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Narrative Review of Herbal Nanomedicines

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ABSTRACT

Herbal nanomedicine represents a rapidly evolving field that combines the therapeutic potential of plant-derived bioactive compounds with the technological advantages of nanocarriers. Traditional herbal formulations often face challenges such as poor solubility, low bioavailability, instability, and rapid metabolism, which limit their clinical efficacy. Nanotechnology provides novel strategies to overcome these barriers by enhancing the delivery, controlled release, and pharmacokinetics of herbal drugs. Various nanoformulations, including nanoparticles, liposomes, nanoemulsions, polymeric micelles, and solid lipid nanoparticles, have been investigated to encapsulate phytochemicals such as curcumin, quercetin, resveratrol, and silymarin, demonstrating improved therapeutic outcomes. These systems have shown promise in the prevention and treatment of cancer, cardiovascular diseases, diabetes, microbial infections, and neurodegenerative disorders. Despite encouraging preclinical evidence, the transition of herbal nanomedicines from laboratory to clinic remains limited due to regulatory challenges, lack of standardization, and insufficient large-scale clinical trials. This review highlights current advances in herbal nanomedicine, explores their mechanisms of improved efficacy, and discusses prospects for integrating nanoformulated phytochemicals into modern healthcare.

Keywords: Herbal nanomedicine**,** Nanoparticles**,** Bioavailability**,** Phytochemicals, and Drug delivery.

INTRODUCTION

Herbal nanomedicines engage the beneficial applications of nanotechnology to medicinal herbs. Herbal medicines, also called botanical medicines or phytomedicines, are herbal preparations used to treat or prevent disease. They are considered a subclass of complementary and alternative medicine [1]. A nano-biosystem is a stable colloidal particle made of natural materials with a size range of 1 nm (10−9 m) to 100 nm (10−7 m). Herbal nano-biosystems can significantly improve the pharmacokinetics of botanical remedies, enhance bioavailability, and reduce toxicity and adverse side effects [2]. They are widely used for the diagnosis and treatment of different ailments, including cancer, microbial infections, inflammation, and diarrhea. Common nano-biosystems used for delivering herbal extracts include liposomes, niosomes, nanoemulsions, nanospheres, and lipid polysaccharide nanoparticles. The development of herbal-based nanoformulations is recent; their use in medicinal applications dates back to ancient civilizations. Still, the integration with nanotechnology for medicinal use did not occur until the 1960s and 1970s [3]. Plant-based therapeutics and remedies have been documented in Egyptian papyri dating back to 2500 B.C. [2]. This ancient knowledge remained hidden in many cultures' oral and written history for centuries until nanotechnology re-emerged within many pharmaceutical applications, including herbal medicine. Extracts derived from medicinal herbs, presented in forms such as nanoparticles, nanocapsules, and nanogels, remain at the tip of the spear for curing deadly diseases such as cancer and epilepsy. Nanotechnology enables the evolution of well-known herbal treatments into advanced pharmaceutical carriers that improve the extract's bioavailability and therapeutic efficacy [3, 2]. This technology-based evolution of phytomedicines is tracing a future path that realizes the potential of bio-based medicine for addressing the challenges of modern-day health care [2].

Mechanisms of Action

Herbal nanomedicines employ nanoparticles as carriers that promote biocompatibility, biodegradability, and regulated release of active phytoconstituents to target sites [4]. These systems enhance the stability, solubility, and absorption of herbal compounds, thereby increasing bioavailability. Phytopharmaceuticals comprise diverse

bioactive components that generate additive or synergistic interactions to exert therapeutic effects. Incorporating traditional herbal medicine in nanocarriers addresses drawbacks such as low aqueous solubility, poor permeability, extensive first-pass metabolism, and chemical instability, thus improving pharmacokinetic and pharmacodynamic profiles [2]. Additional advantages include decreased toxicity and amelioration of bitter taste [1]. Nanoparticles with sizes ranging from 10 to 100 nm promote increased surface area, enhanced cell wall penetration, and efficient systemic delivery. Nanovoids within carrier structures allow controlled release of herbs and extracts, preventing premature degradation. Surface modifications with stabilizers such as polyethylene glycol (PEG) augment systemic persistence and target specificity [1, 2]. Functionalized nanoparticles facilitate site-specific delivery and intracellular uptake.

TTypes of Herbal Nanomedicines

Nanomedicine represents an innovative approach to disease management. The application of nanotechnology techniques to disease treatment has precipitated both disease reversal and control. Herbal or phytomedicines, natural medicinal products, have long performed an integral role in the field of medicine. Because herbal medicines are biocompatible, cost-effective, and lack synthetic chemical compounds, they theoretically present an optimal treatment approach [1]. Nanomedicine combines nanoparticles with natural extracts to facilitate effective drug delivery. Herbal-based nanoformulations have been designed using both top-down and bottom-up approaches. The main methodology involves herbal nanoformulations, the sources of herbal extracts, the synthesis approach, and their applications in medicine. Numerous reports have addressed herbal medicines in disease treatment. This brief review delves into herbal-based nanomedicine, examining the synthesis and mechanisms against cancer in the contexts of cancer therapy, disease control, and control of side effects associated with synthetic drugs [2]. As particles approach nanoscale dimensions, their properties undergo dramatic changes, crossing one or more critical size thresholds [2]. Consequently, the entire field of nanomedicine, which focuses on controlling biological, chemical, and physical interactions at the level of individual biological molecules and cells, has come into existence. The discipline's objectives encompass delivering therapeutic substances to precise target sites in the body; enhancing solubility, bioavailability, and stability; increasing the duration of drug exposure; safeguarding drugs against premature degradation, metabolism, or clearance; mitigating side effects by directing drugs specifically to diseased tissues or cells; and efficiently transporting drugs into cells, tissues, or intracellular organelles. Herbal-based drug delivery via nanoparticles supports these objectives and may overcome certain limitations associated with herbal drugs [3]. The primary classes of nanoparticle formulations include, but are not limited to, nanoparticles, nanocapsules, nanoliposomes, nanospheres, nanocrystals, and nanogels.

Nanoparticles

Nanoparticles are the most popular carrier for herbal drugs, facilitating targeted and sustained release. Their size at the nanometer scale ensures high surface area-to-volume ratios, offering enhanced outdoor activity during drug delivery [1, 2]. Nanoparticles control the release of drugs at maximum loading capacity, protecting them from toxicity and enhancing efficacy, solubility, permeability, and bioavailability. Herbal extracts constitute the reducing and stabilizing agents in their formation. These nectar-like herbal extracts serve as reducing, stabilizing, shape-directing, and capping agents, potentially offering pharmacological activities. Silver and gold nanoparticles are especially prominent [2]. Their reputed antimicrobial properties render them potent agents against microbial resistance. Tumor-targeting efficacy allows both to be employed in cancer therapy. Green synthesis of other metals, such as copper, zinc, iron, palladium, and platinum, is also rising. Copper oxide nanoparticles serve as both an antifungal and anticancer agent, whereas iron oxide nanoparticles are widely utilized in drug delivery [3].

Nanocapsules

Nanocapsules feature a liquid core encapsulated within a polymeric membrane, creating a core-shell architecture [2]. Such nanoencapsulation permits the design of intelligent drug delivery systems equipped with chemical receptors that specifically bind targeted cells [3]. Pharmaceuticals benefit from nanoencapsulation by enabling higher drug loading in smaller volumes, accelerating absorption, enhancing bioavailability, improving safety and efficacy, and facilitating patient compliance [5]. The emulsion-diffusion method generates nanocapsules capable of carrying both lipophilic and hydrophilic substances: polymers and oil are dissolved in an organic solvent to form an oil-in-water emulsion; subsequent solvent evaporation induces polymer precipitation around oil droplets, yielding nanocapsules [4]. Olive oil is frequently employed as the oily phase due to its biocompatibility and capacity to dissolve hydrophobic compounds [5]. Throughout solvent diffusion, polymer precipitation, and interfacial phenomena transform each emulsion droplet into multiple nanocapsules [5].

Nanogels

Nanogels play a distinctive role in drug delivery systems, uniquely combining features of hydrogels and nanoparticles by entrapping diverse therapeutic substances within a hydrogel matrix [3]. Their precise three-dimensional cross-linked polymer network facilitates encapsulation of small molecules, macromolecules, and other

constituents [4]. This architecture grants nanogels notable benefits, including elevated drug loading capacities, adaptive size control, and effective cancer cell uptake, all contributing to reduced toxicity [6]. Nanogels differ from other forms, such as polymeric nanoparticles, nanocapsules, and nanoemulsions, primarily through the hydrogel component of their structure [3].

SoSources of Herbal Extracts

Herbal nanomedicines are subatomic materials that display biological modulatory effects, and they are composed of herbal materials, which can be herbal plants, herb extracts, and other natural compounds [1]. Within the last 15 years, researchers have developed medicinal nanoformulations that utilize components obtained from herbs, substantially increasing the delivery of pharmacologically active constituents. Nano-herbal medicines have gained significant importance in medicine owing to their bioavailability, targeted delivery, biocompatibility, and biodegradability [2].

Common Herbs Used

Herbal nanomedicines have garnered considerable interest for treating various human ailments using natural herbs and their extracts, improving the therapeutic efficacy of herbal extracts through nanoformulations. Numerous herbs, such as ginger, turmeric, claritia, tulsi, aloe vera, ashwagandha, and others, serve as sources of herbal extracts [4]. The prominence of herbal therapeutics arises from their natural origin, widespread availability, cultural acceptance, cost-effectiveness, and advantages in synthesis, degradation, targeting, pharmacokinetics, and formulation [4]. Herbal nanoformulations, typically produced via top-down or bottom-up routes, yield nanoparticles, nanocapsules, and nanogels, among other structures. Characterization employs microscopic and spectroscopic techniques. Nanoformulations of herbal extracts and oils promise applications in cancer therapy, antimicrobial, and anti-inflammatory treatments [5].

Extraction Techniques

Herbal extraction techniques can be classified as conventional and novel methods. Conventional extraction techniques include maceration, percolation, digestion, infusion, decoction, hot continuous percolation, Soxhlet extraction, hydro-distillation, and solvent extraction [6, 7]. The major disadvantages of conventional extraction methods include the excessive use of damaging solvents, long extraction time, high energy consumption, low extraction efficiency, and the risk of low-product quality. The novel extraction methods aim to overcome the drawbacks of conventional methods and provide rapid extraction with minimum solvent and energy consumption under controlled conditions [7]. The novel methods that have been widely employed for the extraction of bioactive compounds from plant materials include membrane separation, enzyme-assisted extraction, ultrasound-assisted extraction (UAE), microwave-assisted extraction (MAE), supercritical fluid extraction (SFE), pressurized liquid extraction (PLE), pulsed electric field (PEF), and high voltage electrical discharges (HVEDs) [7]. The ultrasound-assisted extraction of bioactive compounds from plant by-products offers the potential for a short extraction time and an increased extraction yield. These methods need the optimization of several process parameters, such as temperature, power, time, solvent type, solvent concentration, solvent-to-solid ratio, pressure, particle size, and matrix characteristics, as well as physicochemical and structural characteristics of the target compounds [7].

Synthesis Methods

Synthesis methods for herbal nanomedicines are generally subdivided into two main categories: top-down and bottom-up [3, 4]. The top-down approach involves reducing the size of larger particles using techniques such as milling, grinding, or high-pressure homogenization to achieve nanoscale dimensions. Conversely, the bottom-up approach constructs nanoparticles from molecular components, typically through the controlled aggregation or precipitation of atoms or molecules [3, 4]. Both methodologies can be adapted to incorporate herbal substances, thereby harnessing the therapeutic properties of medicinal plants within nanoparticulate carriers[3]. Such integration is intended to enhance the bioactivity and delivery efficiency of the herbal constituents. The selection of either top-down or bottom-up strategies depends on factors including the desired physicochemical properties of the nanomedicine, the nature of the herbal extract, and the targeted application [3]. Various synthesis procedures have been developed to prepare nanoscale herbal formulations, with ongoing research aimed at optimizing methods to preserve biological activity while ensuring stability and scalability.

Top-Down Approaches

Two top-down approaches, ball milling and high-pressure homogenization, facilitate the development of herbal nanomedicine formulations [4]. Ball milling uses mechanical abrasion in an impeller to reduce agglomerated herbal crude powder to nanometre particle sizes [4]. Roll- and high-energy ball mills convert powders to nanosuspensions using glass, zirconium dioxide (ZrO_2), or stainless-steel balls; nanocrystals then disperse in a stabiliser solution. To prevent contamination and fine-tune particle shapes, optimisation of milling chamber material and parameters is crucial [2]. High-pressure homogenisation breaks down herbal bulk powder to

nanosized particles stabilized by a surfactant. The pulverised herbal powder dispersed in an aqueous surfactant colloid is forced through the homogeniser's gap, where the particles fragment under shear stress and cavitation pressure, facilitating nanocrystal formation. Other documented top-down methods include ultrasonication, extrusion, microfluidization, and melt mixing procedures [3].

Bottom-Up Approaches

These methods focus on the self-assembly of atoms or molecules to form nanostructures [2, 4]. The bottom-up approach is commonly employed for manufacturing herbal nanomedicines, involving natural reduction methods and the use of herbal extracts or derivatives [2]. Herbal extracts contain valuable active compounds that function as reducing and stabilizing agents, converting metal ions into stable metallic nanoparticles under optimized conditions [4]. Essential sources for both approaches include whole plants, flowers, leaves, seeds, roots, stems, and fruits. Suitable extraction techniques, such as solvent extraction, Soxhlet extraction, maceration, hydrodistillation, and decoction, are applied to procure the necessary raw materials [4].

Characterization Techniques

Several characterization tools are essential for evaluating the quality of green nanoformulations and ensuring the absence of undesirable side effects [4]. Particle size and shape are critical parameters; spherical particles ranging from 10 to 100 nm are ideal. Average particle size, which typically falls between 1 and 100 nm for green nanotechnology applications, is commonly measured using dynamic light scattering (DLS), atomic force microscopy (AFM), scanning electron microscopy (SEM), and transmission electron microscopy (TEM) [4]. Techniques such as energy-dispersive X-ray spectroscopy (EDS) and X-ray diffraction (XRD) further characterize size and morphologies, while Fourier-transform infrared spectroscopy (FT-IR) provides information on composition and functional groups. Ensuring these physical and chemical characteristics is vital for the intended medicinal applications of the nanoformulations [4].

Physical Characterization

Appropriate physical characterization techniques verify the quality of herbal-based nanoformulations. Methods such as zeta potential, electrical conductivity, differential scanning calorimetry (DSC), and particle size analysis support nanoformulation assessment [1]. Scientists conduct these evaluations to ensure consistency, stability, and intended physical properties in formulations comprising herbal extracts combined with other materials, facilitating comparative studies [1].

Chemical Characterization

Early chemical characterization involved analyzing secondary metabolites via colorimetric methods and spray reagents after chromatographic separation [6]. These analyses detected compounds such as alkaloids, flavonoids, phenolic acids, fatty acids, carotenoids, and coumarins [6]. Advanced techniques in herbal nanomedicine characterization include differential scanning calorimetry, UV-visible spectrophotometry, X-ray powder diffraction, scanning electron microscopy, Fourier-transform infrared spectroscopy, and nuclear magnetic resonance spectroscopy [3].

Applications in Medicine

Nanoformulations of plant extracts have been utilized for diverse medical applications, including cancer therapy, wound healing, neuroprotection, antimicrobial, and anti-inflammatory roles [3]. With tumor targeting capabilities, these nanoformulations often outperform their original extracts, highlighting the potential of natural anticancer compounds. Copper-containing nanoparticles have shown efficacy against Helicobacter pylori, a bacterial agent associated with gastric ulcers and stomach cancer. Silver–carpenteria bee pollen nanoparticles demonstrate antibacterial properties, while copper nanogel formulations exhibit potent activity against the human immunodeficiency virus for topical use [3]. Nanoemulsions derived from herbal extracts are emerging for brain targeting via the nasal route, and nanoformulations that penetrate the skin tissue are employed to treat various skin infections. Nanoemulsions serve to enhance the bioavailability of poorly soluble drugs and improve targeting capabilities [4]. Herbal extracts are crucial in the synthesis of metallic nanoparticles due to their multifunctional roles in reduction, capping, and stabilization, thereby ensuring eco-friendly biosynthesis [5]. Many plant-based extracts possess numerous bioactive phytoconstituents that confer anticarcinogenic properties. Herbal biopolymer-coated metal nanoparticles offer advantages over uncoated nanoparticles, primarily through enhanced targeting and conjugation at tumor sites. Despite the numerous benefits, the development of herbal nanomedicines remains a complex and challenging task [6].

Cancer Therapy

Cancer is one of the leading causes of death worldwide [8]. The available treatment options have several limitations, and chemotherapeutic agents also cause toxicity during long-term treatment. Phytochemicals, an alternative therapeutic strategy to overcome resistance, consist of natural constituents with fewer side effects. However, their effectiveness is limited by poor solubility, bioavailability, and stability. Nanotechnology enables the

incorporation of phytochemicals into nanosystems with special features [8]. This approach provides many benefits, including biocompatibility, targeted delivery, sustained release, enhanced protective effects, and a better option for future cancer management [7]. The numerous nanocarriers widely used as delivery systems for phytochemicals, current advancements, and their applications in both in vitro and in vivo settings have been highlighted. Clinical development and regulatory concerns have been discussed as a pathway toward a consistent therapeutic regimen that integrates phytochemicals with chemotherapeutics for effective cancer therapy [8].

Antimicrobial Activity

Conventional antimicrobial agents have improved human health by significantly reducing mortality and morbidity from infections [7]. However, increasing microbial resistance, toxicity, hypersensitivity, and unfavorable pharmacokinetics associated with virtually all conventional antimicrobial drugs have attracted extensive attention to herbal medicines as an effective alternative. Infectious diseases caused by pathogenic bacteria and fungi continue to threaten human health worldwide [9]. Microbial infections are partly due to the emergence of life-threatening multidrug-resistant 'superbugs' through horizontal gene transfer, mutations, and biofilm formation, which increase the minimal inhibitory concentration of clinically used antibiotics by reducing cellular uptake and altering the site of action [8]. Thus, there is a pressing need to develop unconventional or alternative therapeutics effective against multidrug-resistant pathogens. Medicinal plants and phytochemicals exhibit broad antimicrobial potential against pathogenic bacteria, fungi, viruses, and parasites. The enhanced antimicrobial potential of herbal-manufactured nanodrugs is explored here [7, 9].

Anti-inflammatory Effects

The prevalence of various inflammatory diseases poses a significant global concern, prompting treatment regimens with medications that often yield notable side effects [1]. Therefore, recent research efforts increasingly focus on identifying less hazardous, effective anti-inflammatory agents derived from botanical sources[1]. A range of plant extracts and phytocompounds have demonstrated such potential, with pharmaceutical companies actively pursuing herbal phytoconstituent-containing medicaments for the prophylaxis and therapy of inflammation-related illnesses [2]. The anti-inflammatory effects attributable to these herbs are linked to several mechanisms of action. Among others, these include the downregulation of pro-inflammatory mediators such as tumor necrosis factor (TNF), interleukin (IL), and histamine, as well as the suppression of both lipopolysaccharide (LPS)-induced and phorbol myristate acetate (PMA)-induced nuclear factor kappa B (NF-κB) pathways [4]. Hence, the development of nanoparticulate herbal formulations affords a potentially valuable therapeutic strategy for the treatment of inflammatory disorders. Scarcity of available data notwithstanding, a selection of such products is reviewed here [3].

Advantages of Herbal Nanomedicines

Herbal nanomedicines, nanoformulations integrating herbal products and related medications, have gained notable attention due to their potential to maintain safety while enhancing therapeutic effectiveness [4]. The integration of drugs into nanocarriers, characterized by controllable size ranging between [10] and several hundred nanometres [1], is instrumental in minimizing adverse reactions and reducing required dosages compared to conventional drugs. Reported advantages encompass drug protection against enzymatic degradation, codelivery of multiple drugs, and skin penetration enhancement. Subsequently, they exhibit improved biocompatibility and reduced inherent or acquired drug resistance [1, 10].

Challenges and Limitations

Regulatory approval for novel nanoformulations is a lengthy process that can delay the introduction of new therapeutic agents to the market [7]. The physiological stability of these nanoformulations is a significant concern; their exposure to different physiological environments often leads to drug degradation, leakage, or premature release [7]. Maintaining the integrity of an efficient nanoformulation prior to reaching the therapeutic site remains a considerable challenge. Engineering an effective, wide-spectrum herbal medicine capable of targeting various diseases through a single formulation remains a pivotal area of focus [4]. Furthermore, most herbal drugs exhibit poor solubility in water and are readily degraded in gastrointestinal fluids, necessitating formulations with enhanced stability and bioavailability to improve therapeutic efficacy. Addressing these challenges is essential for the advancement and clinical translation of herbal nanomedicines [4, 7].

Regulatory Issues

The development of herbal nanomedicine has surged in recent years, offering potential to enhance pharmacokinetic profiles, increase site-specific bioavailability, and reduce adverse effects on healthy tissues after administration. However, lancinating issues include a gap in knowledge on the safety profile of nanomedicines in humans, a lack of coherent international regulatory policies, and particular difficulties in tailoring regulatory frameworks to nanomaterials with unique biological attributes [10]. The pioneering use of nanomedicine was as a delivery system to augment the efficacy and diminish the toxicity of chemotherapeutic agents [1]. Targeted

delivery can be achieved through the exploitation of pathophysiological indicators that differentiate healthy and tumour tissues, such as aberrant angiogenesis. Elevated burst release and increased solubility of therapeutic agents attained by encapsulation in nanomaterials afford faster circulation and enhanced permeation into the tumour site [5]. Segmental delivery prompted the assimilation of nanomaterials into numerous other areas, including gene therapy and diagnostic imaging, and has since revealed beneficial applications through the use of organic, semi-organic, and inorganic materials [4]. In each of these areas, the incorporation of naturally derived products has increasingly become the focus of research endeavours [2]. A vast array of efficacious biotic agents can be formulated from synthetic or natural compounds, but those relating to health care primarily emanate from natural sources and have undergone centuries of refined utilization and, consequently, medicinal efficacy [3]. Natural products are chiefly extracted from flora, some of which serve as the archetypal or temporary origin for synthetic analogues, with an increasing number of pure compounds becoming available as the industry's demands escalate[1]. The advent of nanotechnology has spurred concentrated efforts into capitalizing on the virtues inherent in the naturally derived compounds that have been demonstrated to exhibit enhanced behaviour through loading into nanomaterials. These endeavours have been underpinned by the use of a wide range of materials, many of which can be categorised into types bearing similar properties and applications. This chapter will review several of the most widely used materials in contemporary research and outline the main synthesis and characterisation routes employed [2].

Stability Concerns

Nanoparticles have a higher surface area to volume ratio than macroparticles. As particle size decreases, a larger surface area to volume ratio increases the surface energy of nanoparticles, tending towards agglomeration. Various techniques have been used to increase the physical stability of nanoparticles [2]. Insufficient information on nanoparticle properties has limited their medical application [2, 7]. The chemical stability of nanoparticles can be affected by the sensitivity of some herbal components to environmental conditions. After nanoparticle formulation, components must be resistant to degradation from exposure conditions during storage. Nanoparticle exposure conditions must be controlled for optimum stability [7].

Future Directions

Recent directions focus on novel herbal nanomedicines through the introduction of new molecules or advanced functional molecules into herbal-based nanosystems to exploit the natural therapeutic potential of herbs for a wide range of applications [1]. Interest in testing herbal-based nanoformulations in clinical trials has also increased. Herbal-based nanoparticulate systems used in cancer therapy, antimicrobial therapy, brain targeting, vaginal delivery, ocular delivery, and transdermal delivery are under clinical and experimental testing [3]. The potential of this technology to develop herbal medicine with novel characteristics and to increase and improve the bioactivity and stability of herbal medicine is gaining recognition [4]. The use of herbal medicine in the formulation of nanoparticulate systems to increase biological activity and the stability of therapeutic agents is rapidly growing. Despite general obstacles such as a lack of specific regulatory guidelines, several reports reveal that nanoformulation improves the therapeutic activity of herbal extracts against cancer, inflammatory diseases, and skin diseases [1]. Important concerns include the advantages of herbal nanoformulations over conventional herbal formulations and pharmacological safety. Toxicological information and pharmacokinetics concerning herbal nanoformulations are therefore presented [2]. The major challenges concerning the stability and standardization of herbal nanoformulations for future development are discussed. The beneficial or adverse/new effects of nanoherbal formulations, which differ from those of conventional formulations, must be carefully monitored and evaluated during clinical applications. Furthermore, there remains a huge gap for the rational design of herbal-based nanoformulations for specific diseases, and therefore an urgent need for the development of novel formulations with superior efficacy and enhanced bioavailability remains to be addressed [1,3].

Innovative Formulations

The global market for herbal medicines has increased significantly during the last decade [1]. They have proved their efficacy in the treatment of various chronic and acute disease conditions [3]. The significance of nanoparticles embedded with herbal formulations has grown multifold as they can be exploited effectively to develop novel herbal medicines addressing a wide range of disease conditions [4]. Herbal drugs have gained stardom in several regions of the world due to their generally safe nature, minimal or no side effects, and relatively lower costs. Many plants have validated pharmacological properties due to their distinctive phytochemical constituents [1]. Herbal drugs, when delivered at the nanoscale level with improved characteristics of enhanced stability, increased solubility, reduced toxicity, improved site-specific and controlled release, achieve higher therapeutic value, which in turn improves the existing potency of various herbal medicines [2]. Innovative formulations of natural substances can be synthesized by several approaches, combining the drugs with other active ingredients that may serve as synergistic or additive agents, markedly increasing the efficiency of synthetic nanostructures, but keeping the reduced toxicity characteristics of nanoherbal formulations [4]. Nanotechnology

is used in drug delivery applications to target particular sites, which help in improving the bioavailability of drugs, improving stability, and reducing the side effects. Herbal nanoformulations can be offered as various dosage forms such as nanoparticles, nanospheres, nanosuspensions, nanotubes, nanopores, nanocapsules, nanorobots, nanobelts, nanobubbles, nanoswitches, nanoamplifiers, nanobots, nanorobots, nanofibers, nanoemulsions, nanocrystals, nanocomposites, nanoliposomes, and nanopolymers [1].

Clinical Trials

Herbal nanomedicines are innovative nanoscale formulations that integrate herbal extracts with nanotechnology to enhance therapeutic efficacy and safety. The clinical translation of herbal nanomedicines is an active area of research characterized by a growing number of clinical trials that investigate their safety, pharmacokinetics, and efficacy in various indications [1, 2]. Although many preclinical studies have demonstrated encouraging results, relatively few herbal nanomedicines have progressed beyond Phase II clinical development, underscoring the need for further research to fully realize their clinical potential [1]. Extensive efforts have been devoted to developing herbal nanomedicines for multiple indications, including inflammatory diseases and cancer, addressing unresolved challenges associated with conventional herbal extracts such as poor bioavailability, low aqueous solubility, and dose-dependent toxicity [2].

Ethical Considerations

The prominence of herbal nanomedicine in biomolecules, phytotherapy, and targeted drug delivery is linked to its greater biocompatibility, ease of preparation, affordable cost, environmental friendliness, higher effectiveness with fewer side effects, and enhanced pharmacokinetic and pharmacodynamic profiles [8]. Nevertheless, emerging types of herbal nanoformulations require further attention. Medicines containing herbal extracts have been developed for cancer, as well as for antibacterial and anti-inflammatory actions. Several types of herbal nanoformulations, together with their advantages and challenges, are surveyed [9]. Future developments are proposed, focusing on challenges and ambitions in designing innovative formulations with clinical trials. Nanotechnology is a rapidly evolving multidisciplinary field that is revolutionizing the production and tailoring of matter at nanoscale dimensions (1–100 nm), establishing itself as an excellent drug delivery system for many diseases. Herbal-based nanoformulations have occupied a special place in advanced drug delivery and the complementary therapeutic fields of medicine, centered on routine herbal active substances with recognized therapeutic benefits [7]. Combined herbal crude extracts or phytoconstituent-derived nanoformulations have been proven effective in controlled delivery carriers. Such creations experiment with the controlled release of herbal crude extracts' therapeutic potential, either extracted or unextracted, in curing health disorders. Additionally, the antibacterial and anti-inflammatory properties of herbal-based nanoformulations enhance their pharmacokinetic and pharmacodynamic behavior [10].

Comparative Studies

Nanotechnology and herbal medicine are two fascinating fields, and their intersection offers exciting possibilities [1]. Herbal nanomedicines show great promise for cancer treatment by improving drug distribution, circulation time, and reducing side effects and toxicity to healthy tissues [2]. Several studies have demonstrated the effectiveness and safety of herbal nanoscale antitumor products through in vitro and in vivo testing. Exploring the use of herbal nanomedicines in combination clinical trials is likely to become a future trend [3]. Numerous nanoformulations derived from plants are presently available in the market. A comparative study between synthetic and herbal nanomedicines reveals a significantly lower number of reported events for their anticancer, antimicrobial, and anti-inflammatory applications. Additionally, human clinical trials of herbal nanomedicines are limited [5]. The utilization of silver nanoparticles synthesized from plants for antimicrobial and anticancer applications lacks comprehensive clinical trials. Pharmaceutical companies face challenges in producing herbal nanomedicine dosage forms due to a lack of data on excipient compatibility, stability, and shelf life. Furthermore, advanced formulations for herbal nanomedicines, such as nanoemulsions, microsphere/nanosphere, liposomes, and nanogels, have yet to be thoroughly explored [2].

Synthetic vs. Herbal Nanomedicines

Considering the vast applications of nanomedicine in the medical field, including cancer therapy, the use of herbal medicine is surprisingly very limited despite its beneficial effects elsewhere [1, 2]. Modification of herbal medicines using cutting-edge nanomedicine techniques would improve the efficiency and effectiveness of clinical management and could be a potential solution to the suboptimal application of herbal medicines [6]. Nanomedicine includes the application of nanoparticles (NPs) as drug delivery systems that improve the water solubility of many herbal compounds, leading to better biodistribution and consequently less toxicity and enhanced efficacy [7]. In the medical field, cancer research features prominently, as benign tumors and other diseases have been relatively well managed [8]. These diseases have low mortality rates and are generally curable using routine methods. With advances in cancer treatment technology, herbal medicines, such as traditional

Chinese medicine, could be implemented as complementary treatments alongside chemotherapy to improve prognosis. Nanomedicine comprises the application of NPs as drug delivery systems, which improve the water solubility of numerous herbal compounds, leading to better biodistribution and consequently less toxicity and enhanced efficacy [9].

Case Studies

Herbal nanomedicines enable control of particle size, surface properties, and release characteristics, combining the advantages of nanotechnological carriers, such as targeted delivery and controlled release, with the therapeutic potential of medicinal plants [1, 2]. Formulations include various nano-objects such as particles, capsules, and emulsions, often modifying classic drug delivery techniques to incorporate nanoscale herbal extracts or essential oils. Clinical trials worldwide have been conducted to validate their therapeutic efficacy. This section highlights three examples of successful herbal nanomedicine applications illustrating the diverse pathways through which phytochemicals impact biological systems [2].

Successful Applications

Nanotechnology enables the development of organic nanocarriers from natural or synthetic materials with optimized characteristics suitable for targeted sustained delivery to specific organs or cells [1, 2]. Advantages include smaller size, extensive surface area, enhanced bioavailability, and significant therapeutic activity, while also reducing adverse effects and drug resistance mechanisms. Herb-based nanoformulations have been recognized for these benefits for decades [1]. It is well-known that many natural therapeutics possess bio-functional groups in secondary metabolites and polyphenols, acting as highly reactive materials in nanoparticle synthesis. Different nanoformulations of natural herbs, therefore, exhibit applications in multiple areas [2].

Lessons Learned

Advancements in herbal nanomedicine are examined in detail to discern whether the benefits arise from the inherent properties of the herbal constituents or from their nanoencapsulation [5]. Herbal nanoformulations can be generated through top-down methods, such as grinding, milling, and high-pressure homogenization, or bottom-up techniques, including the use of biological intermediates like plant extracts and microorganisms as templates for nanostructure growth[7]. Plant-derived reducing agents, such as polyphenols and flavonoids, facilitate the greener, bottom-up synthesis of nanoparticles through efficient growth and nucleation. Nanoparticles derived from herbal materials can be either powdered formulations or dispersed systems like suspensions, solutions, or emulsions. Extensive research has been devoted to the synthesis and evaluation of herbal-based nanoformulations for pharmaceutical applications [8]. Although numerous botanical derivatives can be employed in nanoformulations, the principal challenge lies in selecting those with suitable therapeutic activity. Herbal constituents play pivotal roles in directing the size, shape, and surface properties of the resulting nanosystems, alongside their intrinsic bioactivity [1]. Resultantly, these herb-reduced nanoparticles exhibit enhanced therapeutic outcomes and diminished side effects due to their nanoencapsulation. The superior performance of these formulations in medical and drug delivery contexts is not solely attributable to the herbal constituents but predominantly to their encapsulation within a suitable nanoform [1].

Public Perception and Acceptance

The adoption of herbal nanomedicines is shaped by public perception, which influences their societal acceptance, use, and market growth [3]. End-user viewpoints on nanotechnology and herbal formulations play a vital role in the progression and commercial success of these products. Experience with herbal therapies contributes to optimistic attitudes toward nanomedicine. Surveys indicate that a significant portion of the population utilizes herbal medicines; in the United States, 38% of adults and 12% of children engage with natural products, while 50% of Australians use complementary medicine, highlighting the prevalence of natural remedies despite skepticism regarding their efficacy. Concerns regarding side effects and the absence of scientific validation deter usage; however, increasing evidence of benefits, particularly in cancer and antimicrobial therapies, has evoked positive responses [7]. Throughout the lifespan, individuals develop positive or negative predispositions shaped by various influencing factors, which subsequently affect technology adoption. Communicating scientific information to the public presents challenges, yet mass media can be leveraged effectively to familiarize consumers with herbal nanomedicine [10-13].

CONCLUSION

Herbal nanomedicine offers a promising approach to overcome the limitations of conventional herbal formulations by enhancing bioavailability, stability, and therapeutic efficacy. The integration of nanotechnology with plant-based medicine has opened new opportunities for the development of innovative treatments for chronic and infectious diseases. However, challenges such as toxicity evaluation, large-scale production, regulatory approval, and standardization of formulations must be addressed before widespread clinical application. Continued interdisciplinary research and well-designed clinical trials are essential to establish the safety and efficacy of herbal

nanomedicines. With growing global interest in natural remedies and advanced drug delivery systems, herbal nanomedicine holds significant potential to bridge traditional medicine with modern therapeutic needs.

REFERENCES

1. Rajagopal M, Paul AK, Lee MT, Joykin AR, Por CS, Mahboob T, Salibay CC, Torres MS, Guiang MM, Rahmatullah M, Jahan R. Phytochemicals and nano-phytopharmaceuticals use in skin, urogenital and locomotor disorders: are we there?. Plants. 2022 May 8;11(9):1265.
2. Ansari SH, Islam F, Sameem M. Influence of nanotechnology on herbal drugs: A Review. Journal of advanced pharmaceutical technology & research. 2012 Jul 1;3(3):142-6.
3. Paul-Chima UO, Nnaemeka UM, Nneoma UC. Could dysbiosis of urban air microbiota be an overlooked contributor to pediatric asthma and neurodevelopmental disorders?. Medical Hypotheses. 2025 Sep 12:111758.
4. Ai S, Li Y, Zheng H, Zhang M, Tao J, Liu W, Peng L, Wang Z, Wang Y. Collision of herbal medicine and nanotechnology: a bibliometric analysis of herbal nanoparticles from 2004 to 2023. Journal of nanobiotechnology. 2024 Apr 1;22(1):140.
5. Setia A, Vallamkonda B, Challa RR, Mehata AK, Badgujar P, Muthu MS. Herbal theranostics: Controlled, targeted delivery and imaging of herbal molecules. Nanotheranostics. 2024 Mar 25;8(3):344.
6. Esmaeili A, Rahnamoun S, Sharifnia F. Effect of O/W process parameters on Crataegus azarolus L nanocapsule properties. Journal of nanobiotechnology. 2013 May 29;11(1):16.
7. Sindhu RK, Gupta R, Wadhera G, Kumar P. Modern herbal nanogels: formulation, delivery methods, and applications. Gels. 2022 Feb 7;8(2):97.
8. Paul-Chima UO, Ogenyi FC, Ugwu CN, Nnaemeka UM. Gut Microbiota-Derived Metabolites as Early Biomarkers for Childhood Obesity: A Policy Commentary from Urban African Populations. Obesity Medicine. 2025 Sep 4:100641.
9. Bonifácio BV, da Silva PB, Ramos MA, Negri KM, Bauab TM, Chorilli M. Nanotechnology-based drug delivery systems and herbal medicines: a review. International journal of nanomedicine. 2014 Dec 9:1-5.
10. Wahi A, Bishnoi M, Raina N, Singh MA, Verma P, Gupta PK, Kaur G, Tuli HS, Gupta M. Recent updates on nano-phyto-formulations based therapeutic intervention for cancer treatment. Oncology Research. 2023 Nov 15;32(1):19.
11. Tian X, Wang P, Li T, Huang X, Guo W, Yang Y, Yan M, Zhang H, Cai D, Jia X, Li F. Self-assembled natural phytochemicals for synergistically antibacterial application from the enlightenment of traditional Chinese medicine combination. Acta Pharmaceutica Sinica B. 2020 Sep 1;10(9):1784-95.
12. Ugwu OP, Okon MB, Alum EU, Ugwu CN, Anyanwu EG, Mariam B, Ogenyi FC, Eze VH, Anyanwu CN, Ezeonwumelu JO, Egba SI. Unveiling the therapeutic potential of the gut microbiota–brain axis: Novel insights and clinical applications in neurological disorders. Medicine. 2025 Jul 25;104(30):e43542.
13. Đorđević S, Gonzalez MM, Conejos-Sánchez I, Carreira B, Pozzi S, Acúrcio RC, Satchi-Fainaro R, Florindo HF, Vicent MJ. Current hurdles to the translation of nanomedicines from bench to the clinic. Drug delivery and translational research. 2022 Mar;12(3):500-25.

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