RESEARCH PAPER

Plant-Based Nanocarriers in Naturopathy: Bridging Botanical Science and Advanced Drug Delivery Systems

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Abstract

Plant-based nanocarriers are a burgeoning intersection of naturopathy, phytotherapy and modern drug delivery. Traditional herbal formulations are commonly employed in naturopathic and conventional medicine; but many plant-derived compounds are poorly soluble in water, have low bioavailability, poor stability, high metabolic rates, and exhibit variable efficacies. Nanocarrier systems represent a potential solution to these challenges, through enhanced solubility, permeability, cellular uptake, targeted delivery, and sustained release of bioactive plant compounds. This narrative review examines the conceptual basis, types, mechanisms, uses, benefits, safety issues and challenges of plant-based nanocarriers in herbal formulations. Key nanocarriers mentioned include phytosomes, liposomes, solid lipid nanoparticles, nanostructured lipid carriers, polymeric nanoparticles, nanoemulsions, microemulsions, and plant-mediated metallic nanoparticles. They may be applied in inflammatory and autoimmune diseases, cancer, wound healing, anti-infection, respiratory disease and metabolic disease. The article also discusses the importance of green nanotechnology, in which plant extracts are used as reducing, stabilizing and capping agents to prepare nanoparticles. While plant-based nanocarriers can potentially enhance efficacy and consistency of herbal medicine, issues of toxicity, reproducibility, stability, scalability, regulatory and clinical testing still need to be addressed. In general, plant-based nanocarriers offer a scientifically advanced approach to blend traditional botanical wisdom with evidence-based naturopathic and pharmaceutical development.

Keywords: Plant-based nanocarriers; Naturopathy; Herbal medicine; Botanical therapeutics; Phytochemicals; Green nanotechnology

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1. Introduction

Naturopathy is an alternative health-care system that prioritises the body's ability to self-heal through natural therapies, lifestyle management, dietary modification, detoxification, and use of plant-based products. In naturopathy, medicinal plants play a pivotal role as herbal medicines because they are rich in various bioactive constituents including alkaloids, flavonoids, terpenoids, polyphenols, tannins, glycosides and essential oils. These phytoconstituents have long been used for the treatment of inflammation, metabolic dysfunction, oxidative stress, infections, gastrointesinal disorders, immune dysfunction and lifestyle-related chronic diseases. The importance of plant-based medicine is also evident in other medical traditions such as Ayurveda, where medicinal plants are considered not only as disease-curing agents, but also as adjunctive

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agents in promoting physiological balance and good health (Kumar et al., 2017).

Although herbal formulations have been used for centuries, traditional herbal products have certain scientific and pharmaceutical challenges. Phytochemicals are often poorly soluble in water, poorly absorbed in the gastrointestinal tract, unstable, or rapidly metabolised, and have low systemic bioavailability. This may lead to low concentrations of active ingredient reaching target tissues, resulting in variable therapeutic activity. Herbal extracts can also be variable in composition due to variations in plant material, growing conditions, extraction procedures, storage and formulation. These factors decrease their repeatability and complicate the development of herbal medicines for modern therapeutic applications. Despite the great pharmacological potential of natural compounds, their development for clinical use is often limited by poor pharmacokinetics and formulation issues (Bilia et al., 2017).

Nanomedicine offers a novel approach to address these challenges and enhance the delivery, stability, solubility and biological activity of medicines. Nanoparticle-based drug delivery systems are usually designed to be at the nanoscale level, enabling them to interact more effectively with biological membranes and cellular processes. These systems can increase drug absorption, prevent chemical or enzymatic degradation of active drugs, allow for sustained release of active compounds and increase targeted drug delivery to tissues. Nano-based drug delivery is therefore considered to be a growing area with the potential to enhance therapeutic benefits while minimising toxicity (Patra et al., 2018). Nanoparticle systems can also be used to improve solubility, targeted delivery, and efficacy of drugs (Rizvi & Saleh, 2018).

Recently, nanotechnology has been applied to herbal medicine, resulting in the development of herbal nanocarriers such as phytosomes, liposomes, solid lipid nanoparticles, nanostructured lipid carriers, polymeric nanoparticles, nanoemulsions and plant-mediated metallic nanoparticles. Such delivery systems are important for phytochemicals because many of these compounds are lipophilic, unstable or poorly bioavailable in their natural state. Through their incorporation into nanocarriers, botanical compounds can be made more bioavailable, better absorbed by cells, more potent and more effective. The evolution of nanomedicine from laboratory platforms to marketed and investigational nanodrugs shows the increasing role of nanomedicine in drug development (Ventola, 2017).

Plant-based nanocarriers are particularly important for the practice of naturopathy as they can combine traditional botanical knowledge with modern nanotechnology. In contrast to entirely synthetic nanocarriers, green nanocarriers (nanocarriers derived from plants) can incorporate natural phospholipids, plant oils, polysaccharides, phytochemicals or plant extracts as stabilising agents, reducing agents or therapeutic compounds. This is congruent with naturopathy as it promotes biocompatibility, sustainability and natural product use. But translation demands consideration of safety, toxicity, pharmacokinetics, efficacy and quality. Drugs containing nanoparticles have translational issues with manufacturing, regulatory, scalability and commercialization, which also apply to herbal nanomedicine (Hua et al., 2018).

The clinical development of nanoparticles also justifies the need to consider herbal nanocarriers in an evidence-based manner. Nanoparticles are increasingly being studied and applied in clinical practice due to their drug delivery and therapeutic selectivity (Anselmo & Mitragotri, 2019). Next-generation design approaches of precision nanoparticles can enhance targeting, stability, release, and efficacy (Mitchell et al., 2021). This opens a door to upgrade botanical medicines while preserving their natural and holistic properties.

Hence, this narrative review is an overview of botanical nanocarriers as a fusion of naturopathy, botanical medicine, and nanomedicine. It covers the drawbacks of traditional herbal products, nanocarrier-based drug delivery, key types of plant-based nanocarriers, their applications and clinical potential, and safety and regulatory concerns. Herbal nanocarriers may offer new approaches for more efficient, consistent, and scientifically rigorous naturopathic therapies, blending traditional plant-based medicines and nanotechnology.

2. Conceptual Foundations

2.1 Naturopathy and Botanical Therapeutics

Naturopathy considers health to be restored and maintained when the body is facilitated to heal itself through nutrition, lifestyle, detoxification, and botanical medicine. Botanical medicine is a key component of this model because medicinal plants contain phytochemicals like flavonoids, phenolic acids, alkaloids, terpenoids, tannins, and essential oils that are responsible for antioxidant, anti-inflammatory, antimicrobial, metabolic and anticancer effects. Medicinal and food plants are now increasingly being acknowledged as an important source of bioactive compounds for pharmaceutical and functional health purposes (Yu et al., 2021). In these applications, phytochemicals are not considered solely in terms of chemical activity, but also as components of a broader system that supports physiological balance and holistic health. Natural compounds derived from plants have demonstrated significant potential in the prevention and treatment of various diseases, including anticancer properties, and are thus relevant for naturopathic and complementary health care (Iqbal et al., 2017). The recent development of nanonutraceuticals also links botanical therapeutics to immune support and prevention through enhanced delivery and efficacy of bioactive natural substances (Jampilek & Kralova, 2020). The conceptual model of plant nanocarriers from the perspective of naturopathy and botanical medicine to drug delivery is shown in Figure 1

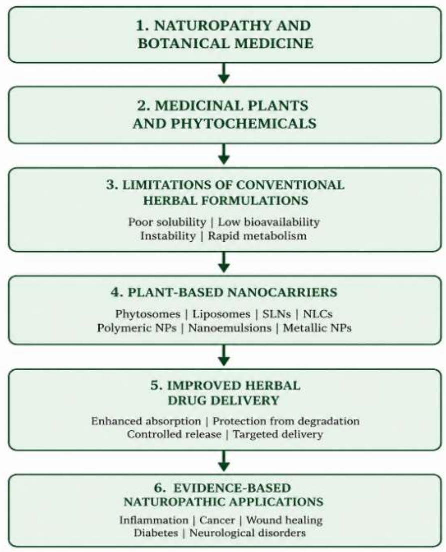

Figure 1. Conceptual framework of plant-based nanocarriers in naturopathy.

2.2 Basics of Nanotechnology in Drug Delivery

Drug delivery nanotechnology refers to the design and application of nanomaterials (typically 1-100 nm) to enhance the delivery, stability, absorption and efficacy of active ingredients. Nanoformulations can improve the solubility of poorly soluble compounds, protect labile compounds from degradation, increase their circulation time, and allow regulated or sustained release. This is relevant for various plant-derived bioactives, which are often poorly absorbed and quickly metabolised. Nanoformulations of bioactives are now extensively explored for targeted and enhanced efficacy (Kumari et al., 2022). Metal nanoparticles and other nanosystems are also promising in biomedical applications, particularly in cancer treatment, where enhanced cellular uptake and targeted activity are desirable (Khursheed et al., 2022). In this new era of medicine, targeted delivery is becoming increasingly crucial as it can enhance therapeutic efficacy and minimise side effects and toxicity (Anand et al., 2023).

2.3 Green Nanotechnology

Green nanotechnology is the sustainable production of nanoparticles using biological agents such as plant extracts, microorganisms and biomolecules. During plant-mediated synthesis, phytochemicals function as reducing, stabilizing and capping agents that aid in the conversion of metal ions to nanoparticles with minimal use of toxic chemicals. Green synthesis of zinc oxide nanoparticles using plants highlights the use of green chemistry methodology for nanomaterial synthesis (Ahmed et al., 2017). Plant-extract-mediated green synthesis is known to be simple, economical, biocompatible, and sustainable (Jadoun et al., 2021). Plant-based nanoparticles are being developed for use in medicine, agriculture, environmental and antimicrobial agents (F. Khan et al., 2022). Likewise, green synthesis of metal and metal oxide nanoparticles facilitates safe and sustainable nanotechnology (Singh et al., 2018). Recent research on plant-extract-based metallic nanoparticles also suggests that green nanotechnology can integrate traditional herbal formulations with innovative drug delivery and medicine (Yadi et al., 2018).

3. Types of Plant-Based Nanocarriers

3.1 Phytosomes

Phytosomes are phospholipid complexes where plant-derived active molecules are bound to phospholipids by chemical or physical interaction to enhance absorption, stability and membrane permeability. This approach is particularly beneficial for plant-based compounds like curcumin, silybin, quercetin and other polyphenols that are poorly soluble in water and have low bioavailability in traditional herbal formulations. Phytosomes can improve drug entry into biological membranes and also have potential applications in transdermal and complementary medicine (Chen et al., 2022). The main nanocarrier systems derived from plants are presented in Table 1.

Table 1. Major Types of Plant-Based Nanocarriers

Nanocarrier type	Key feature	Main advantage	References
Phytosomes	Phytochemical–phospholipid complex	Improves absorption and permeability	(Chen et al., 2022)
Liposomes / vesicular carriers	Phospholipid bilayer vesicles	Deliver hydrophilic and lipophilic compounds	(Alavi & Hamidi, 2019)
Solid lipid nanoparticles	Solid lipid matrix	Improves stability and controlled release	(More et al., 2021)

Nanostructured lipid carriers	Solid + liquid lipid matrix	Higher drug loading than SLNs	(Jacob et al., 2025)
Polymeric nanoparticles	Natural/biocompatible polymers	Supports targeted and sustained delivery	(Raval & Bhattacharya, 2025)
Nanoemulsions / microemulsions	Oil–water colloidal system	Improves solubility of lipophilic phytochemicals	(Dammak et al., 2020)
Plant-mediated metallic nanoparticles	Plant extract-mediated metal nanoparticles	Antimicrobial, anticancer, and biomedical potential	(Rafique et al., 2017)

3.2 Liposomes and Vesicular Carriers Derived from Plant Components

Liposomes and other vesicular systems are primarily made of phospholipids bilayers that can encapsulate hydrophilic and lipophilic phytochemicals. These structures are useful for delivery of herbal drugs as they enhance solubility, protect labile compounds, and enable sustained release. Liposomes, transferosomes, ethosomes and phytosomes are commonly used for phytochemical delivery in oral, topical and transdermal formulations (Jacob et al., 2025). Liposomes and lipid nanoparticles can enable passive and active targeting, especially in cancer treatment, where enhanced targeting can minimise side effects (Alavi & Hamidi, 2019).

3.3 Solid Lipid Nanoparticles and Nanostructured Lipid Carriers

Solid lipid nanoparticles (SLNs) and nanostructured lipid carriers (NLCs) are lipid-based nanocarriers that can enhance the loading, stability and sustained release of active ingredients. SLNs are made of solid lipids, while NLCs are a blend of solid and liquid lipids, resulting in a less crystalline structure with improved drug loading. These nanocarriers are gaining traction in the delivery of phytochemicals for cancer due to their potential to enhance the pharmacokinetics and efficacy. Nanoformulations of phytochemicals are also being developed to treat resistant cancers by improving cellular uptake and overcoming delivery challenges (More et al., 2021).

3.4 Polymeric Nanoparticles and Natural Polymer-Based Systems

Polymeric nanoparticles made from natural or biocompatible polymers are another key delivery system for herbal medicines. Chitosan, alginate, cellulose and hyaluronic acid are examples of materials that can enhance mucoadhesion, biodegradability and targeting. Hyaluronic acid is particularly valuable due to its biocompatibility and receptor targeting capability (Gupta et al., 2019). Polymeric nanoparticles coated with hyaluronic acid are being developed for targeted cancer treatment, overcoming drug resistance, and modulating the tumour microenvironment (Raval & Bhattacharya, 2025).

3.5 Nanoemulsions and Microemulsions

Herbal oils and lipophilic phytochemicals can be delivered by nanoemulsions and microemulsions, colloidal systems. They enhance the solubility, dispersion, bioavailability and stability of water-insoluble plant constituents. Employment of natural emulsifiers instead of synthetic surfactants allows safer and more sustainable formulation (Dammak et al., 2020). The latest developments in nanoemulsion-based formulations also demonstrate their effectiveness in improving drug delivery and bioavailability (Deshmukh & Jain, 2026).

3.6 Metallic Nanoparticles Synthesized Using Plants

Metallic nanoparticles made through plants are synthesized using plant extracts as reducing, capping and stabilizing agents. Green-synthesised silver, gold, zinc oxide, and other metallic nanoparticles have demonstrated antimicrobial, anticancer, antioxidant, photocatalytic and biomedical activities (Habeeb Rahuman et al., 2022; Rafique et al., 2017; Shahzadi et al., 2025). These systems are an eco-friendly bridge between herbal science and nanomedicine (Panchal et al., 2025).

4. Mechanisms Enhancing Herbal Drug Delivery

Nanocarriers improve drug delivery of herbal medicines by overcoming the main formulation challenges of plant-based bioactives. Phytochemicals like curcumin, quercetin, and resveratrol are poorly soluble, poorly permeable, unstable and highly metabolised, leading to low therapeutic efficacy in traditional formulations. Nanocarriers enhance solubility and permeability through their small size, high surface area, and ability to interact with cell membranes. Curcumin nanocarriers enhance dispersion, stability, absorption, and bioavailability, and enable controlled release (Jacob et al., 2024). Nanocarriers of quercetin also increase solubility, prevent degradation, and facilitate active transport (Tomou et al., 2023). Resveratrol nanocarriers enhance the pharmacokinetics of the drug by improving stability, solubility and targetability . Nanocarriers can also facilitate passive and active targeting, enabling better drug targeting to the disease site. Ligand-based targeting, such as transferrin receptor-based targeting, also enhances cell-specific targeting and tissue targeting, even across biological barriers, including the blood-brain barrier (Choudhury et al., 2018). Therefore, nanocarriers offer controlled release, targeting, and enhanced therapeutic efficacy for herbal drugs. Figure 2 highlights the major ways nanocarriers enhance the solubility, stability, permeability, targeting, cellular uptake and controlled release of herbal bioactives.

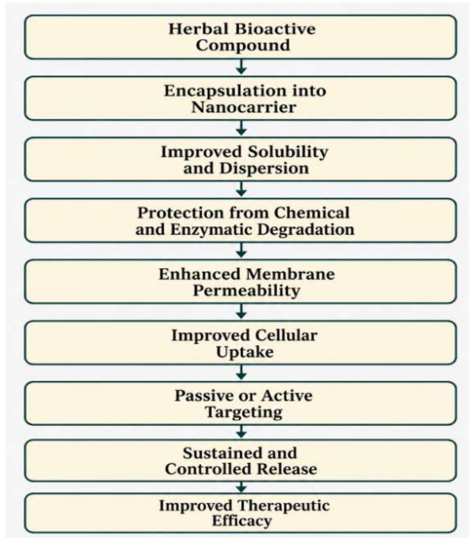

Figure 2. Mechanisms by which nanocarriers enhance herbal drug delivery.

5. Applications in Naturopathy and Herbal Medicine

5.1 Respiratory, Anti-inflammatory, and Autoimmune Applications

The potential of plant-based nanocarriers in respiratory, inflammatory and autoimmune diseases is significant due to the numerous antioxidant, immunomodulatory and anti-inflammatory effects of many botanical compounds. Medicinal plants are commonly employed in naturopathy to aid respiratory activity, decrease airway inflammation and enhance immune homeostasis. The ethnomedicinal significance and pharmacological potential of traditional medicinal plants used to treat asthma in Pakistan have also been reported but the given reference lacks full publication data and has to be checked before submission (L. Ahmad et al., 2025). Another role of polyphenols relates to autoimmune and inflammatory disease since they could potentially control the oxidative stress, inflammatory cytokines, and immune reactions (H. Khan et al., 2019). The absorption and therapeutic consistency of such compounds can be enhanced by nanoformulating them.

5.2 Anticancer Applications

The use of nanocarriers in the delivery of herbal anticancer therapies is a highly researched area since most plant-derived anticancer agents are poorly soluble, unstable, and do not accumulate in the tumor. The compounds produced by algae are becoming a popular natural source of pharmaceutical drugs to treat cancer, owing to their bioactive metabolites and therapeutic versatility (I. Z. Ahmad & Singh, 2024). The use of nanodiagnosis and nanotreatment is of special interest in colorectal cancer, where nanocarriers have the potential to enhance the tumor targeting, drug retention, and therapeutic response (Barani et al., 2021). Innovative formulation technologies are additionally under exploration to treat immunomodulatory natural products with highly sophisticated 3D tumor spheroids and organoid models that can enhance preclinical applicability (Hong & Lyu, 2025). The chemopreventive properties of a plant-derived triterpenoid, lupeol, have been demonstrated, and nanoparticles of lupeol can be used to deliver the drug more efficiently (Abedi et al., 2025). Curcumin has been one of the most researched phytochemicals in the cancer-related herbal medicine and has clinical evidence of its wide therapeutic application (Salehi et al., 2019). Nanocurcumin has the potential to enhance the solubility, bioavailability, and pharmacological properties of curcumin, allowing it to be used in the future in more advanced applications in the field of naturopathic and integrative oncology (Karthikeyan et al., 2020). Table 2 gives the key therapeutic uses of plant-based nanocarriers.

Table 2. Applications of Plant-Based Nanocarriers in Naturopathy and Herbal Medicine

Application area	Examples of bioactives/sources	Nanocarrier relevance	References
Respiratory and inflammatory disorders	Medicinal plants, polyphenols	Supports anti-inflammatory and immune-modulating effects	(Salehi et al., 2019)
Autoimmune disorders	Polyphenols, flavonoids	May regulate oxidative stress and immune response	Khan et al. (2019)
Cancer	Curcumin, lupeol, algae-derived compounds	Improves tumor targeting and bioavailability	(Karthikeyan et al., 2020)
Wound healing	Curcumin	Enhances local delivery and tissue repair	(Hussain et al., 2017)

Antimicrobial uses	Plant extracts, silver nanoparticles	Improves microbial inhibition and local action	(Eker et al., 2025)
Metabolic disorders	Antidiabetic plant compounds	Improves delivery of antidiabetic phytochemicals	(Zolkepli et al., 2022)
Advanced preclinical models	Immunomodulatory natural products	Supports formulation testing in spheroids/organoids	(Hong & Lyu, 2025)

5.3 Wound Healing, Antimicrobial, and Biomedical Applications

Nanocarriers made of plants can also be applied to the healing of wounds, antimicrobial therapy, and general biomedical purposes. Curcumin has been associated with anti-inflammatory, antioxidant, antimicrobial, and wound-healing effects, although, its clinical application is hindered by a lack of biological availability and solubility. Nanoencapsulation has the ability to preserve curcumin, increase local delivery, tissue penetration, and wound-healing effects (Hussain et al., 2017). These nano-based herbal systems can be used in line with the naturopathic concept since they can facilitate the repair of tissues as well as reduce the amount of synthetic agents required at high doses.\

5.4 Metabolic Disorders

Plant-based therapeutics are conventional in managing metabolic diseases like diabetes and obesity to control glucose metabolism, oxidative stress, inflammation, and lipid balance. Nanocarriers can enhance the efficiencies of plant-based antidiabetic agents by increasing solubility, stabilizing bioactives against degradation, and facilitating release control. Recent studies suggest that nanocarrier systems can be a beneficial tool to deliver antidiabetic phytochemicals and to fight hyperglycaemia (Zolkepli et al., 2022). The use of traditional Chinese medicine in the treatment of diabetes has been explored using meta-analysis and network pharmacology methodologies and it has been suggested that multi-compound herbal systems might have multifactorial biological processes (Tang et al., 2025). Therefore, nanocarriers derived of plant-based materials can boost the naturopathic control of metabolic diseases by enhancing the dependability and bioavailability of botanical interventions.

6. Advantages Over Conventional Herbal Therapy

Plant-based nanocarriers have a number of benefits over traditional herbal formulations due to their enhanced delivery and therapeutic outcomes of bioactive compounds. Most herbal compounds are not water soluble, have low gastrointestinal absorption, high metabolism and low bioavailability, which may decrease clinical activity. Nanoformulation is a way to overcome these barriers by decreasing the size, increasing the surface area, and enhancing interaction with the biological membranes. Indicatively, nanocurcumin is reported to be a promising therapeutic formulation as it has the capability to enhance the solubility, stability, absorption, and bioactivity of curcumin relative to traditional curcumin preparations (Karthikeyan et al., 2020). Better bioavailability could enable lower doses to have the desired therapeutic effect, which will decrease dose-related toxicity and increase patient compliance. Nanocarriers also have the ability to offer controlled release, prevent degradation of phytochemicals and target delivery to a particular tissue. Moreover, the nano-based herbal formulations could facilitate enhanced standardization due to the ability to control particle size, drug loading, release profile, and formulation quality. Plant-based nanocarriers, therefore, are a new approach to effective, reliable, and acceptable herbal therapy.

7. Safety, Toxicity, and Regulatory Considerations

Despite the significant benefits of using plant-based nanocarriers in the delivery of herbal drugs, their safety profile should be properly considered prior to clinical use. Due to their small size, high surface area, surface charge, and cellular penetration capabilities, nanoparticles can have complex interactions with biological systems. Such properties can be used to enhance therapeutic delivery, although they might induce toxicological issues including oxidative stress, inflammation, immune activation, organ retention, biodistribution, and unwanted cellular uptake. Consequently, the assessment of safety ought to involve the size of the particle, surface chemistry, degradation, dose response, cytotoxicity, genotoxicity, immuno-toxicity and long term biocompatibility.

Nanocarriers of plants can be considered safer since they have the potential to utilize natural polymers, phospholipids, plant oils, or phytochemical reducing agents. But not all natural is non-toxic. Biological response and reproducibility can be influenced by variability of plant extracts, variability in the synthesis method, impurities and variability between batches. Further preclinical models, such as 3D tumor spheroids and organoids, have become more popular in testing natural-product formulations due to their superior abilities to recapitulate tissue architecture, drug penetration, and therapeutic response over simple cell culture models (Hong & Lyu, 2025). The green synthesis using plants could help eliminate the utilization of toxic chemicals and lead the way to more harmless nanoparticle production as shown in Figure 3.

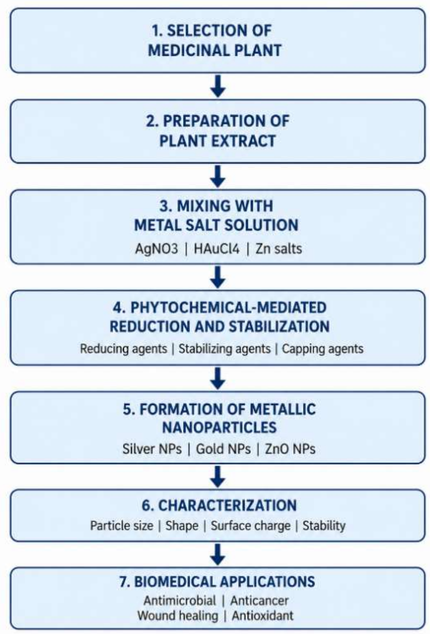

Figure 3. Green synthesis pathway of plant-mediated metallic nanoparticles.

Regulatory assessment of herbal nanomedicine is not a simple task since these products represent two complicated groups: botanical preparations and nanoparticle drug delivery. There are requirements of clear standards in quality control, characterization, pharmacokinetics, toxicity testing, manufacturing scale up, and clinical validation. Targeted therapeutics can enhance the results of treatment in cancer and other chronic diseases, although the risks that accompany them will need to be evaluated with the help of rigorous preclinical and clinical trials (Anand et al., 2023). Thus, the further advancement of plant-based nanocarriers ought to focus on evidence-based validation, standard procedures, regulatory transparency, and patient safety.

8. Challenges and Limitations

Plant-based nanocarriers have been shown to have therapeutic potential; however, there are many practical and scientific challenges associated with their application. A significant constraint is scale-up, since when formulations are prepared at industrial scales the properties of nanoparticles, including size, shape, surface charge and drug-loading capacity, can vary. Storage stability is also a factor of concern, because nanocarriers can either be aggregated, release active compounds, oxidized or change their release behavior over time. Green synthesis is particularly challenging to reproduce due to variations in plant extracts depending on species, season, geographical location, mode of extraction and phytochemical composition. This has the potential to influence nanoparticle assembly and biologic functionality.

The second big issue is that there are no standard protocols on how to prepare, characterize, toxicity test and clinical evaluate herbal nanocarriers. A lot of research is still restricted to laboratory/preclinical models, whereas human clinical trials are still not well-designed. Uncertainty in regulation is another hindrance of translation since these systems are an amalgamation of botanical medicine and nanotechnology. Thus, the reproducible synthesis, long-term stability, quality control, safety validation, and clinical evidence should be considered in future research. Table 3 summarizes the key benefits, drawbacks and future perspectives of plant-based nanocarriers.

Table 3. Advantages, Challenges, and Future Directions of Plant-Based Nanocarriers

Category	Key points	Relevance	References
Bioavailability improvement	Better solubility, permeability, and absorption	Enhances clinical value of poorly soluble phytochemicals	(Tomou et al., 2023)
Controlled release	Gradual release of active compounds	Reduces dose frequency and improves compliance	(Jacob et al., 2024)
Targeted delivery	Passive and active targeting	Improves tissue-specific delivery and reduces toxicity	(Alavi & Hamidi, 2019)
Safety concerns	Toxicity, immune response, organ accumulation	Requires detailed preclinical and clinical evaluation	(Anand et al., 2023)
Standardization issues	Plant variability and batch inconsistency	Limits reproducibility of herbal nanomedicine	(Jadoun et al., 2021)
Scale-up and stability	Aggregation, leakage, oxidation, manufacturing difficulty	Affects commercialization and storage	(Anselmo & Mitragotri, 2019)

Future directions	AI-based design, personalized medicine, regulatory frameworks	Supports evidence-based naturopathic translation	(Hua et al., 2018)

9. Future Perspectives and Research Directions

Future studies on the application of plant-based nanocarriers should aim at turning herbal nanomedicine into an experimental into a clinically dependable component of evidence based naturopathy. A good option is the personalized medicine, where nano-herbal formulations could be tailored based on personal health condition, metabolism, disease condition, and treatment requirements. Artificial intelligence can assist in development of formulations by predicting phytochemical interactions, particle size optimization, enhancing drug-loading capacity, and selecting appropriate carrier systems.

Nano-herbal complexes could offer synergistic effects, delivering a combination of several plant bioactives in a desired and controlled way. This method is particularly applicable to chronic diseases, in which metabolism, immunity, inflammation, and oxidative stress are interrelated. Nonetheless, clinical translation must be well-supported with a solid body of evidence based on pharmacokinetic analysis, toxicity testing, manufacturability, and controlled clinical trials. The quality standards, safety demands, labelling regulations, and regulatory routes of herbal nanocarriers should be defined in future policy framework. In sum, plant-based nanocarriers have the potential to transform the naturopathy practice to meet the needs of modern culture that integrates traditional botanical knowledge with modern drug delivery technology.

10. Conclusion

Plant based nanocarriers are another change that will help modernize naturopathy and herbal medicine. Conventional botanical therapeutic has long been prized due to its natural origin, therapeutic diversity and holistic relevance but many phytochemicals are poorly soluble, with low bioavailability, unstable with poor predictability, and with variable therapeutic effects. Nanocarrier-delivery systems are offering a scientific method in order to address these limitations by enhancing absorption, preventing degradation of bioactive compounds, controlled release, and targeted delivery. Nanocarrier systems such as phytosomes, liposomes, solid lipid nanoparticles, nanostructured lipid carriers, polymeric nanoparticles, nanoemulsions, and plantmediated metallic nanoparticles have distinct benefits in delivering herbal drugs. These systems could enhance the therapeutic potential of compounds like curcumin, quercetin, resveratrol, catechins and other plant-based bioactives. Their use in inflammation, cancer, wound healing, infections, respiratory diseases and metabolic diseases proves their applicability in integrative and naturopathic health care. Other issues with the field include toxicity, safety evaluation, reproducibility, stability in storage, scale-up, regulatory, and poor clinical validation. Thus, the development of the future should be facilitated by the standardized formulation techniques, strict preclinical trials, properly designed clinical trials, and clear regulatory policies. In general, plant-based nanocarriers constitute a valuable niche between ancient botanical knowledge and the current drug delivery science. They can be used to make naturopathic interventions safer and more effective using evidence-based nanotechnology and aligning with natural healing principles.

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