drug Delivery

In addition to the benefits mentioned earlier, lipid-based nanoparticles like solid lipid nanoparticles (SLNs), liposomes, and phytosomes also offer advantages such as compatibility with the body and the ability to enhance the solubility of herbal drugs that don't dissolve well in water. Lipid-based nanocarriers are made using various materials and techniques depending on their intended use. Challenges such as increasing production size and physical instability like clumping should be considered when choosing how to make them. After making the nanoparticles, factors like their size, shape, and surface properties should be measured because they have a big impact on how cells take them in and how well they work in medicine. (21)

Liposomes, which are vesicular nanoparticles, are formed by concentric lipid bilayers containing amphipathic phospholipid molecules. These structures are created in water-based environments and enclose a portion of the surrounding solvent. Apart from enhancing drug solubility, liposomes have been deemed effective carriers in herbal delivery due to their capability to accommodate both hydrophilic and lipophilic drugs, thereby enhancing bioavailability and therapeutic effectiveness. (21)

In 1989, Indena, an Italian pharmaceutical and nutraceutical company, successfully developed complexes of phospholipids (phosphatidylcholine) and plant actives known as Phytosome® and then patented the innovation. (22) Phytosomes, also referred to as phytolipid delivery systems, exhibit greater stability compared to liposomes due to the presence of a chemical bond in their structure. They enhance the bioavailability of poorly soluble herbal medicines by improving their absorption in the gastrointestinal tract. Several phytosomes containing various phytoconstituents such as grape seed, hawthorn, Ginkgo biloba, milk thistle, ginseng, and green tea are available commercially in the United States. (23)

In 1990, solid lipid nanoparticles (SLNs), colloidal nanoparticles containing lipids that remain solid at room and body temperature, were introduced. SLNs offer several advantages, including outstanding physicochemical stability and enhanced protection compared to other nanoparticles like liposomes and polymeric nanoparticles. Furthermore, their biocompatibility and small size (ranging from 50 to 1000 nm) allow for the utilization of SLN herbal formulations across various routes of administration. (24,25)

Polymeric nanocarriers for herbal drug delivery

Lately, there's been a surge in interest surrounding the utilization of polymeric nanoparticles (NPs) as a delivery system for drugs in phytomedicine. These NPs typically range in size from 10 to 1000 nm and are classified into nanospheres and nanocapsules based on their structural composition. Nanospheres consist of polymeric matrices where the active substance is evenly dispersed, whereas nanocapsules exhibit a core-shell arrangement with a polymeric shell encapsulating the active ingredient in the core or adsorbed onto the polymeric membrane. Biodegradable and biocompatible synthetic or natural polymers are utilized in crafting polymeric NPs. These particles facilitate controlled drug release and targeted delivery to specific anatomical sites in the body. (26,27)

Dendrimers have garnered significant attention in herbal delivery within the realm of polymers, owing to their distinctive polyvalency, monodispersity, and controllable structure. (28) Dendrimers are comprised of three main components: the central core, the generations, and the terminal groups. The drug can be linked to the terminal group either covalently or non-covalently, and it can also be encapsulated within the hydrophobic core. Polyamidoamine (PAMAM) stands out as the first commercially available dendrimer, renowned for its role in enhancing the absorption of poorly water-soluble drugs. (29,30).

Polymeric micelles, featuring a core-shell structure with dimensions ranging from 10 to 100 nm, represent another type of polymeric nanoparticles formed through the self-assembly of block copolymers comprising both hydrophilic and hydrophobic blocks in an aqueous environment. The hydrophobic core offers advantages such as enhanced solubility and protection against drug degradation and intracellular accumulation. Meanwhile, the outer hydrophilic layer can enhance biocompatibility and facilitate active targeting. Generally, polymeric micelles exhibit greater stability compared to surfactant micelles. (31, 21)

Inorganic Nanoparticle

Recently, there has been a surge in the use of various types of inorganic nanoparticles (NPs) for drug delivery purposes. These include metal NPs, mesoporous silica nanoparticles (MSNs), carbon nanotubes (CNTs), and magnetic NPs.

Metal NPs, which encompass quantum dots (QDs), gold, silver, platinum, iron (II, III) oxide, titanium dioxide, and zinc oxide, were initially discovered by Faraday in 1908. They have garnered attention in herbal drug delivery due to their unique properties, including a high surface area to volume ratio, numerous low coordination sites, the ability to transition between metallic and molecular states, and high surface energies. (32-34)

Mesoporous silica nanoparticles (MSNs) are extensively utilized in drug delivery, both orally and parenterally, owing to their remarkable chemical stability and biocompatibility. They possess large surface area and porosity, enabling them to carry substantial cargo amounts. (35,36)

Compared to other inorganic nanoparticles, carbon nanotubes (CNTs) exhibit relatively higher compatibility. These nanoparticles, characterized by their tubular structure, are formed by rolling graphite sheets and are classified into two types: single-walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs). SWCNTs have the capability to enhance the solubility and bioavailability of herbal medicines. Additionally, owing to their hollow structure and potential for surface functionalization, they play a crucial role in enhancing the physical and chemical properties of herbal drugs. (37, 38)

Magnetic nanoparticles (NPs) represent another category of inorganic NPs, with $Fe2O3$ in the form of superparamagnetic NPs standing out due to its resistance to oxidation, unlike other magnetic NPs such as nickel and cobalt. This property makes it promising for biomedical applications, particularly in targeted drug delivery. The ability to accumulate magnetic NPs in the target tissue through the application of an external magnetic field holds significant potential for targeted therapy. (39)

Methods of developing Nano phytomedicines

High pressure homogenization Method

Utilizing the high-pressure homogenization technique, lipid particles undergo transformation into nanoparticles through the application of elevated pressure and shear stress. This method, categorized into hot and cold homogenization, is extensively employed for large-scale production of lipid-based nanoparticles, encompassing emulsions, liposomes, and solid lipid nanoparticles (SLNs). In both variations, the initial step entails dissolving the drug in molten lipid. During hot homogenization, the pre-emulsion undergoes homogenization at a temperature exceeding the lipid's melting point. Conversely, in cold homogenization, suspension homogenization occurs at room temperature. (40, 41)

Solvent emulsification-diffusion method

In this approach, the polymer or lipid is dissolved within an organic solvent before being emulsified into an aqueous phase containing an emulsifier. Subsequently, the solvent is removed under vacuum conditions to yield polymeric or lipid-based nanoparticles (NPs). Unlike the homogenization method, this technique operates at lower temperatures, making it suitable for formulating temperature-sensitive drugs. Nonetheless, the use of organic solvents may raise concerns regarding potential toxicological issues. (42, 43)

Co -Precipitation Method

Co-precipitation stands out as the predominant method employed in the synthesis of metal oxide and core-shell nanoparticles (NPs). Renowned for its cost-effectiveness, rapidity, simplicity, and scalability, this approach holds significant appeal for industrial applications. Notably, it yields nanomaterials characterized by high purity without necessitating elevated pressure, temperature, or the use of hazardous organic solvents. Its versatility and straightforwardness render it easily adaptable for large-scale production. (44, 45)

Phase Coacervation

Coacervation represents a prevalent technique in microencapsulation, categorized into two distinct types: simple and complex. In simple coacervation, a colloidal solute like ethyl cellulose or chitosan is employed, whereas complex coacervation involves the preparation of a polymer solution through the interaction between two oppositely charged agents, such as gelatin and chitosan. Typically, this method entails the phase separation of two liquid phases, leading to the formation of a polymer-rich phase known as the coacervate, alongside a polymer-depleted phase termed the equilibrium solution. (46, 47)

Salting Out Method

In this technique, both the drug and polymer are initially dissolved in a solvent. Subsequently, the solubility of the polymer is diminished by introducing an electrolyte, leading to its precipitation and encapsulation of the drug. This method is predominantly employed for the formulation of nanospheres. (48, 49)

Supercritical Fluid-based Method

The supercritical fluid technique is regarded as a crucial method for producing nanoparticles with a narrow size distribution, free from solvent residues in the final product, making it invaluable for the preparation of various biomedical nanomaterials. Carbon dioxide and water are the most frequently utilized supercritical solvents in this process. (50)

This technique is based on dissolving the drug and carrier materials (such as polymers) in the supercritical solvent at critical temperature and pressure. Subsequently, the solution is expanded by spraying it into the expansion chamber at lower pressures. This expansion induces the deposition of materials, resulting in the formation of nanoparticles. (51)

Nanoprecipitation technique

The nanoprecipitation methodologies, alternatively referred to as solvent displacement procedures, were pioneered by Fessi et al. Typically, in this approach, the polymer and medication are dissolved within a solvent compatible with water, subsequently introduced into a non-solvent medium. Upon entry into the non-solvent, the polymer's solubility diminishes rapidly, leading to the precipitation of polymer encapsulating the medication. It is imperative to incorporate an emulsifying agent or stabilizer, such as poloxamers, to prevent the aggregation of nanoparticles (NPs) throughout the nanoprecipitation process. (52,53)

Self-assembly Methods

Self-assembly is a natural process where individual units arrange themselves spontaneously to form precise structures, making it particularly advantageous for crafting two-dimensional nanostructures like nanosheets. This phenomenon can transpire either under external influence or without any external intervention, known as dynamic and static processes, respectively. (54,55)

Harnessing Nano-sized Herbal Remedies for Cancer and Other Medical Conditions

Traditional herbal medicines and natural remedies have a rich history in treating ailments, distinct from modern allopathic approaches due to their use of multiple constituents working synergistically against diseases. Derived from organisms such as fungi, bacteria, animals, and plants, these natural products act as potent biological agents. Many pharmaceuticals available today trace their origins back to these natural sources, underscoring the pivotal role of herbal items. Research spanning pharmacy, pharmacology, and medicine focuses on these herbal remedies. Efforts to incorporate herbal extracts into advanced formulations aim to capitalize on their benefits and overcome challenges like dosing and absorption limitations. Noteworthy natural products and derivatives, including anticancer drugs like paclitaxol and doxorubicin, antibiotics like erythromycin and streptomycin, and other compounds like immunosuppressants and fungicides, have roots in herbal remedies. Additionally, various drugs like aspirin, quinine, morphine, and colchicine have been extracted from plants and used effectively to treat diverse conditions. This rich heritage of natural remedies continues to demonstrate potential in cancer treatment and managing inflammation through plant-based formulations like Curcumin, Triphala, Pomegranate, Kalonji, Sariva, among others. (7)

Scientists have utilized elements from Chinese botanicals to develop a groundbreaking anti-cancer medication, employing nanotechnology to enable these natural remedies to infiltrate cancer cells while leaving healthy cells unharmed. This involved extracting cancer-fighting components from Chinese herbs such as milkvetch root, saltwort, cassia twigs, and liquorice root, then utilizing herbal drug nanotechnology to shrink these elements. This reduction allowed them to penetrate cancerous cells without causing harm to healthy ones. Encouragingly, initial animal testing stages have concluded successfully, securing patent rights across 42 nations. This innovative medication boasts several benefits: it specifically targets cancerous cells, exhibits rapid therapeutic effects, displays no toxicity towards other bodily organs, and can be taken orally without the need for physician oversight. Additionally, when combined with Western medicine, it reduces dosages and combats resistance to cancer treatments, significantly enhancing overall effectiveness. Encouraging experimental findings have demonstrated its efficacy against various cancers, encompassing lung, breast, bone, liver, tongue, cervix, ovary, brain, and skin, both primary and metastatic lymphoma. Notably, its impact on lymphoma is particularly noteworthy, exhibiting tumour softening, reduced size, or complete disappearance within a two-month treatment period (18).

Polymeric micelles, ranging in size from 10 to 40 nanometers, can be easily made from poly (ethylene glycol)/phosphatidyl ethanolamine (PEG-PE) blends. These micelles dissolve well and securely hold considerable amounts of hard-to-dissolve anticancer drugs like m-porphyrin, tamoxifen, and taxol. Loading drugs into these stable polymeric micelles can offer a practical way to deliver medications to tumors by using the improved permeability and retention effect. Additionally, advancements in delivering camptothecin, a plant-derived drug targeting DNA topoisomerase, have boosted its efficacy against tumors. Camptothecin damages DNA by specifically attacking DNA topoisomerase, making it effective against various cancers (19).

Nanotechnology explores the use of plant viruses for targeted drug delivery in cancer treatment. Researchers have successfully adapted a common plant virus to transport drugs exclusively to specific cells within the human body, minimizing impact on surrounding tissues. These minuscule “smart bombs,” thousands of times smaller than a human hair, hold promise for significantly improving chemotherapy effectiveness while minimizing or eliminating adverse side effects. The virus boasts attributes allowing it to survive outside a plant host and carries a 17 nm cargo space ideal for ferrying chemotherapy drugs directly to tumor cells. Through attachment of “signal peptides” to its exterior, termed as cellular “seekers,” the virus can identify and penetrate specific cells like cancer cells, releasing its cargo. Among various nanoparticles utilized as cell-targeting vehicles, the plant virus excels due to its stability, manufacturing convenience, cell-targeting abilities, and capacity to carry therapeutic cargo.

Calcium plays a pivotal role in maintaining the virus's cargo containment. Abundant in the bloodstream, calcium levels significantly drop inside individual cells, triggering the virus to release the cancer drugs exclusively into the targeted cells. The virus's resilient shell ensures no leakage while closed and facilitates gradual opening upon reaching the cell nucleus, enhancing drug efficacy. This innovative approach is anticipated to mitigate the common side effects of conventional chemotherapy while maximizing treatment effectiveness. These nanoparticles can be stabilized and directed to specific cells, like cancer cells, by attaching specific proteins to them. Viruses lacking a lipid envelope offer a precisely organized container structure enabling attachment of targeting molecules. Red Clover Necrotic Mosaic Virus (RCNMV), a 36 nm diameter plant virus with a genome comprising two single-strand RNA molecules, encapsulates various nanoparticles up to 17 nm in diameter. The process involves mimicking a specific site on the genomic RNA to trigger virion assembly, forming uniform virus-like particles around 33 nm in diameter encapsulating the nanoparticles. The smaller size of these particles aids in direct delivery to the cell nucleus through the nuclear pore complex, ensuring sturdy encapsulation for efficient purification (20).

CONCLUSION

The integration of nanotechnology with herbal medicine represents a significant advancement in the field of pharmacology, offering innovative solution for the enhancement of traditional treatments, herbal drugs, while widely appreciated for their therapeutic potential and natural origins, often face challenges such as poor solubility, limited bioavailability, and instability. Nanotechnology provides a robust platform to address their limitations and unlock the full potential of herbal compounds.

The convergence of nano technology and herbal medicine holds tremendous promise for the future of health care by harnessing the strengths of both fields, we can develop more effective, safer, personalised treatment options. However, it is essential to approach this integration with careful consideration of ethical, safety ad environmental implications to ensure sustainable and responsible advancement. Nanotechnology not only enhances the therapeutic potential of herbal drugs but also paves the way for the ground breaking discoveries and innovation in medicine. The journey ahead is exciting and full of potential, promising a new era in the application of natural remedies.

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