World Journal of Biology Pharmacy and Health Sciences
eISSN: 2582-5542
Cross Ref DOI: 10.30574/wjbphs
Journal homepage: https://wjbphs.com/

(REVIEW ARTICLE)

Check for updates

Observing nanotechnology in herbal medicine

Diksha Sharma *, Lakshay and Kapil Kumar Verma

Minerva College of Pharmacy, Indora (H.P), India.

World Journal of Biology Pharmacy and Health Sciences, 2024, 20(01), 176–191

Publication history: Received on 19 August 2024; revised on 02 October 2024; accepted on 04 October 2024

Article DOI: https://doi.org/10.30574/wjbphs.2024.20.1.0723

Abstract

Application of nanotechnology in herbal medicine promises promising improvements in medication delivery, bioavailability, and therapeutic efficacy. Nanotechnology has become a transformational tool in many industries. Even while traditional herbal remedies are abundant in bioactive chemicals, they frequently suffer from issues like low stability, poor solubility, and ineffective absorption by the body. By making it possible to encapsulate herbal ingredients in nanoparticles and improving their solubility, targeting abilities, and controlled release, nanotechnology overcomes these constraints. Reviewing current advancements in nanoparticle formulations, including liposomes, polymeric nanoparticles, and nanoemulsions for herbal extracts, this research investigates the nexus between nanotechnology and herbal medicine.

The advantages of nano-herbal formulations are covered, including the possibility of site-specific drug administration, less toxicity, and enhanced pharmacokinetics. This investigation also explores safety evaluations, regulatory issues, and the difficulties of increasing output. Combining nanotechnology with traditional herbal medicine not only brings back the benefits of age-old cures but also opens the door to safer, more accessible, and more effective treatment choices in contemporary medicine.

Keywords: Nanotechnology; Bioavailability; Absorption; Herbal; Liposomes; Formulations

1. Introduction

The Greek word "nanos," which means "dwarf," is where the name "nanotechnology" originates. The nanoscale, or 10-9 m, is the size of the nanodevice and nanostrategy. Nanotechnology refers to the characteristic interactions between molecular level matter and designed materials by including the clumping of atoms, molecules, and molecular fragments into incredibly small particles between 1 and 100 nm. Because of their unusually small size, nanoparticles can be utilized to target diseased areas that are infected without the need for a specialized ligand to attach to them. This makes nanotechnology a novel and growing tool in the drug discovery field (1). Drug delivery system brought forth a new drug delivery system, a fresh method to get around the problems with the old drug delivery systems. The most recent development in the field of pharmaceutical drug delivery is the use of tailored drug delivery nanoparticles to treat chronic diseases like cancer (2).

In the twenty-first century, nanotechnology is an advanced scientific method. It is possible to apply nanotechnological techniques for the improvement of herbal medication's bioavailability by examining the connection between biological medicine and nanotechnology. According to available data, nanotechnology is one of the newest, most promising, and fastest-developing technologies of the modern period. It also considerably aids in the advancement of biological medicine and the improvement of herbal drug bioavailability (3). The development of nanoherbal medications with high bioavailability will be made possible by the application of nanotechnology to the nanomization of herbal drugs,

* Corresponding author: Diksha Sharma

ushering in a new era in herbal drug research. Research on the nanomization of herbal medications for the treatment of cancer and other disorders will lead to a breakthrough in this area (4).

The ancient Indian medicinal system known as Ayurveda is based on the use of herbs and herbo-mineral formulations. Seven metals are utilized therapeutically in Ayurveda: lead (Pb), zinc (Zn), copper (Cu), iron (Fe), silver (Au), and tin (Sn). These go through a number of steps before becoming therapeutic in nature. "Bhasma" is a metal-based medication that is made from raw metal through a number of methodical steps to transform it into a useful form (5). "Swarna Bhasma," or gold ash, is a medicinal form of gold metal that contains nanosized particles when assessed using a variety of instruments and methods. The particle's size was determined to be roughly 56 nm. Additionally, Swarna Bhaska was examined. "Bhasma" is a powdered metallo-medicine with nano-to submicron-sized particles. The raw metal is transformed into a medicinal form using a traditional method that involves grinding it with certain herbs and other materials and repeatedly burning it (6). One unique aspect of the preparation process is that it is entirely mechanical in nature, with chemical properties significantly different from those of nanoparticles made via chemical means.

Since they have fewer negative effects and more therapeutic activity than other medications, phytomedicines have been used more often than other treatments since ancient times. The popularity of herbal pharmaceuticals is a topic of interest for both developed and developing countries, mostly because of their natural origin and minimal adverse effects. The development of creative, unique herbal medications has received tremendous help from rapidly expanding nanotechnologies. Nutraceuticals are foods and food ingredients that offer health advantages over those of basic nutrition; nevertheless, the bioavailability of many nutraceuticals is low. The difficulties and technological obstacles pertaining to the solubility, bioavailability, stability, and delivery of bioactives from food have been addressed by applications of nanotechnology (7). The swift advancement of nutraceutical nanotechnology holds immense potential in developing novel and effective functional foods as a means of averting and potentially even curing some non-communicable illnesses. Numerous studies on various types of nanomaterial preparation techniques for herbal medicine delivery and nutraceuticals have previously been published in the field of nanotechnology (8).

2. History and development

Natural goods, especially plants, have been used to heal human illnesses since ancient times. Traditional remedies and medicine continue to form the foundation for the development of modern medicine.Many regions of the world, including ancient China, Egypt, Africa, America, and India, employed plants for therapeutic purposes long before written history was written down. The early 19th century saw the development of chemical analysis, which led to the extraction and alteration of botanical constituents (9). Due to a lack of scientific support and challenges with standardization, extraction, and identification of specific medicinal components in intricate polyherbal systems, herbal medicines were not given serious consideration for development as innovative formulations for a very long time. Modern phytopharmaceuticals research, on the other hand, addresses the scientific gaps in the field of herbal medicine, allowing for the development of innovative formulations such as solid dispersions, liposomes, nanoparticles, microemulsions, matrix systems, and so forth. The development of colloidal nanogels, nanotubes, and nanomicellar systems has allowed curcumin to be utilized both alone and in conjunction with other chemotherapy drugs such as Paclitaxel (10).

2.1. Common herbal remedies and their uses

A common principle of traditional medicine asserts that natural remedies were passed down from ancient generations who had figured out cures for various ailments over time. Herbs and Their Traditional Uses:-

- **Echinacea:** commonly used to stimulate the immune system and assist with colds/respiratory infections.
- **Ginger:** Used for digestive problems it has a very nice anti-nausea feeling. It also has Anti Inflammatory Properties.
- **Chamomile:** Often used as a gentle sedative and to reduce insomnia, anxiety or digestive complaints.
- **Turmeric:** Curcumin has anti-inflammatory effect with antioxidant properties It is commonly used for joint pain and arthritis (11).
- **Garlic:** although it has cardiovascular benefits like lowering blood pressure and cholesterol levels. It is also an antimicrobial.
- **Dandelion:** A diuretic and for liver health. The leaves are good for digestion and the root is great to support liver function.
- **Licorice Root:** Helps Digestion & Sore Throats. It is also used in the management of respiratory conditions (12).

2.2. How nanotechnology is applied in herbal medicine

There has been a recent trend in applying nanotechnology to boost the efficacy, bioavailability and delivery of herbal molecules. Here's how it works:

2.2.1. Improved Bioavailability

- **Nanoparticles:** Herbal medications could be embedded in nanoparticles, which are little bearers that expansion the ingestion of these drugs inside the body. It is particularly beneficial for poorly water soluble or highly insoluble herbs.
- **Nanoemulsions:** These are emulsions of oil in water with a particle size range between 20-1000 nm stabilized by surfactants. Nanoemulsions help dispersing herbal extracts into the body effectively which enhances their absorption and bioavailability (13).

2.2.2. The Controlled Release and Targeting

- **Liposomal Delivery:** liposomes are spherical vesicles that can encapsulate herbal extracts. They protect the active compounds from degradation and increase delivery through controlled release, they specifically direct an herb into a particular location of your body.
- **Dendrimers:** Highly branched, tree-like structures that can carry more herbal molecules and deliver them to desired site reducing the side effects with enhancing therapeutic efficiency.

2.2.3. Increased Stability and Shelf Life

Encapsulates biologically activesubstances, notably including volatile or instable herbal compounds; protects the ingredients encapsulated from external factors (e.g., light, heat and oxygen) (14). This is useful for increasing the shelf life of herbal medicines.

Solid Lipid Nanoparticles (SLNs): SLNs offer a safe microenvironment for the herbal extracts that otherwise degrade and thus help in increasing the storage life.

2.2.4. Improved Solubility

- **Nanosuspensions:** it might be achieved by formulating a poorly soluble herbal compound into nanosuspension which is colloidal dispersion of fine solid particles with particle size less than 1um. Therefore, they dissolve more readily in biological fluids and bring about an improvement of therapeutic effects.

2.2.5. Improved Antimicrobial characteristics

- **Nanoformulations:** Nanotechnology-based enhancements in herbal formulations with antimicrobial properties have more synergy to inhibit range of pathogens (15). Some examples are silver nanoparticles blended with a herbal extract for exhibiting synergistic antimicrobial properties (16).

3. Potential benefits and innovations

Herbal medicine has the potential to greatly benefit from nanotechnology, which could revolutionize the formulation, administration, and use of these age-old medicines. Here are a few of the most significant possible advantages and innovations: Potential Benefits

3.1. Enhanced Bioavailability

- **Improved Absorption**: Nanotechnology can increase the absorption of herbal compounds, especially those with poor water solubility, by reducing their particle size to nanoscale (17). This allows them to penetrate biological membranes more easily, leading to enhanced bioavailability.

3.2. Targeted Drug Delivery

- **Precision Treatment**: Nanocarriers can be designed to deliver herbal compounds directly to specific cells or tissues, minimizing side effects and maximizing therapeutic efficacy. This targeted approach is particularly beneficial for conditions like cancer, where precise delivery can improve outcomes.

3.3. Controlled Release

- **Sustained Therapeutic Effect**: Nanotechnology enables the design of systems that release herbal compounds slowly over time, ensuring a sustained therapeutic effect (18). This reduces the need for frequent dosing and improves patient compliance.

3.4. Protection of Active Ingredients

- **Enhanced Stability**: Many herbal compounds are sensitive to environmental factors like light, heat, and oxygen. Nanotechnology can protect these compounds from degradation, ensuring that they remain effective until they reach their target (19).

4. Nano particles delivery system

Types of nanoparticles used: Different kinds of nanoparticles are employed in the field of nanotechnology to improve the potency, stability, and delivery of herbal medicine. The following are a few popular varieties of nanoparticles:

4.1. Liposomes, Lipid-Based Nanoparticles

- **Structure:** Phospholipid bilayers make up one or more spherical vesicles.
- **Application:** For the purpose of preventing degradation and enabling controlled release, both hydrophilic and hydrophobic herbal components are encapsulated (20).
- **Benefit:** Improves the targeted delivery and bioavailability of herbal ingredients.SLNs, or solid lipid nanoparticles:
- **Structure:** Solid at room temperature, composed of solid lipids stabilized by surfactants.
- **Application:** Provides protection and regulated release when giving herbal medications that are poorly soluble.
- **Benefit:** Extends the shelf life and enhances the stability of herbal ingredients.

5. Enhancing bioavailability and efficacy

5.1. Improving absorption of herbal compounds

Enhancing the bioavailability and therapeutic efficiency of herbal medicines by employing nanotechnology to improve absorption of these substances is a crucial objective. The low bioavailability, volatility, and poor solubility of many herbal substances limit their usefulness (21). Nanotechnology improves the transport and absorption of herbal substances, providing numerous ways to address these issues.

5.1.1. Improving Solubility

The poor water solubility of many herbal components makes them hydrophobic, which restricts the body's ability to absorb them. These hydrophobic substances can be encapsulated by nanocarriers, which increases their solubility in the watery environment of the gastrointestinal system (22).

5.1.2. Enhancing Stability and Resistance to Deterioration

Due to their acidic pH, many herbal substances are easily broken down by the stomach's enzymes or other digestive system agents. By shielding these substances from harm as they travel through the gastrointestinal (GI) tract, nanocarriers can guarantee that they enter the bloodstream undamaged (23).

5.1.3. Encouraging Uptake of Cells

By facilitating the passage of herbal components across biological membranes, nanotechnology can improve the absorption of these compounds into cells. Because of their small size, nanocarriers can be absorbed by cells by a variety of processes, including passive diffusion and endocytosis.

- **Polymeric Micelles:** By improving membrane permeability, these nanostructures, which have a hydrophobic core and a hydrophilic shell, can encapsulate herbal medications that are poorly soluble and aid in their absorption (24).
  Active Targeting: To improve the localized absorption of herbal medications, nanocarriers can be functionalized with ligands (such as antibodies or peptides) that bind selectively to receptors on target cells.

For example, delivering herbal components packaged in nanoparticles to cancer cells or inflammatory tissues can enhance the absorption of those compounds by diseased cells.Through passive targeting, nanocarriers can take advantage of the inflammatory or tumor-associated increased permeability and retention (EPR) effect (25). This enhances the local concentration and absorption of the herbal ingredient by allowing the nanocarriers to gather in these regions (26).

6. Targeted delivery and precision medicine

The novel method of targeted delivery and precision medicine in nanotechnology for herbal medicine blends the age-old knowledge of plant-based medicines with the most recent developments in drug delivery systems (27). These tactics make use of nanotechnology to provide more individualized, effective treatments with fewer negative effects. This has created new opportunities to improve the medicinal potential of herbal compounds—which frequently struggle with issues like volatility and low bioavailability (28).

6.1. Herbal Medicine by Targeted Delivery in Nanotechnology

Targeted delivery enhances the therapeutic efficacy while lowering negative effects by delivering herbal bioactive ingredients to the targeted tissues or cells using nanocarriers (29). This method allows for greater utilization of herbal components with medicinal potential, such as quercetin, resveratrol, and curcumin.

6.2. Targeted Delivery Mechanisms in Herbal Medicine

- **Active Targeting:** Herbal compound-loaded nanocarriers can be functionalized with ligands (antibodies, peptides, etc.) that bind to certain receptors that are overexpressed on sick cells. For instance, in cancer treatment, a curcumin-containing nanoparticle can be functionalized to target tumor cells by attaching itself to particular markers, like integrins or folate receptors.
- **Passive Targeting:** Tumor tissues and inflammatory areas have aberrant vasculature, which allows nanocarriers to passively concentrate there. This is achieved by taking advantage of the increased permeability and retention (EPR) effect. This can be exploited by herbal nanoparticles to enhance drug accumulation at the location of sickness (30). For example, resveratrol-encapsulated nanoparticles may passively target tumor cells, therefore raising local medication concentrations.
- **Stimuli-Responsive Targeting:** When certain environmental cues, like as pH, temperature, or enzymes, are present, herbal components contained in stimuli-sensitive nanocarriers can be released at the target region. For instance, in the acidic milieu of tumors, pH-sensitive nanoparticles containing a herbal anti-cancer ingredient like curcumin may release the medication.

6.3. Nanocarriers for Specific Distribution

When it comes to enhancing the transport of herbal ingredients to certain locations, nanocarriers are essential. Several often employed nanocarriers consist of: Biocompatible delivery systems known as liposomes are capable of encasing both hydrophilic and hydrophobic herbal substances, shielding them from deterioration and delivering them to the intended cells (31).

- **Polymeric nanoparticles:** Herbal chemicals can be released in a regulated and targeted manner using nanoparticles made of biodegradable polymers,such as polylactic-co-glycolic acid (PLGA).
- **Solid Lipid Nanoparticles (SLNs):** Lipid-based nanocarriers that offer targeted delivery and controlled release improve the stability and bioavailability of herbal constituents.

6.4. Using Nanotechnology in Precision Medicine for Herbal Medicine

The goal of precision medicine is to customize care for each patient taking into account their lifestyle, genetic, and environmental characteristics. Herbal compounds may now be delivered precisely thanks to nanotechnology, which guarantees that the correct patient receives the right dose at the right time. Individualized Care Employing Genomic and Biomarker-Based Targeting in Herbal

- **Nanomedicine:** Finding certain biomarkers or genetic variants can help precision medicine make treatment decisions. Herbal compound-loaded nanocarriers can be tailored to target particular indicators in disorders like inflammation or cancer (32). Herbal nanoparticles that target specific biological pathways, such as receptor overexpression or specific mutations, can be used to treat cancer patients.

- **Pharmacogenomics:** Precision medicine relies on an understanding of how various people metabolize and react to herbal ingredients. Because of the controlled and prolonged release of herbal ingredients made possible by nanotechnology, it is now simpler to customize dosages according to each patient's specific genetic composition. This guarantees that the herbal remedy is tailored for optimal effectiveness and negligible adverse effects.

7. Accessing the safety of nanoparticles in herbal medicine

Given the increased interest in using nanotechnology to improve the delivery and efficacy of herbal substances, evaluating the safety of nanoparticles in herbal medicine is an important topic of research. Herbal medicine's assessment of nanoparticle safety necessitates a multipronged approach that takes into account the characteristics of the nanoparticles as well as the herbal ingredients. Key elements and techniques for evaluating safety are listed below:

7.1. Nanoparticle Characterization:

Size, Shape, and Surface Area: The physical characteristics of nanoparticles are distinct and can affect how they interact with biological systems (33). Because smaller nanoparticles have a greater surface area than volume, they might be more reactive.

- **Surface Charge and Chemistry:** Surface alterations can change a nanoparticle's toxicity. For instance, compared to neutral or negatively charged particles, positively charged nanoparticles may interact with cell membranes differently.
- **Composition and Degradability**: Nanoparticles' biocompatibility and rate of breakdown in the body can be greatly influenced by the material (metal, polymer, or lipid) from which they are formed.

7.2. Research on Toxicology

- **Cytotoxicity Tests:** To find out if the nanoparticles are harmful to cells, in vitro research employing cell cultures is used. MTT, LDH, and trypan blue exclusion tests are examples of common assays (34).
- **In Vivo Animal Models**: Research on animals is utilized to evaluate the metabolism, dispersion, and possible toxicity of nanoparticles in intricate biological systems. These examinations can be used to determine toxicity specific to particular organs, such as the kidneys, lungs, or liver.
- **Carcinogenicity and Genotoxicity:** Nanoparticles may interact with DNA to cause cancer or mutations. This risk is evaluated using tests like the Ames test and in vivo micronucleus assays.

Certain nanoparticles have the potential to elicit allergic reactions and immunological responses. This risk can be assessed with the aid of assays that measure cytokine production, inflammation, or allergic reactions (34).

7.3. Biodistribution and Pharmacokinetics

ADME stands for absorption, distribution, metabolism, and excretion. Predicting the safety of nanoparticles requires an understanding of their absorption, accumulation sites, metabolism, and excretion processes (35).

- **Organ-Specific Accumulation**: Certain nanoparticles have a propensity to gather in particular organs, which may cause toxicity that is only found there. Imaging methods like PET, CT, or MRI scans can be used to monitor the dispersion of nanoparticles in living things.

7.4. Contacts between Herbs and Nanoparticles

- **Synergistic or Antagonistic Effects**: Herbal substances' biological activity may be increased or decreased by nanoparticles. The efficacy and safety profile of the formulation may be impacted by this interaction. Stability testing is necessary to make sure that the herbal ingredients in the formulation do not break down or interact with the nanoparticles in a way that could result in the production of hazardous byproducts (36).

8. Regulatory and ethical issues

The integration of nanotechnology into herbal medicine raises special ethical and regulatory questions because of the technology's novelty as well as the traditional elements of herbal therapy (37). To guarantee the safety, efficacy, and ethical production of herbal products enhanced with nanotechnology, these concerns are essential.

8.1. Regulation Concerns

8.1.1. Absence of Clear Directions

- **Lack of a Uniform Definition**: When it comes to herbal products, regulatory agencies around the world, such the FDA in the United States and the EMA in Europe, are unable to agree upon a common definition of what defines a nanoparticle. This creates difficulties for regulatory supervision and classification.
- **Herbal Medicine as Supplements:** Many herbal medicines are often classified as dietary supplements and, therefore, are subject to less stringent regulatory frameworks compared to pharmaceuticals. Introducing nanoparticles into these formulations may warrant more rigorous standards similar to drugs (38).

8.1.2. Safety and Toxicology Protocols

- **Inadequate Safety Testing**: Traditional herbal medicines may not undergo the same level of scrutiny as pharmaceuticals. With the addition of nanotechnology, existing toxicology protocols may not be sufficient to assess long-term health risks. Nanoparticles can penetrate biological barriers and accumulate in tissues, potentially leading to unforeseen toxic effects.
- **Properties of Nanoparticles**: Because of their distinct behaviors, such as their capacity to penetrate the blood-brain barrier, interact with cellular DNA, and last in the body and environment, regulatory bodies must develop safety measures that are tailored to these properties (39).

8.2. Ethical Issues

8.2.1. Openness on Safety and Risk

- **Inadequate Long-Term Data**: Since nanotechnology is still in its infancy, nothing is known about the long-term impacts of using nanoparticles in people. Companies must be open and honest about these risks in order to uphold ethics, and authorities must make sure that no product is released into the market before its time (40).
- **Informed Consent**: Consumers should be thoroughly informed about the advantages and disadvantages of using nanoparticles in herbal medicine, whether in clinical trials or commercial contexts (41). Any possible health hazards need to be made very apparent.

8.2.2. Analysis of Risk and Benefit

- **Rationale for Nanotechnology Use**: If nanoparticles offer a definite benefit in terms of safety, efficacy, or delivery (42) then using them in herbal medicine is the right thing to do ethically (43). The substantial advantages that nanoparticles may offer the patient should outweigh any possible hazards.
- **Vulnerable Populations**: People in poor nations and the elderly are two groups that frequently use herbal remedies. It is imperative that ethical considerations guarantee that these groups do not receive new technology exposure without sufficient safety data or awareness of associated concerns.

8.2.3. Access and Equity

- **Accessibility and Affordability**: The use of nanotechnology in herbal medicine might lead to substantial price increases, which raises moral questions regarding affordability. The exclusion of low-income populations from receiving nano-enhanced herbal items due to their high cost could exacerbate health disparities.
- **Global Differences in Regulation:** Unregulated or insufficiently examined nano-herbal items may be evaluated in nations with laxer regulatory laws (44). Products that are sold in areas with less regulatory monitoring raise ethical questions since they may jeopardize customer safety.

8.2.4. Customary Knowledge and Intellectual Property

Exploitation of Indigenous Knowledge: Traditional knowledge, frequently held by Indigenous or local groups, is the foundation for many herbal remedies. When businesses improve these treatments with nanotechnology and then patent the formulas without giving the indigenous tribes who created the herbal knowledge proper credit or acknowledgment, ethical problems result.

- **Patenting and Access:** If businesses dominate the technology, patenting nano-herbal compositions may restrict people's ability to obtain traditional medications (45). The commercialization of natural resources and conventional treatments gives rise to moral questions in light of this.

8.2.5. Environmental Responsibility

- **Sustainability Issues**: The process of producing nanoparticles can be resource-intensive, raising questions regarding the materials' and techniques' long-term environmental viability. Businesses should use green nanotechnology practices ethically to reduce environmental harm.
- **Environmental Impact of Waste:** When items are disposed of incorrectly or through excretion, nanoparticles from herbal medicine may find their way into the environment. Making sure that nano-herbal goods are made with as little of an ecological impact as possible is part of ethical duty.

9. Successful examples of nanotechnology in herbal medicine

Herbal medication has the potential to be safer, more effective, and more efficiently delivered thanks to nanotechnology. Here are a few instances of effective nanotechnology use in herbal medicine:

9.1. Turmeric, or curcumin nanoparticles

- **Background:** The active ingredient in turmeric, curcumin, has strong antioxidant and anti-inflammatory qualities, but its bioavailability is limited.
- **Nanotechnology Use:** Curcumin has significantly improved in terms of stability, controlled release, and bioavailability since it was encapsulated in nanoparticles. Curcumin nanoparticles have been demonstrated in studies to be effective in treating Alzheimer's, arthritis, and cancer.
- **Success:** When compared to conventional curcumin extracts, nanocurcumin formulations have demonstrated improved therapeutic efficacy in cancer models and inflammatory illnesses.

9.2. Grape-shaped resveratrol nanoparticles

- **Context:** Resveratrol is a naturally occurring antioxidant present in grapes, however because of its quick metabolism, it is not very bioavailable.
- **Nanotechnology Application:** To increase resveratrol's solubility, bioavailability, and stability, scientists have created nanoparticles filled with the compound. The substance is more successful when used in cancer, cardiovascular illnesses, and neurological conditions because these nanoparticles provide regulated release.
- **Success:** Compared to its conventional version, nanoresveratrol has demonstrated superior efficacy in preventing tumor growth and enhancing heart health.

9.3. Apples and onions contain quercetin nanoparticles.

- **Context:** Quercetin is a flavonoid having anti-inflammatory, anti-cancer, and antioxidant qualities; yet, its limited water solubility prevents it from being used therapeutically.
- **Nanotechnology Application:** To improve quercetin's absorption and stability, nanoparticles have been made. The bioavailability of quercetin has been greatly increased by encapsulating it in liposomes or polymer-based nanoparticles.
- **Success:** In comparison to conventional quercetin, these nanoparticles have shown better anti-inflammatory and anti-cancer properties in experimental models (46).

9.4. Ginkgo Biloba Nanoemulsions Background:

Ginkgo Biloba is used in traditional medicine for cognitive enhancement and blood circulation, but the active compounds have low solubility and bioavailability.

- **Nanotechnology Application:** Ginkgo biloba nanoemulsions and liposomal formulations have been developed to increase the solubility and bioavailability of its active ingredients.
- **Success:** Clinical trials have shown that these nanoformulations are more effective in improving memory and cognitive function compared to conventional Ginkgo extracts.

9.5. Polyphenol Nanoparticles from Green Tea

- **Context:** Although green tea polyphenols, particularly epigallocatechin gallate (EGCG), are unstable and poorly absorbed by the body, they have strong anti-cancer and antioxidant properties (47).
- **Nanotechnology Application:** Green tea polyphenol-loaded nanoparticles have been created to enhance absorption, prevent degradation of the active ingredients, and enable targeted delivery to cancer cells.

- **Success:** By increasing the bioavailability of EGCG and slowing tumor growth, green tea nanoparticles have been demonstrated to improve the results of cancer treatment in animal models.

10. Comparative analysis of traditional vs nanotechnology enhanced remedies

- **Conventional therapies:** Conventional therapies are those that are made from natural materials like minerals, plants, and animal byproducts. They are widely utilized in complementary and alternative medicine modalities such as homeopathy, Traditional Chinese Medicine (TCM), and Ayurveda (48). These treatments have been created over many centuries, drawing from both cultural customs and empirical understanding.

10.1. Improved by nanotechnology remedies

The manipulation of matter at the atomic or molecular level is referred to as nanotechnology. Nanotechnology is utilized in medicine to target certain cells or tissues, improve diagnostic methods, and improve drug administration. Nanoparticles are used in nanotechnology-enhanced treatments to improve the effectiveness, accuracy, and bioavailability of the active substances in medications.

10.2. Performance

- **Conventional Treatments**: Anecdotal and historical accounts are frequently used to determine efficacy. While some ancient treatments-like aspirin made from willow bark-have been scientifically verified, many don't have thorough clinical research to support their efficacy. Rather than focusing on treating individual symptoms, traditional treatments are frequently holistic in nature, treating the body as a whole (49).

10.3. Improved by nanotechnology remedies

Usually, a great deal of clinical research and scientific investigation goes into developing these treatments. Drug solubility and stability are increased by nanoparticles, resulting in more efficient delivery of active components. For instance, cancer treatments based on nanoparticles are very effective because they may target tumor cells without endangering nearby healthy tissue (48).

10.4. Action Mechanism

- **Conventional Treatments:** Conventional treatments frequently make use of natural substances that function in a variety of ways, including anti-inflammatory, antioxidant, and antibacterial properties. These treatments frequently have a sluggish rate of action and a restricted bioavailability, or the amount of a drug that the body can absorb and use (49).

10.5. Improved by nanotechnology remedies

By utilizing nanocarriers or nanoparticles to encapsulate active substances, nanotechnology improves their delivery. These carriers have the power to increase absorption, regulate drug release over time, and guarantee that the medication is delivered more precisely to the intended location. Compared to conventional therapies, this leads to a quicker and more successful course of action (50).

10.6. Security and Adverse Reactions

- **Conventional Medicines:** Conventional medicine is typically regarded as safe when applied appropriately, particularly if it comes from natural sources. On the other hand, adverse effects including toxicity or allergic reactions might result from abuse, contamination, or a lack of uniformity. Certain treatments also interact with contemporary medications.

10.7. Improved by nanotechnology remedies

Nanoparticles may raise additional safety issues, like the possibility of cellular toxicity. However, because these treatments are frequently made for targeted distribution, they might lessen the systemic negative effects that are frequently connected to prescription drugs. To guarantee safety, regulatory control is essential.

10.8. Price and Availability

- **Conventional Medicines**: Frequently more accessible and economical, particularly in areas with inadequate healthcare facilities. In many groups, traditional remedies are readily accessible due to their strong integration into cultural practices and availability from local suppliers.

10.9. Improved by nanotechnology remedies

Because of the sophisticated technology required for their creation and manufacturing, these treatments are usually more costly (51). Because they are mostly found in affluent areas with sophisticated medical facilities, lower-class populations may find it more difficult to access them.

10.10. Standardization and Regulation

- **Conventional Treatments:** Depending on the nation, regulations and standards differ dramatically. Traditional treatments are frequently exempt from stringent pharmacological regulations. Potency and quality variations may result from this lack of consistency enhanced by nanotechnology Solutions. Agencies such as the FDA (U.S.) and EMA (Europe) enforce stringent rules on medicines based on nanotechnology, guaranteeing that they fulfill elevated criteria for safety and effectiveness. Nonetheless, the swift advancement of technology can occasionally pose a threat to established regulatory structures (51).

11. Emerging technology and innovation

Numerous industries, including healthcare and medicine, are being revolutionized by nanotechnology. Nanotechnology has the potential to increase drug delivery, bioavailability, targeted therapy, and minimize negative effects when used in herbal medicine (52). The following are some significant advancements and uses of nanotechnology in herbal medicine:

11.1. Using nanoparticles to deliver drugs

- **Nanocarriers:** Herbal components are encapsulated in nanoparticles, including as liposomes, dendrimers, and polymeric nanoparticles. The solubility, stability, and bioavailability of herbal extracts are enhanced by these carriers.
- **Controlled Release:** Herbal medications can be released gradually and under control thanks to nanoparticles. This lowers the number of doses needed and permits longer therapeutic benefits.
- **Targeted Delivery:** Herbal medications can now be directly delivered to particular tissues or cells thanks to nanotechnology. By ensuring that the active ingredients reach the targeted site of action, this boosts effectiveness and reduces negative effects.

11.2. Extractions from Herbs Nanoencapsulated

- **Improving Bioavailability:** A lot of herbal substances are not well absorbed by the body and have a low solubility in water (53). Researchers can increase these chemicals' bioavailability and increase the efficacy of herbal remedies by encasing them in nanocarriers.
- **Protection against Degradation:** The use of nanotechnology shields delicate plant molecules from the damaging effects of heat, light, and pH. This aids in preserving the active compounds' effectiveness and stability.

11.3. Nanosensors for Herbal Drug Efficacy Diagnostic

- **Applications:** Real-time monitoring of the effectiveness of herbal remedies is possible with nanosensors. By identifying biomarkers in the body, these sensors give information about how well the herbal remedy is functioning and whether any changes should be made.
- **Precision medicine:** Using nanotechnology, herbal remedies can be customized based on a patient's health situation, providing more targeted and efficient interventions (53).

11.4. Using Herbal Nanomedicine to Treat Cancer

- **Anti-Cancer Properties:** Studies have shown the anti-cancer effects of several herbal components, including quercetin, resveratrol, and curcumin. These substances are being made into nanoformulations using nanotechnology, which improves their capacity to target cancer cells without endangering healthy tissues.

- **Synergistic Effects:** The integration of several herbal ingredients into a single nanoformulation is made possible by nanotechnology, which may have the ability to provide synergistic effects that improve therapy outcomes for cancer patients (54).

11.5. Antimicrobial and Anti-Inflammatory Properties of Nanoparticles

- **Enhanced antibacterial Efficacy:** Nanotechnology can be used to improve herbal remedies that possess antibacterial qualities. As an illustration, nano-silver particles made from herbal plants have shown strong antiviral, antibacterial, and antifungal properties.
- **Anti-Inflammatory Effects:** Anti-inflammatory herbal extracts can be delivered by nanoparticles more effectively, which makes them very useful in the treatment of inflammatory conditions like arthritis.

11.6. Flavonoids & Polyphenols in Nanoformulations

- **Encapsulation of Polyphenols:** The body breaks down polyphenols quickly, such as those in green tea, grape seed, and other herbal sources. By encapsulating these polyphenols using nanotechnology, their stability and therapeutic potential are enhanced.
- **Flavonoid Nanoformulations:** Many herbal remedies contain flavonoids, which can be nanoencapsulated to increase their absorption and efficacy in treating disorders including diabetes and cardiovascular diseases (55).

11.7. Sustainable and Eco-friendly Production Green Nanotechnology:

Using plant extracts as reducing and stabilizing agents for nanoparticle synthesis is a sustainable approach in nanotechnology. This eco-friendly method avoids the use of toxic chemicals and supports green chemistry principles in the production of herbal nanomedicines.

11.8. Regulatory and Safety Considerations Toxicity Studies:

The application of nanotechnology in herbal medicine also brings challenges related to the safety and toxicity of nanoparticles. Ongoing research is focused on ensuring that nanomedicine formulations are safe for human use.

12. Potential challenges and areas for further research

While there are many intriguing ways that nanotechnology can improve herbal medicine, more study is needed in a number of areas to guarantee its safe and efficient use (56).

12.1. Toxicology and Safety Issues

- **The nanoparticles' toxicity:** Despite their advantages, nanoparticles may be harmful. Because of their small size, they can pass across biological barriers, such as the blood-brain barrier, and have unexpected effects on tissues that are not their intended target. Concerns over long-term toxicity are raised by the possibility that some nanoparticles will accumulate in the body.
- **Biocompatibility:** Because of the intricate ways in which nanomaterials interact with biological systems, it is vital to comprehend the biocompatibility of various nanoparticles, particularly those made of metals or synthetic polymers.
  Degradation and Removal: It's critical to comprehend how the body breaks down nanoparticles and removes them from the system. A buildup of nanoparticles in organs due to improper clearance could be harmful.

12.2. Difficulties with Regulation and Standardization

- **Absence of Regulatory Frameworks:** Since herbal medicine and nanotechnology are relatively new fields of application, it's possible that current regulatory frameworks do not adequately handle the special qualities of nanomedicine (57). There is a need for standardized international standards, and guidelines for the approval of nano-herbal formulations are still being developed.
- **Quality Assurance:** It is difficult to achieve standardization in the production of nano-herbal products. The effectiveness and safety of the goods may be impacted by variations in the size, shape, and surface chemistry of the nanoparticles. Maintaining uniformity in manufacturing processes is crucial for quality assurance.
- **Regulation of Herbal Supplements:** A lot of herbal products fall under the category of supplements, which are frequently subject to looser rules than those governing pharmaceuticals. To guarantee the safety and effectiveness of the nanotechnology used in these products, more stringent regulation may be necessary.

12.3. Nanoformulations' Stability and Scalability

- **Stability of Nanoparticles:** One major question is how stable nanoparticles are under different environmental circumstances (such as light, temperature, and pH). Since many herbal components are prone to deterioration, it is important to carefully formulate them before encasing them in nanoparticles to guarantee their stability during transportation and storage.
- **Scalability of Production:** There are many obstacles to overcome when transferring laboratory-scale nanoformulations to industrial-scale manufacturing (58). It is necessary to do additional research and development in three crucial areas: reproducibility of formulations, uniformity in particle size, and scalability of nanoparticle manufacturing.

12.4. Price and Availability

- **High Production Costs:** Producing nanoparticles can be costly, particularly when using sophisticated materials. This may restrict the availability of nano-herbal medications, especially in underdeveloped areas where traditional herbal treatment is extensively practiced.
- **Cost-effectiveness for Customers:** It may be challenging to use these technologies in low- and middle-income communities, who may most benefit from accessible healthcare solutions, due to high production costs that could result in higher prices for consumers.

12.5. Insufficient Knowledge of Pharmacodynamics and Pharmacokinetics

- **How Nanoparticles Act in the Human Body:** There is currently a lack of knowledge on the pharmacokinetics (the body's absorption, distribution, metabolization, and excretion of nanoparticles) and pharmacodynamics (the effects of nanoparticles on the body) of nano-herbal formulations. Investigations on the behavior of various nanoparticles in the body, their interactions with herbal ingredients, and their effects on therapeutic outcomes are warranted.
- **Plant-Nanoparticle Interactions:** Numerous bioactive chemicals can be found in herbal substances, and their interactions with nanoparticles are intricate. In particular, whether the nanoparticles change the activity or bioavailability of the herbal components they contain needs more investigation to fully comprehend these interactions.

12.6. Environmental and Ethical Issues

- **Environmental Impact:** The creation and disposal of nanoparticles, particularly when metals or synthetic elements are involved, give rise to environmental concerns (59). The creation of biodegradable nanoparticles is one of the environmentally responsible and sustainable methods for producing nanoparticles that are required.
- **Problems with Ethics in Research and Use:** When nanotechnology is used in conventional medicine, ethical concerns could arise, especially if the application of the technology is opaque. Certain cultures view the advent of nanotechnology as at odds with their deeply ingrained historical and spiritual practices, which are the foundation of traditional herbal treatment.

12.7. Slight Clinical Data

- **Inadequate Clinical Trials:** In spite of encouraging preclinical findings, there aren't enough thorough clinical trials to assess the efficacy and safety of herbal medicines made using nanotechnology in humans. To give conclusive proof that these formulations are safe and effective in real-world situations, more human studies are required.
- **Insufficient Long-Term Research:** The majority of research on nano-herbal medicine focuses on immediate results. Long-term research is required to evaluate the effectiveness, safety, and any adverse effects of using herbal medications that have been nanoformulated on a regular basis.

12.8. Interactions with Different Medicines and Treatments

- **Interactions between Herbal Medicines and Conventional Drugs:** These interactions may have unfavorable effects. These interactions could be altered by adding nanoparticles to herbal preparations. To understand how nano-herbal formulations interact with traditional medications, more research is required.
- **Combination with Other remedies:** Research is being done on the use of nanotechnology to combine traditional and herbal remedies. More research is necessary to understand how nano-herbal formulations interact with other medical therapies in order to prevent unfavorable outcomes.

12.9. Views and Adoption by the Public

- **Skepticism about Nanotechnology:** Some groups may be averse to the adoption of nanotechnology, especially those who use traditional herbal therapy. Spreading awareness of the advantages, safety, and effectiveness of nano-herbal medicine will require open dialogue and public education (59).
- **Cultural Considerations:** Herbal medicine's traditional traditions, which frequently prioritize natural, unaltered components, may clash with nanotechnology. Successful incorporation of nanotechnology will require resolving cultural concerns and interacting with populations who use herbal medicine.
- **Research Areas:** Development of Biodegradable and Biocompatible Nanomaterials: The goal of this work should be to produce ecologically benign and human-safe nanoparticles. Enhanced Knowledge of Interactions between Nanoparticles and Herbal Compounds: Additional investigation is required to determine the impact of nanoparticles on the bioactivity of herbal compounds.
- **Uniform Testing Procedures:** It's imperative to provide uniform procedures for evaluating the security and effectiveness of formulations including nanoherbs.
- **Long-Term Studies and Clinical Trials:** Additional research is required to determine the efficacy and safety of nano-herbal medications in people.
- **Integration with Personalized Medicine:** Studies should look into how personalized medicine methods and nanotechnology might work together to customize herbal remedies for specific patients based on their genetic composition and current state of health (60).

13. Conclusion

The integration of nanotechnology into herbal medicine represents a significant advancement in the field of natural therapeutics, enhancing the bioavailability, stability, and therapeutic efficacy of herbal compounds. Through various nano formulations, such as nanoparticles, liposomes, nano emulsions, and nanospheres, the inherent limitations of traditional herbal medicine, including poor solubility, rapid degradation, and low bioavailability, can be effectively addressed. These nanocarriers offer targeted delivery, controlled release, and improved absorption, ultimately leading to enhanced therapeutic outcomes and reduced side effects.

The application of nanotechnology in herbal medicine not only modernizes traditional therapeutic practices but also opens new avenues for drug development and personalized medicine. However, despite the promising potential, challenges such as scalability, regulatory approval, safety concerns, and long-term effects of nanomaterials on human health and the environment need to be thoroughly addressed. Continued research focusing on the optimization of nanocarrier systems, comprehensive toxicological studies, and clinical trials is crucial for the safe and effective integration of nanotechnology in herbal medicine.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Rani R, Sharma A, Singh G, Mittal A. Nanotechnology: Applications in herbal medicine. J Herb Med. 2017;5(4):93-102.

[2] Shinde RL, Deore SL. Herbal drug incorporation in nanotechnology: a review. Pharmacognosy Rev. 2019; 13(1):57-65.

[3] Pandey A, Prajapati VK. Nanotechnology in modern herbal medicine. J Nanosci Nanotechnology. 2017; 17(3):2375-2387.

[4] Sharma P, Mittal D, Sharma S, Nair A, Asthana S. Nanotechnology: A modernized approach for herbal drug delivery. Int J Pharm Investig. 2019; 9(2):47-53.

[5] Patil R, Kajale N, Choudhari K. Herbal medicines and nanotechnology: A united approach for therapeutic enhancement. Indian J Res Pharma Biotechnology. 2020;8(4):121-128.

[6] Khan F, Singh VK, Patra S, Biswas T. Role of nanotechnology in enhancing bioavailability and efficacy of herbal medicines. J Control Release. 2021; 336:254-270.

[7] Gupta N, Chauhan JS, Verma S. Nanomedicine and herbal therapeutics: Potential applications in drug delivery. Curr Pharm Biotechnol. 2018; 19(1):90-99.

[8] Arya V, Sharma A. Recent advances in nanotechnology-based herbal formulations: A review. Int J Pharm Sci Res. 2020; 11(2):571-583.

[9] Jamdade A, Patil P, Gade A. Nanotechnology for improving the therapeutic efficacy of herbal drugs. J Nanomed Nanotechnol. 2021; 12(2):354-360.

[10] Parveen S, Misra R, Sahoo SK. Nanoparticles: A boon to enhance bioavailability of poorly water-soluble drugs. Indian J Pharm Sci. 2019; 81(2):147-158.

[11] Bharath S, Mathews SM. Herbal medicine-based nanomedicines: A comprehensive review of recent trends and future perspectives. Front Pharmacol. 2020;11:612-620.

[12] Bhattacharya S. Nanotechnology: A promising approach for enhancing bioavailability of herbal medicines. J Biomed Nanotechnol. 2017;13(4):425-438.

[13] Ahmed S, Saeed Z, Bashir M, Irfan M. Nano-herbals: Recent advancements in herbal medicines. J Drug Deliv Sci Technol. 2019;53:101-110.

[14] Sharma G, Kaushik A, Kukreti V. Nanotechnology in herbal medicine: recent trends and future prospects. J Nanomedicine Res. 2017;5(4):1-5.

[15] Alam A, Rahman MA, Alqahtani A. Nanotechnology as a promising tool for enhancing the bioavailability of herbal medicines. Pharm Nanotechnol. 2019;7(1):47-55.

[16] Rizvi SA, Saleh AM. Applications of nanoparticle systems in drug delivery technology. Saudi Pharm J. 2019;26(1):64-70.

[17] Raval N, Maheshwari R, Kalyane D, Kalia K, Tekade RK. Innovation and challenges in nanotechnology for herbal medicine. Nanosci Nanotechnol Asia. 2019;9(2):64-79.

[18] Jain A, Gaur RK. Nanoherbal formulations: Recent trends and future prospects. Nanomedicine. 2020;8(2):112-121.

[19] Devi S, Singla P, Negi P, Saini V, Kumar D. Recent developments in herbal nanoparticles. Int J Pharm Sci Res. 2018;9(9):36-44.

[20] Kumar R, Singh M. Emerging role of nanotechnology in herbal medicine: An overview. Curr Drug Discov Technol. 2021;18(3):234-241.

[21] Sasidharan S, Nirmala V, Lalitha S, Chatterjee C. Nanotechnology applications in herbal drug formulations. Trop J Pharm Res. 2019;18(2):45-53.

[22] Sahoo SK, Parveen S, Panda JJ. The present and future of nanotechnology in human health care. Nanomedicine. 2019;8(2):102-111.

[23] Kumar D, Gupta D, Singh S. Impact of nanotechnology on herbal medicine: A review. Int J Curr Pharm Res. 2019;11(3):12-21.

[24] Kumar GP, Rajeshwarrao P. Nanotechnology in herbal medicines: A review. Int J PharmTech Res. 2019;11(4):248-253.

[25] Singla R, Kaur H, Jain T. Recent advances in nanotechnology for herbal drug delivery. Drug Deliv Transl Res. 2020;10(1):344-356.

[26] Gupta A, Kumar S. Role of nanotechnology in improving efficacy of herbal drugs. J Adv Pharm Educ Res. 2017;7(4):105-109.

[27] Pandey AK, Prajapati VK. Applications of nanotechnology in herbal medicine for cancer treatment. J Nanosci Nanotechnol. 2018;18(3):2276-2282.

[28] Suresh D, Reddy N, Choudhury SR. Nanoparticle formulations of herbal medicines: A revolution in pharmacology. Asian J Pharm Sci. 2020;15(2):96-108.

[29] Ahmad R, Kumar S, Mishra A. Nanotechnology in herbal medicines: A critical overview. Curr Nanosci. 2019;15(2):100-110.

[30] Mohammadi M, Azhdarzadeh M, Mohammad A, et al. Application of nanotechnology in herbal medicine: Recent updates and future perspectives. J Pharm Sci. 2018;27(3):12-20.

[31] Bhavsar D, Shah SS. Nanomedicine: The future of herbal drug formulations. Future Sci OA. 2018;4(1):42-56.

[32] Khalid R, Shams S, Saeed S. Nanotechnology and herbal medicine: Clinical implications. Int J Pharm Res. 2017;12(2):212-218.

[33] Parekh HS, Gupta S, Nair K. Applications of nanotechnology in herbal medicines. Asian J Pharm Clin Res. 2018;11(1):234-237.

[34] Bhargava A, Pant J. Recent advancements in nanotechnology for enhanced bioavailability of herbal medicines. J Adv Sci Eng. 2019;8(4):453-460.

[35] Chen Z, Wang Z, Wang Y, et al. Nanomedicine in herbal cancer therapy. Acta Pharm Sin B. 2020;10(11):2055-2073.

[36] Kaur N, Kishore L, Singh R. Applications of nanotechnology in herbal medicines: A review. J Nanosci Nanotechnol. 2019;19(1):123-133.

[37] Dhiman P, Singh M, Sharma A. Nanotechnology-based approaches in herbal medicines for the treatment of cancer. Adv Sci Technol Lett. 2021;32(4):171-181.

[38] Ali MH, Nazimuddin S, Ansari SH. Nanotechnology-based herbal formulations: Recent developments. Indian J Pharm Sci. 2020;82(1):11-22.

[39] Ahmad N, Hassan W, Ahmed Z. Herbal drug delivery systems based on nanotechnology: A review. Biomed Pharmacother. 2020;110(4):111-119.

[40] Arafat SM, Singh R. Recent trends in nanotechnology-based herbal drugs for improved therapeutic effects. J Ethnopharmacol. 2021;264:113242.

[41] Kumar B, Sharma K, Negi V. Nanotechnology in traditional herbal medicines: An overview. J Control Release. 2019;302:165-176.

[42] Singh P, Tiwari S. Nanotechnology and herbal medicine: Recent developments. Curr Drug Targets. 2020;21(1):12-23.

[43] Kaushik D, Kapoor D. Applications of nanotechnology in herbal formulations for the treatment of diseases. Eur J Pharm Sci. 2020;144:105246.

[44] Tiwari R, Verma H, Chaudhary A. Nanotechnology in modern herbal medicines: A futuristic approach. J Pharm Pharmacol. 2019;71(6):1025-1037.

[45] Patel B, Chaudhary H. Herbal nanomedicines: Emerging trends and future challenges. Nanomedicine. 2018;13(3):331-345.

[46] Kumar P, Anand G. Recent developments in nano-formulations of herbal medicines for treatment of cancer. J Cancer Res Ther. 2021;17(1):5-12.

[47] Sharma RK, Chaudhary G. Nanotechnology in herbal medicines: Current status and future prospects. Drug Discov Ther. 2020;14(5):324-330.

[48] Iqbal M, Hussain A, Mahboob A. Role of nanotechnology in the development of modern herbal medicines. J Herb Med. 2019;8(2):1-6.

[49] Kumar S, Gulati M. Nano-based approaches for herbal drug delivery. Int J Nanomedicine. 2018;13:73-85.

[50] Singh V, Aggarwal R. Nanotechnology applications in herbal cancer therapy. J Nanosci Nanotechnol. 2018;18(1):195-203.

[51] Shukla R, Singh P. Nanotechnology in herbal medicine: Recent advancements. Phytother Res. 2020;34(7):1553-1566.

[52] Goswami S, Vishwakarma AK. Nanotechnology in herbal drugs: A review. Int J Pharm Tech Res. 2019;11(2):15-21.

[53] Saha P, Paul S. Nanotechnology and herbal medicine: A strategic approach. Nanomedicine. 2017;8(4):567-578.

[54] Choudhary A, Sharma S. Nanotechnology-based herbal medicine for cancer treatment: Challenges and future prospects. Curr Cancer Drug Targets. 2021;21(2):85-97.

[55] Ram K, Awasthi A. Nanotechnology in herbal drugs: An overview. Res J Pharm Biol Chem Sci. 2019;10(3):121-127.

[56] Gupta RK, Singh R. Herbal medicines and nanotechnology: A modern approach. Int J Nanomedicine. 2020;15:431-445.

[57] Jain NK, Vyas SP. Nanotechnology in traditional herbal medicine: Revolutionizing the future of therapeutics. Curr Pharm Des. 2018;24(1):123-134.

[58] Chauhan S, Rana A. Nanotechnology: The future of herbal medicine. Int J Pharm Sci Res. 2019;10(5):213-221.

[59] Yadav R, Singh S. Herbal drugs incorporated with nanotechnology: A review. J Pharm Sci Innov. 2020;9(3):150-155.

[60] Verma N, Saxena R. Nanotechnology and herbal formulations: A paradigm shift in therapeutic treatments. J Pharm Sci Res. 2018;10(6):1737-1741