

Available online on 15.03.2025 at <http://jddtonline.info>

Journal of Drug Delivery and Therapeutics

Open Access to Pharmaceutical and Medical Research

Copyright © 2025 The Author(s): This is an open-access article distributed under the terms of the CC BY-NC 4.0 which permits unrestricted use, distribution, and reproduction in any medium for non-commercial use provided the original author and source are credited



Open Access Full Text Article



Review Article

Nano technology-based drug delivery systems and herbal medicine

Khushi S. Kathole *, Pooja R. Hatwar , Ravindra L. Bakal , Vaishnavi G. Karule

Shri Swami Samarth Institute of Pharmacy, At Parsodi, Dhamangaon Rly, Dist -Amravati (444709) Maharashtra, India.

Article Info:

Abstract



Article History:

Received 11 Dec 2024
Reviewed 24 Jan 2025
Accepted 20 Feb 2025
Published 15 March 2025

Cite this article as:

Kathole KS, Hatwar PR, Bakal RL, Karule VG, Nano technology-based drug delivery systems and herbal medicine, Journal of Drug Delivery and Therapeutics. 2025; 15(3):133-141 DOI: <http://dx.doi.org/10.22270/jddt.v15i3.7017>

*Address for Correspondence:

Khushi S. Kathole, Shri Swami Samarth Institute of Pharmacy, At Parsodi, Dhamangaon Rly, Dist -Amravati (444709) Maharashtra, India.

Nanotechnology has revolutionized the field of herbal medicine by enhancing the bioavailability and efficacy of phytoconstituents. This review article discusses the application of nanotechnology in herbal medicine, including the use of nanoparticles, liposomes, and nanoemulsions for targeted drug delivery. The advantages of nanotechnology-based herbal formulations, such as improved solubility, stability, and bioavailability, are highlighted. Additionally, the review discusses the potential of nanotechnology in enhancing the therapeutic efficacy of herbal medicines, including their anti-inflammatory, antioxidant, and anticancer properties. The article also explores the various types of nanocarriers used in herbal medicine, including polymeric nanoparticles, solid lipid nanoparticles, and nanostructured lipid carriers. The role of nanotechnology in enhancing the permeability and retention of herbal medicines in the body is also discussed. Overall, the review provides a comprehensive overview of the application of nanotechnology in herbal medicine, highlighting its potential in enhancing the therapeutic efficacy and bioavailability of phytoconstituents.

Keywords: Nanotechnology, Herbal medicine, Liposomes, Nanosuspension, Nano emulsion.

Introduction

Throughout human history, different groups of people have known about and used plants as herbal treatments. It started when people learned how to choose plants for food and to treat diseases.¹ The study of nanotechnology involves looking at, designing, making, and using substances and materials on the nanoscale. It has been used a lot in biological fields.² To get health benefits like nutritional benefits, medical benefits, and cosmetic benefits, herbal dosage forms contain certain amounts of plant ingredients or components. The progress made in plant-based medicine has shown that herbal drugs are very important and can help find cures for diseases that are still not able to be cured.³ The ability to transform less soluble, poorly absorbed, and unstable chemicals into promising pharmaceuticals is one of the many special qualities and enormous potential of herbal medicines that use nanotechnology-based delivery methods. Nanotechnology-based delivery methods are therefore a good idea.⁴ (a) Improved delivery of poorly soluble drugs; (b) targeted drug delivery in a cell- or tissue-specific manner; (c) drug transcytosis across tight epithelial and endothelial barriers; (d) delivery of massive macro-molecule drugs to intracellular sites of action; (e) a combination of more than one medication

or therapeutic modality for combination therapy; (f) visualization of drug delivery sites through the combination of therapeutic agents with imaging modalities; and (g) real-time display on the in vivo efficacy of a therapeutic agent all could be accomplished with the support of nanotechnology. In addition, generic medicine companies might discover hard to rapidly produce identical medicines due to the manufacturing complexity of therapeutics that utilize nanotechnology.⁵ To deal with these problems, nanotechnology-based drug delivery is becoming more popular as an alternative way to make treatments work better by changing the physical and chemical qualities of antiviral drugs.⁶

History and Development

Natural products, such as plants, have been utilized to cure human diseases since long ago. Traditional treatments and medicine continue to serve as the base for the development of modern medicine. A lot of parts of the world, especially ancient China, Egypt, Africa, America, and India used plants for medicinal purposes long before written record was born. The early 19th century marked the creation of chemical analysis, which led for the extraction and modification of botanical constituents. Due to their lack of scientific backing and

processing challenges, including standardization, extraction, and identification of specific medicinal substances in complex poly herbal systems, herbal medicines were long neglected for development of creative mixtures.⁷

Nanotechnology-Based Drug Delivery System for Phytochemical Compounds

The study states that 70% of the active ingredients that come from plants are hydrophobic. Effective disease prevention and treatment need the consumption of phytonutrients. These methods of delivery, which have the ability to increase the bio-activity of Phytochemical substances, include lipid- and polymer-based delivery techniques.⁵ Also, the application of nanotechnology offers a strong plan for TCM development in the future in addition to a technological basis for modernization.⁸

Nanosuspension

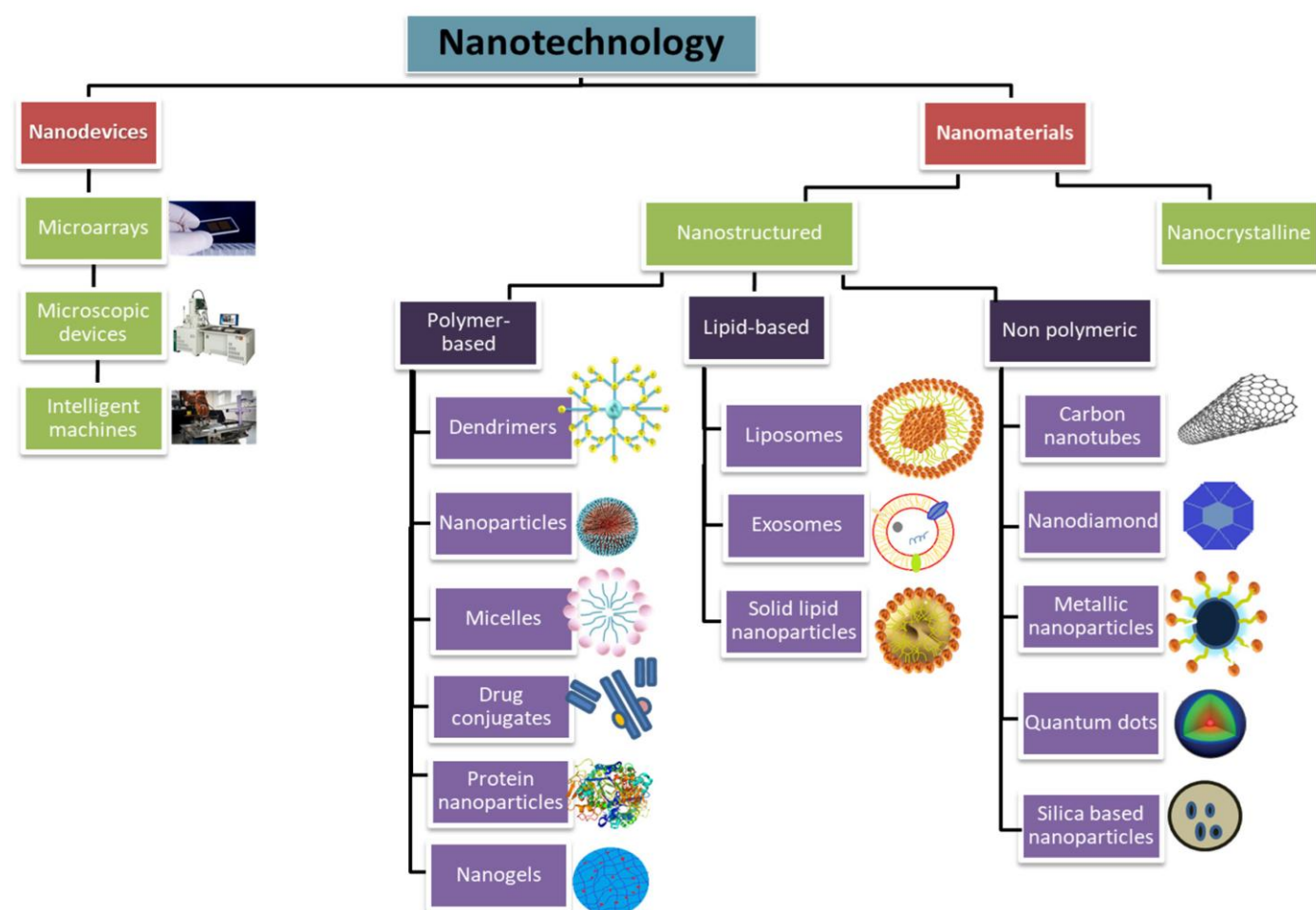
The only components in nanosuspension (NS) are pure drug crystal and a polymer for consistency. A variety of techniques, include high-speed homogenization, sonication, pearl-milling, high-pressure homogenization, and nano precipitation, were used to prepare.⁹ The created nanosuspensions significantly lowered blood glucose levels while demonstrating good stability and improved flavonoid absorption.⁹ Only submicron colloidal dispersions of medicine nanocrystals make up the nanosuspension. It is one of the most promising methods for delivering poorly soluble active ingredients since it is surrounded by stabilizers.¹⁰

Nanoemulsion

A nanoemulsion is a transparent or translucent system with sizes ranging from 20 to 500 nm that is thermodynamically unstable yet kinetically stable. In accordance with the distributed classification.¹⁰ Transdermal administration and oral administration are the two main methods of administering nanoemulsion.¹¹ There are now three primary methods by which natural medicines can be delivered using nanoemulsions. First, utilizing nanoemulsion technology, monomeric chemicals with anti-tumor activity that were extracted from herbal remedies were directly encapsulated.¹¹ Because they are structurally straightforward from a composition standpoint, nanoemulsified systems are incredibly adaptable. They come in a variety of dosage forms, including sprays, liquids, creams, gels, and aerosols, and they can be administered through a variety of routes, including ocular, topical pulmonary, intravenous, and intranasal.¹² Drugs having a high first-pass metabolism, and hydrophilic properties can have their bioavailability improved by using nanoemulsions. Water soluble cosolvents, oils, lipids, surfactants, and water make up the nanoemulsion system's constituents.⁵ Oil/water nanoemulsions, which are biocompatible and extremely stable at nanoscales (10–1000 nm), are often employed to ensnare and enhance the distribution of hydrophobic medications and pharmaceutically active substances.¹³

Liposomes

Liposomes are spherical vesicles which are often used for carrying medicines since they have lipid bilayers. Drug release is more efficient when liposomes are used. Low concentrations of NPs (below the WHO recommended dosage) aided in the sustained release of stavudine for up to 12 hours while boosting the likelihood that the NPs would reach the reservoir sites in a novel liposome-based system developed by Nayak et al.¹⁴ Because of their unique characteristics, liposomes have been employed for medication delivery for a very long time. A liposome is a region of aqueous solution surrounded by a hydrophobic membrane that stops hydrophilic solutes from dissolving and accumulating lipids. Due to the fact that hydrophobic compounds can dissolve into the membrane, liposomes can receive both hydrophilic and hydrophobic molecules.¹⁵ Artificial membranes referred to as liposomes are primarily composed of chemicals that are amphiphilic, forming a bilayer structure like that of skin cell membranes. Liposomal lipid-like bilayers have medications encapsulated in a hollow portion that makes them sophisticated nano-carriers for medicines.¹⁶ In the last few years, liposomes have been the subject of numerous investigations for regulated drug delivery. Liposomes are made of biodegradable components and are comparatively stable. The liposome's inner core entraps the medications. Because of its biocompatibility, low toxicity, biodegradability, and ability to incorporate both hydrophilic and hydrophobic medicines, it has proven to be an excellent carrier system for delivering a range of therapeutic agents.¹⁷ First reported by Bangham and associates in 1964, liposomes are the first closed bilayer phospholipid structures. They have been suggested as DDS for enhancing encapsulation, stability, and circulation time and specific modification.¹⁸ [Phosphatidylcholines (PCs), phosphatidylserine, phosphatidylglycerol, and sphingomyelin are indications of cylindrical-shaped lipids which are often used in LIP formulations since they possess a tendency to form a stable bilayer in aqueous solution ¹⁹. Its composition is primarily composed up of phospholipids, sterols, and antimicrobial agents, and it offers beneficial characteristics such as variable surface charge, biocompatibility, biodegradability, membrane fluidity, and low toxicity. These characteristics allow these systems to be used in the biomedical, pharmaceutical, and bioengineering fields.¹² A significant advance in nanoscale drug delivery systems is represented by liposomes, which are spherical vesicles with a lipid bilayer structure.²⁰ In pediatrics, liposomes are the most extensively researched nanotechnology-based formulations.²¹ The first class of nanocarriers used in academia and the pharmaceutical industry for medication delivery is liposomes.²² One benefit of utilizing liposomes as vehicles is that they quickly accumulate in phagocytic cells, which identify them as foreign particles and allow liposomes to be present ²³

Figure 1: NPs based drug delivery systems. ²⁴

Nano medicine

Many traditional drugs have been linked to inadequate pharmacokinetics, bioavailability, and toxicity, all of which restrict the scope of their use.¹⁵ It is a truth that clinical translation of nanomedicine for cancer treatment is still very difficult. Although nanotechnology has made significant contributions to oncology by reducing the harmful side effects of medications, patient survival has not increased overall.²⁵ The application of nanotechnology in medicine, or "nanomedicine," has already changed and influenced many facets of clinical practice and research and has the potential to have an important impact on human health. Materials based on nanotechnology that have special physical, chemical, and biological properties provide a range of novel ways to treat, diagnose, and prevent a wide range of illnesses and ailments.²⁶ It has been suggested that nanomedicine, which minimizes dose amount and frequency while maintaining a similar pharmacological profile and fewer adverse effects, is a new trend in the medical and pharmaceutical fields.²⁷ Like all pharmaceuticals, nanomedicines have unrealized promise mostly due to their complex a priori design.²⁸ The administration of medications and compounds that would not otherwise be useful or viable therapeutics.²⁹

Nano herbal formulation

Phytoconstituents and herbal medications are thought to be safer and more effective than allopathic medications. The usage of natural remedies is rising on a global scale. To increase the bioavailability and achieve targeted distribution of these naturally occurring medications, principles of nanoscience and technology have been utilized.³⁰

Nanotechnology for herbal drug delivery

Particularly in the medical industry, nanotechnology can be utilized to create goods with unique and enhanced actions and physicochemical features. Targeted therapy, regulated release of phytomedicine, reduced therapeutic dose and side effects, enhanced bioavailability, and protection against degradation of payload are all provided by nanocarriers.³¹ Ingredients taken from plants, animals, microbes, or their metabolites, among other sources, are known as natural products. Their wide range of sources, high level of safety, and variety make them extremely popular.³²

Dendrimers

Dendrimers are an exciting group of systems for drug delivery that could tackle some of the issues associated with existing licensed anticancer drugs. They have the

ability to decrease drug toxicity, overcome drug resistance, and improve drug solubility and bioavailability. Anticancer medications have been integrated into dendrimers and micelles, which has improved cellular absorption, sustained release of the drug, reduced adverse effects, and increased anticancer activity both in vivo and in vitro. Typically, dendrimers are utilized to covalently bind certain targeting moieties including folic acid, antibodies, sugar epidermal growth factor, and biotin in order to successfully target drugs to tumor tissues.²⁷ When it comes to the therapeutic effectiveness of new natural substances in cancer treatments, nanotechnology is essential.³³ Dendrimers are three-dimensional branched nano polymers with internal cavities, many branches, and a core. Despite their distinct structure, they are referred to as a subset

of polymeric NPs since they can be made in various generations (layers) and be connected to polymeric molecules in order to achieve particular objectives.¹⁴ Dendrimers are multivalent, tree-like macro-molecules that are employed as nanocarriers to deliver a wide range of medications and bio-active substances. They have a well-branched, defined structure.³⁴ Dendrimers are spherical polymers with a high branching count. Because of their small size and relative simplicity of synthesis and modification as compared to other drug-delivery systems based on nanotechnology, they have gained popularity in the recent few decades as drug delivery systems.³⁵ Hyperbranched globular nano polymeric topologies known as dendrimers have unique, homogenous, and almost mono-disperse structures.³⁶

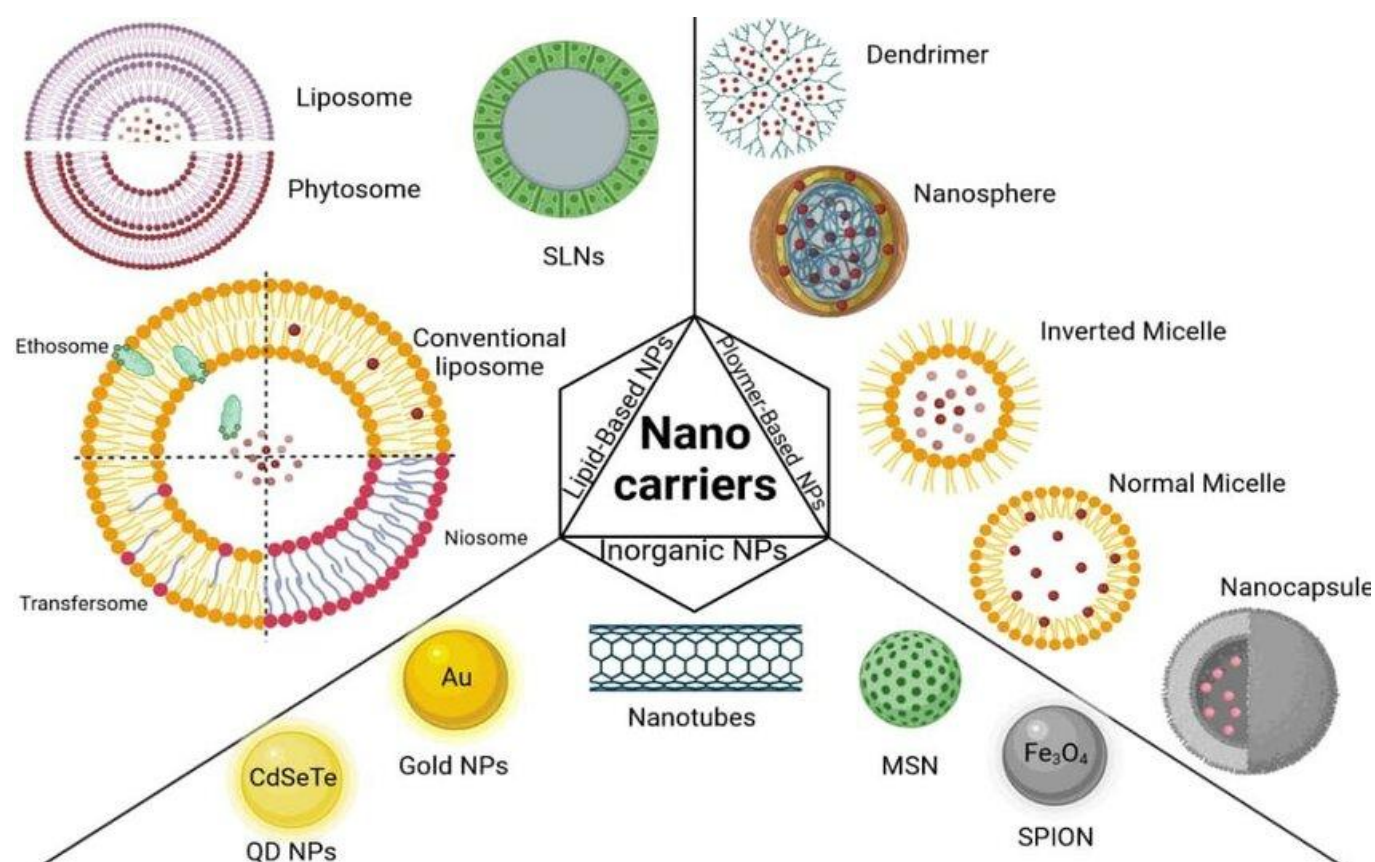


Figure 2: Schematic representation of common nanocarriers for herbal drug delivery.³¹

Lipid-based nanocarriers for herbal drug delivery

The Romans employed nanoparticles and structures in the fourth century AD, demonstrating one of the most intriguing applications of nanotechnology in antiquity.³⁷ Lipid-based nanoparticles are a particular kind of nanocarrier system that has its own unique features. Different lipid nanoparticles exist, include self-emulsifying drug delivery systems, liposomes, solid lipid nanoparticles, and nanoscale lipid carriers.³⁸ Because of their adjustable physiochemical and structural characteristics, using nanoparticles (NPs) as drug carriers can have several benefits over traditional therapies.³⁹ Liquid lipids cause the lipid matrix to

become more disorganized to a greater extent, which in turn increases the drug loading capacity and stability.¹² The capacity of lipid-based delivery methods to penetrate difficult physiological barriers, their ease of synthesis, affordability, and ease of large-scale production have garnered significant attention in recent years.⁴⁰ Lipid-based nano-structures was found to have many advantages, like simple manufacturing, high biocompatibility, and biodegradability, which makes them a viable option for RNA-based therapeutic delivery.⁴¹ Lipid nanoparticles of the second generation are called nano-structured lipid carriers, or NLCs. Their size is in the region of nanometers, allowing for deeper

penetration into the skin's layers. The drug molecule can be shielded by NLCs from external environment-dependent degradation processes such as oxidative, chemical, or physical degradation. When topically applied to a psoriatic plaque model produced by imiquimod, Sathe et al. reported that NLCs of dithranol in a gel form enabled for considerably easier application and increased efficacy over conventional preparations.⁴²

Herbal Medicines and Natural Compounds Nanoformulations

Polymeric Nanoparticles (PNPs)

Because polymeric nanoparticles may carry large amounts of medicine, the system can support and shield the included drug against deterioration. While nanocapsules are created by a thin polymeric envelope enclosing an oil-filled chamber, nanospheres are dense polymeric matrices created using micro-emulsion polymerization.⁴³ Because these polymeric nanoparticles can contain hydrophilic medications, they may be employed as possible skin-transfer agents for the treatment of psoriasis. used a new amphiphilic polymer to create skin-permeating nanoparticles. In comparison to the medication in its free form, they also investigated the drug's long-term release from nanoparticles.⁴² A medicinal substance of interest is encapsulated within the polymeric matrix, adsorbed, or conjugated onto the surface of polymeric nanoparticles, or polymeric NPs for short.¹⁸ The technique known as nanoparticle tracking analysis, or NTA, is used to measure particles that range in size from around 30 to 1,000 nm. ⁴⁴ Polymer Nanoparticles: Via monomers polymerization, polymerization dispersion, or spontaneous assembly of amphiphilic polymers, synthetic or naturally biodegradable polymeric materials may be made into are nanoscale, solid, and spherical entities known as polymeric nanoparticles (PNs).⁴⁵ Natural or synthetic materials can be used to create nanoparticles of polymer (NPs), which can have a variety of shapes and properties.⁴⁶ Particles with a range of nanometric diameters are called polymeric nanoparticles. They are made up of a polymer matrix made of both natural and synthetic polymers.⁴⁷

Solid lipid nanoparticles (SLN)

Solid lipid nanoparticles (SLNs) are an instance of lipid-based vesicular system that have grown more important because of their ability to release medication at a precise location and at a regulated rate. Due to its ability to produce a lipid film on the skin, the lipid-based vesicle's small size allows for deeper penetration into the stratum corneum and skin hydration.⁴² Lipid-based nanoparticles have a solid lipid phase within. Lipid-based NPs are classified into two groups based on their internal structure: solid lipid NPs (SLNs) and nano-structured lipid carriers (NLCs). SLNs, the initial generation of lipid-based nanoparticles, are only made of solid lipids; in contrast, NLCs, an upgraded form of

SLNs, are made of both liquid and solid lipids, with the solid lipid in a comparatively large quantity to create nanoparticles.⁴⁸ SLNs are prepared similarly to an oil-in-water (o/w) emulsion, with the exception that the oil phase is replaced by solid fat or a combination of solid fats.. SLNs are composed of a solid lipid matrix that is in a solid state at both room temperature and body temperature. Waxes, fatty acid esters, and long-chain fatty acids are examples of solid lipids found in SLNs. SLN particle sizes (PS) range from 80 to 1000 nm.²⁷ Therapeutic peptides, proteins, and antigens can be delivered in diverse ways via solid lipid particulate systems, which include lipospheres, lipid microparticles, and SLNs. Biodegradable and biocompatible lipids or lipid molecules are used to create SLNs, the first generation of lipid nanoparticles and the most researched drug carriers.⁴⁹ Lipids that are solid at body temperature and room temperature combine to create SLN, which are then stabilized by surfactants. Triglycerides, waxes, or mixtures of glycerides are the lipids utilized to prepare SLN.¹⁹ Lipidic carrier systems consisting of solid lipids and surfactants are known as solid lipid nanoparticles (SLNs).⁵⁰

Role of Administration of Ayurvedic herbs:

Because the BBB restricts access to the central nervous system, getting beyond it is the largest obstacle to drug delivery into the central nervous system. Many therapeutic drugs have been ineffective for treating brain-related illnesses and injuries, such as Alzheimer's disease, stroke, brain tumors, head injuries, and other CNS disorders, for decades because to the BBB. ⁵¹

Green-synthesized metal nanoparticles using plant

Metal-based nanoparticles find wide applications in a variety of disciplines, including biology, chemistry, engineering, and medicine. The biological uses of metal nanoparticles in pharmacy and medicine are gaining attention. Significant advancements in these growing applications have led to the opening of new application areas and creative synthesis routes for these nanoparticles, including chemical and physical approaches.⁵² Because of their unique characteristics, nanomaterials can function as nanocarriers for specialized medication delivery systems. For theranostic goals, the medicinal and/or diagnostic substances can be conjugated to nanomaterials. ⁵³

Nano-Drug Delivery Systems and Natural Products

The topic of using nanotechnology in natural products is one that is expanding quickly. An increasing amount of people believe that using nanocarriers to effectively carry medications could be a safe means of delivering therapeutic substances to certain regions within organs, tissues, or cells. Since nanotechnology allows one or more natural items to be loaded, the combination of natural products and nanotechnology holds great potential. ⁵⁴

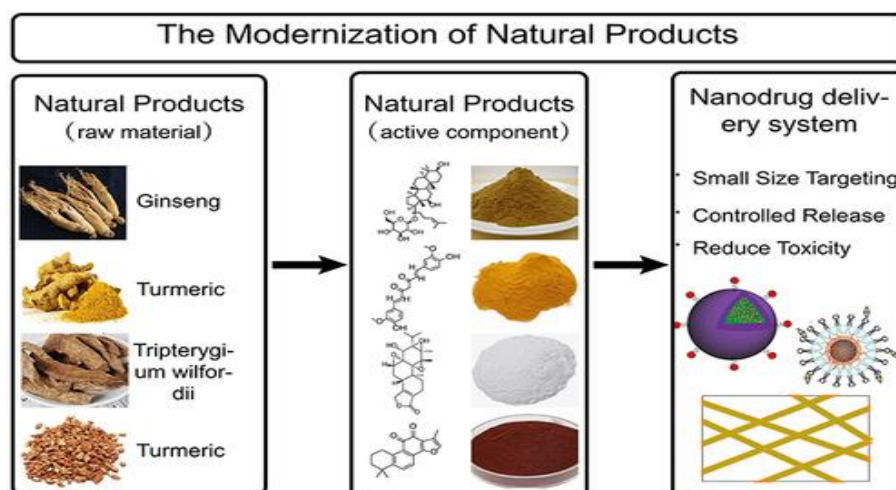


Figure 3: The combination of natural products and nanotechnology promotes the development of the pharmaceutical field.⁵⁴

Emerging Natural Therapeutic Agents

New anticancer medications are mostly derived from natural materials. It is believed that around 50% of anticancer medications now in use, whether directly or indirectly, come from natural products⁵⁵.

(1) Polysaccharides; (2) Terpenoids; (3) Terpenoid; (4) Polyphenol; (5) Terpenoids.⁵⁵

Synthetic-herbal drug combination

Tacrolimus with curcumin: Curcumin is a well-known, traditional medication with a number of advantageous skin-related benefits. Numerous inflammatory cytokines, including IL-1 β , IL-6, TNF- α , and cyclin E, have been observed to be inhibited by it. Its anti-psoriatic actions are typically mediated through the NF- κ B and MAPK

(mitogen-activated protein kinase) pathways. The medicine tacrolimus suppresses the immune system. It inhibits calcineurin, a cytoplasmic protein that binds to calcium and is necessary for T-cell activation and proliferation.⁴²

Delivery Systems for Nutraceuticals

As a result, the distribution systems for them must be chosen to generate goods with constant quality characteristics.⁵⁶ A wide range of opportunities for the development of novel goods and requests in the food system are jeopardized by nano-biotechnology. It can be applied to site-specific delivery of active ingredients or nutraceuticals using a variety of delivery methods, including nano dispersions and nanoemulsions.⁵⁷

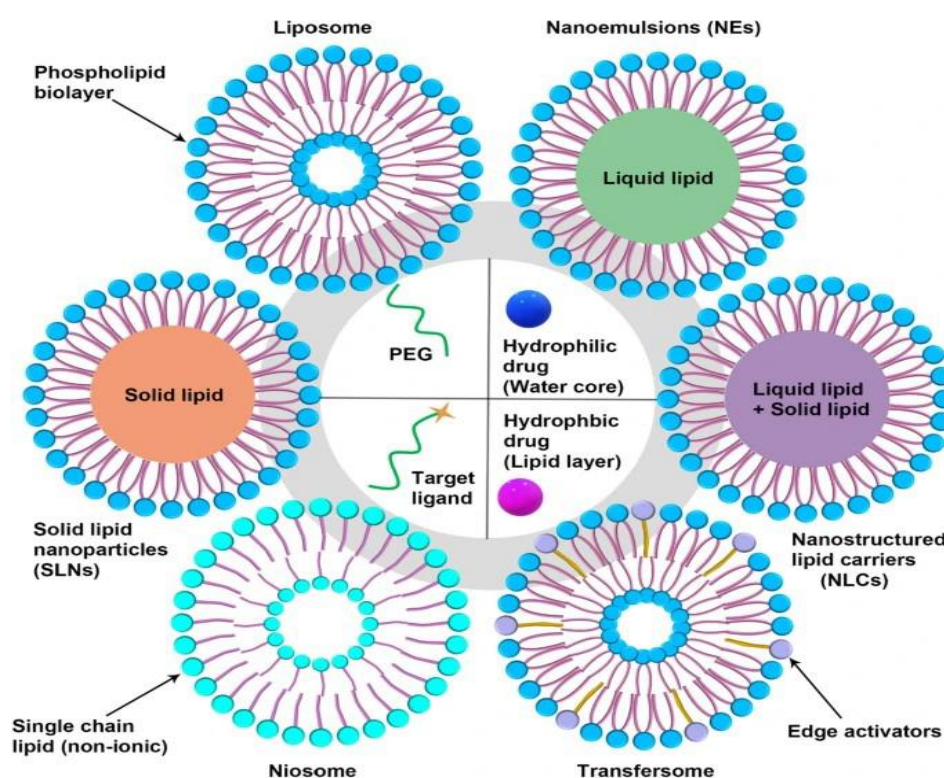


Figure 4: Schematic illustration the formation and application of LNP.⁵⁸

Advantages of nanomaterials

- Herbal by nutrition. They also increase longevity, quality of life, and overall health.⁵⁷
- Because of their alleged safety, potential nutritional value, and medicinal effects, nutraceuticals have generated a lot of interest.⁵⁷
- Growing trends in nutraceuticals include local availability, environmental friendliness, production and processing from renewable sources, and public education.⁵⁷
- Because of their tiny size, they have better penetration into biological membranes and can mix charged solutes with both hydrophilic and hydrophobic drugs.⁴⁴

Application of Nanotechnology on herbal nutraceuticals

These are beneficial for maintaining health as well as helping with acute or chronic Disease

Herbal medicine

1. Herbal extract and nanoparticles work more effectively to combat serious illnesses like kidney stones, diabetes, cancer, and heart attacks. According to reports on nano products, these green nanoparticles have demonstrated antioxidant, anti-diabetic, anti-cancer, antibacterial, drug delivery, and anti-arthritis properties⁵⁹.

2. Important biomedical applications of NP-protein interaction includes theranostic drugs and delivery mechanisms.⁶⁰

Conclusion

The integration of nanotechnology and herbal medicine has revolutionized the field of drug delivery, enabling the development of novel formulations with improved bioavailability, targeted delivery, and reduced toxicity. Nanocarriers such as liposomes, nanoparticles, and dendrimers have been successfully employed to deliver herbal extracts and bioactive compounds, enhancing their therapeutic efficacy. The application of nanotechnology has also improved the solubility and stability of herbal compounds, facilitating their use in various diseases, including cancer, diabetes, and cardiovascular disorders. Furthermore, the use of natural products and nanotechnology has opened up new avenues for the development of safe and effective therapeutic agents. Overall, the synergy between nanotechnology and herbal medicine holds great promise for the development of innovative treatments for various diseases.

Conflict of Interest: The authors declare no potential conflict of interest with respect to the contents, authorship, and/or publication of this article.

Author Contributions: All authors have equal contribution in the preparation of manuscript and compilation.

Source of Support: Nil

Funding: The authors declared that this study has received no financial support.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data supporting in this paper are available in the cited references.

Ethical approvals: Not applicable.

References

- [1] Bonifacio BV, Silva PB, Dose MS, Ros S, Negri KM, Chorilli M "Nanotechnology-based drug delivery systems and herbal medicines: a review" *International Journal of Nanomedicine*, 2013; 9(1):1-15. <https://doi.org/10.2147/IJN.S52634> PMID:24363556 PMCID:PMC3862741
- [2] Zheng Y, Wang Y, Xia M, Gao Y, Zhang L, Song Y, Zhang C, "The combination of nanotechnology and traditional Chinese medicine (TCM) inspires the modernization of TCM: review on nanotechnology in TCM-based drug delivery systems", *Drug Delivery and Translational Research*, 2021;12:1-20, <https://doi.org/10.1007/s13346-021-01029-x> PMID:34260049
- [3] Dr. Tiwari S, Talreja S, and pandey S "A REVIEW ON USE OF NOVEL DRUG DELIVERY SYSTEMS IN HERBAL MEDICINES" *Science and Engineering Journal*, 2020;44(1):190-197
- [4] Dewi MK, Chaerunisaa YA, Muhaimin M, Joni M, "Improved Activity of Herbal Medicines through Nanotechnology" *Molecules*, 2022;12(22): <https://doi.org/10.3390/nano1224073> PMID:36432358 PMCID:PMC9695685
- [5] Farokhzad OC and Langer R, "Impact of Nanotechnology on Drug" *American Chemical Society Nano*, 2009;3(1):16-20, <https://doi.org/10.1021/nn900002m> PMID:19206243
- [6] Pradhan D, Biswasroy P, Goyal A, Ghosh G, and Rath G, "Recent Advancement in Nanotechnology-Based Drug Delivery System Against Viral Infections" *AAPS pharmaceutical Science technology*, 2021;22:1-19, <https://doi.org/10.1208/s12249-020-01908-5> PMID:33447909 PMCID:PMC7808403
- [7] Ansari SH, Islam F, Sameem M, "Influence of nanotechnology on herbal drugs" *Journal of Advanced Pharmaceutical Technology & Research*, 2012 ;3(3):142-146, <https://doi.org/10.4103/2231-4040.101006> PMID:23057000 PMCID:PMC3459443
- [8] Qiao L, Han M, Gao S, Shao, Wang X, Sun. L, Fuc. X, Wei. Q, "Research progress on nanotechnology for delivery of active ingredients from traditional Chinese medicines" *Journal of material chemistry B Accepted Manuscript*, 2012;34:1-19, <https://doi.org/10.1039/x0xx00000x>
- [9] Paul RK, Kesharwani P, and Raza K, "Recent update on nano-phytopharmaceuticals in the management of diabetes" *Journal of Biomaterials Science, Polymer Edition*, 2021; 32(15):1-23, <https://doi.org/10.1080/09205063.2021.1952381> PMID:34228585
- [10] Li S, Chen L and Fu Y, "Nanotechnology-based ocular drug delivery systems: recent advances and future prospects", *Journal of Nanobiotechnology*, 2023:1-23, <https://doi.org/10.1186/s12951-023-01992-2> PMID:37480102 PMCID:PMC10362606
- [11] Hu Y, Song J, Feng A, Li J, Li M, Shi Y, Sun W, Li L, "Recent Advances in Nanotechnology-Based Targeted Delivery Systems of Active Constituents in Natural Medicines for Cancer Treatment", *Molecules*, 2023; 28(23):1-33, <https://doi.org/10.3390/molecules28237767> PMID:38067497 PMCID:PMC10708032
- [12] Baveloni FG, Riccio FVB, Filippo DDL, Fernandes MA, Meneguini AB, Chorilli M, "Nanotechnology-based Drug Delivery Systems as Potential for Skin Application", *Current Medicinal Chemistry*, 2020;28(16):3216-3248,

- <https://doi.org/10.2174/0929867327666200831125656>
PMid:32867631
- [13] Yadav P, Ambudkar SV, Prasad RN "Emerging nanotechnology-based therapeutics to combat multidrug-resistant cancer", *Journal of Nanobiotechnology*, 2022;20:1-35, <https://doi.org/10.1186/s12951-022-01626-z> PMid:36153528 PMCID:PMC9509578
- [14] Asl DF, Mousazadeh M, Taji S, Bahmani A, Khashayar P, Azimzadeh M, & Mostafavi E, "Nano drug-delivery systems for management of AIDS: liposomes, dendrimers, gold and silver nanoparticles", *Nanomedicine*, 2023; 18(3):209-301. <https://doi.org/10.2217/nmm-2022-0248> PMid:37125616 PMCID:PMC10242436
- [15] Kim JS, Puranik N, Yadav D, Jin J, Lee CP "Lipid Nanocarrier-Based Drug Delivery Systems: Therapeutic Advances in the Treatment of Lung Cancer" *International Journal of Nanomedicine*, 2023;18:2659-2675, <https://doi.org/10.2147/IJN.S406415> PMid:37223276 PMCID:PMC10202211
- [16] Liu M, Wei X, Zheng Z, Li Y, Li M, Lin J, Yang L "Recent Advances in Nano-Drug Delivery Systems for the Treatment of Diabetic Wound Healing" *International Journal of Nanomedicine*, 2023;18:1537_1559, <https://doi.org/10.2147/IJN.S395438> PMid:37007988 PMCID:PMC10065433
- [17] Ruman U, Fukurazi S, Masarudin JM, Hussein ZM, "Nanocarrier-Based Therapeutics and Theranostics Drug Delivery Systems for Next Generation of Liver Cancer Nanodrug Modalities", *International Journal of Nanomedicine*, 2020;15:1437-1455, <https://doi.org/10.2147/IJN.S236927> PMid:32184597 PMCID:PMC7060777
- [18] Li Y, and Zhang H "Nanoparticle-Based Drug Delivery Systems for Enhanced Tumor-Targeting Treatment". *Journal of Biomedical Nanotechnology*, 2019; 15(1): 1-27, <https://doi.org/10.1166/jbnn.2019.2670> PMid:30480512
- [19] Silva PB, Freitas ES, Bernegossi J, Goncalves ML, Sato MR, Leite CQ, Pavan FR, Chorilli M, "Nanotechnology-Based Drug Delivery Systems for Treatment of Tuberculosis" *Journal of Biomedical Nanotechnology*, 2016;12(2):241-259, <https://doi.org/10.1166/jbnn.2016.2149> PMid:27305759
- [20] Maurya SD, Prajapati S, Gupta A, Saxena G, Dhakar RC, Formulation Development and Evaluation of Ethosome of Stavudine, *Indian J. Pharm. Educ. Res.* 2010;44(1)
- [21] Yellepeddi V, Joseph A, Nance E, "Pharmacokinetics of Nanotechnology-Based Formulations in Pediatric Populations", *HHS Public Access*, 2020;151-152:1-28, <https://doi.org/10.1016/j.addr.2019.08.008> PMid:31494124 PMCID:PMC6893132
- [22] Dong X, Gao J, Su Y and Wang Z "Nanomedicine for Ischemic Stroke" *International Journal of Molecular Sciences*, 2020 ;21(20):1-22, <https://doi.org/10.3390/ijms21207600> PMid:33066616 PMCID:PMC7590220
- [23] Andreana I, Bincoletto V, Milla P, Dosio F, Stella B, Arpicco S "Nanotechnological approaches for pentamidine delivery", *Drug Delivery and Translational Research*, 2022;12:1912-1926, <https://doi.org/10.1007/s13346-022-01127-4> PMid:35217992 PMCID:PMC8880300
- [24] Falke PB, Shelke PG, Hatwar PR, Bakal RL, Kohale NB, "A comprehensive review on Nanoparticle: Characterization, classification, synthesis method, silver nanoparticles and its application" *GSC Biological and Pharmaceutical Sciences*, 2024;28(01):1-14, <https://doi.org/10.30574/gscbps.2024.28.1.0268>
- [25] de la Torre P, Pérez-Lorenzo MJ, Alcázar-Garrido Á, Flores AI. Cell-Based Nanoparticles Delivery Systems for Targeted Cancer Therapy: Lessons from Anti-Angiogenesis Treatments. *Molecules*. 2020 Feb 7;25(3):715. <https://doi.org/10.3390/molecules25030715> PMid:32046010 PMCID:PMC7038177
- [26] Güven E, "Nanotechnology-based drug delivery systems in orthopedics" *Joint Diseases and Related Surgery*, 2021 32(1):267-273, <https://doi.org/10.5606/ehc.2021.80360> PMid:33463450 PMCID:PMC8073448
- [27] Tagde P, Najda A, Nagpal K, Kulkarni GT, Shah M, Ullah O, Balant S, Rahman HM, "Nanomedicine-Based Delivery Strategies for Breast Cancer Treatment and Management" *International Journal of Molecular Sciences*, 2022;23(5):1-36. <https://doi.org/10.3390/ijms23052856> PMid:35269998 PMCID:PMC8911433
- [28] Paunovska K, Loughrey D, Sago CD, Langer R, Dahlman JE, "Using Large Datasets to Understand Nanotechnology", *HHS Public Access*, 2023;31(43):1-30, <https://doi.org/10.1002/adma.201902798> PMid:31429126 PMCID:PMC6810779
- [29] Milane L, Amiji M, "Clinical approval of nanotechnology-based SARS-CoV-2 mRNA vaccines: impact on translational Nanomedicine", *Drug Delivery and Translational Research*, 2021;11:1310-1315, <https://doi.org/10.1007/s13346-021-00911-y> PMid:33512669 PMCID:PMC7845267
- [30] Chakravarty M & Vora A, "Nanotechnology-based antiviral therapeutics" *Drug Delivery and Translational Research*, 2020;11:747-787, <https://doi.org/10.1007/s13346-020-00818-0> PMid:32748035 PMCID:PMC7398286
- [31] Jalili A, Bagherifar A, Nokhodchi A, Conway B, Javadzadeh Y, "Current Advances in Nanotechnology-Mediated Delivery of Herbal and Plant-Derived Medicines", *Accepted Manuscript (unedited)*, 2023;13(4):1-16, <https://doi.org/10.34172/apb.2023.087> PMid:38022806 PMCID:PMC10676547
- [32] Ma Y, You T, Wang J, Jiang Y and Niu J, "Research Progress on Construction of Lutein-Loaded Nano Delivery System and Their Improvements on the Bioactivity", *Coatings*, 2022;12(10):1-20, <https://doi.org/10.3390/coatings12101449>
- [33] Vieira IR, Tessaro L, Lima AK, Velloso IP, Conte-Junior CA, "Recent Progress in Nanotechnology Improving the Therapeutic Potential of Polyphenols for Cancer", *nutrients*, 2023;15(14):1-43, <https://doi.org/10.3390/nu15143136> PMid:37513554 PMCID:PMC10384266
- [34] Parajapati S, Maurya S, Das M, Tilak VK, Verma KK, Dhakar RC. Potential Application of Dendrimers in Drug Delivery: A Concise Review and Update. *Journal of Drug Delivery and Therapeutics*. 2016;6(2):71-88 <https://doi.org/10.22270/jddt.v6i2.1195>
- [35] Ayub A and Wettig S, "An Overview of Nanotechnologies for Drug Delivery to the Brain", *pharmaceutics*, 2022;14(2): 1-20, <https://doi.org/10.3390/pharmaceutics14020224> PMid:35213957 PMCID:PMC8875260
- [36] Rawding PA, Bu J, Wang J, Kim D, Drelich AJ, Kim Y, Hong S, "Dendrimers for Cancer Immunotherapy: Avidity-based drug delivery vehicles for effective anti-tumor immune response", *HHS Public Access*, 2023;14(2):1-20, <https://doi.org/10.1002/wnan.1752> PMid:34414690 PMCID:PMC9485970
- [37] Bayda S, Adeel M, Tuccinardi T, Cordani M and Rizzolio F, "The History of Nanoscience and Nanotechnology: From Chemical-Physical Applications to Nanomedicine", *molecules*, 2019; 25(1):1-15, <https://doi.org/10.3390/molecules25010112> PMid:31892180 PMCID:PMC6982820
- [38] Kumar R, Mehta P, Shankar KR, Rajora MAK, Mishra YK, Mostafavi E, Kaushik A. Nanotechnology-Assisted Metered-Dose Inhalers (MDIs) for High-Performance Pulmonary Drug Delivery Applications. *Pharm Res.* 2022 Nov;39(11):2831-2855. DOI: 10.1007/s11095-022-03286-y. Epub 2022 May 12. Erratum in: *Pharm Res.* 2022 Nov;39(11):2857. <https://doi.org/10.1007/s11095-022-03306-x> PMid:35689006 PMCID:PMC9828852
- [39] Mohamed NA, Marei I, Crovella S and Abou-Saleh H, "Recent Developments in Nanomaterials-Based Drug Delivery and Upgrading Treatment of Cardiovascular Diseases", *International*

- Journal of Molecular Sciences, 2022;23(3):1-20, <https://doi.org/10.3390/ijms23031404> PMID:35163328 PMCID:PMC8836006
- [40] Xu X, Chang L, Wang Y, Koivisto O, Zhou J, Shu Y, Zhang H, "Nanotechnology-based delivery of CRISPR/Cas9 for cancer treatment" *Advanced Drug Delivery Reviews*, 2021;176(113891):1-31, <https://doi.org/10.1016/j.addr.2021.113891> PMID:34324887
- [41] Lin YX, Wang Y, Blake S, Yu, Mei L, Wang H, Shi J, "RNA Nanotechnology-Mediated Cancer Immunotherapy", *Theranostics*, 2020;10(1):281-299, <https://doi.org/10.7150/thno.35568> PMID:31903120 PMCID:PMC6929632
- [42] Saleem S, Iqbal MK, Garg S, Ali J & Baboota S, "Trends in nanotechnology-based delivery systems for dermal targeting of drugs: an enticing approach to offset psoriasis", *Expert Opinion on Drug Delivery*, *Expert Opinion on Drug Delivery Frontiers in Bioengineering and Biotechnology*, 2020;17(6):1-78, <https://doi.org/10.1080/17425247.2020.1758665> PMID:32315216
- [43] Moradi SZ, Momtaz S, Bayrami Z, Farzaei MH and Abdollahi M, "Nanoformulations of Herbal Extracts in Treatment of Neurodegenerative Disorders", *Frontiers in Bioengineering and Biotechnology*, 2020;8:1-20, <https://doi.org/10.3389/fbioe.2020.00238> PMID:32318551 PMCID:PMC7154137
- [44] Medake RA, Hatwar PR, Bakal RL, Amalkar SV, "Review on Nanogel as a Novel Platform for Smart Drug Delivery System", *Journal of Drug Delivery and Therapeutics*, 2024;14(8):161-174. <https://doi.org/10.22270/jddt.v14i8.6704>
- [45] Li J, Long Q, Ding H, Wang Y, Luo D, Li Z, and Zhang W, "Progress in the Treatment of Central Nervous System Diseases Based on Nanosized Traditional Chinese Medicines", *Advanced Science*, 2024;11(16):1-40, <https://doi.org/10.1002/adv.202308677> PMID:38419366 PMCID:PMC11040388
- [46] Yang J, Jia C, Yang J, "Designing Nanoparticle based Drug Delivery Systems for Precision Medicine", *International Journal of Medical Sciences*, 2021;18(13):2943-2949, <https://doi.org/10.7150/ijms.60874> PMID:34220321 PMCID:PMC8241788
- [47] Kasina V, Mowann RJ, Bahal R and Sartor GS, "Nanoparticle delivery systems for substance use disorder", *Neuropsychopharmacology*, 2022;47:1432-1439, <https://doi.org/10.1038/s41386-022-01311-7> PMID:35351961 PMCID:PMC8960682
- [48] Nie X, Chen Z, Pang L, Wang L, Jiang H, Chen Y, Zhang Z, Fu C, Ren B, Zhang J, "Oral Nano Drug Delivery Systems for the Treatment of Type 2 Diabetes Mellitus: An Available Administration Strategy for Antidiabetic Phytocompounds", *International Journal of Nanomedicine*, 2020; 95:10215-10239, <https://doi.org/10.2147/IJN.S285134> PMID:33364755 PMCID:PMC7751584
- [49] Ma H, Pan Z, Lai B, Zanc, Liu H, "Recent Research Advances in Nano-Based Drug Delivery Systems for Local Anesthetics", *Drug Design, Development and Therapy*, 2023; 17:2639-2655, <https://doi.org/10.2147/DDDT.S417051> PMID:37667787 PMCID:PMC10475288
- [50] Nabi B & Rehman S & Aggarwal S & Baboota S & Ali J, "Nano-based anti-tubercular drug delivery: an emerging paradigm for improved therapeutic intervention", *Drug Delivery and Translational Research*, 2020;10:1111-1121, <https://doi.org/10.1007/s13346-020-00786-5> PMID:32418158 PMCID:PMC7229880
- [51] Chakrapany S, Chandan S, "Nano Carriers of Novel Drug Delivery System for "Ayurveda Herbal Remedies" Need of Hour- A Bird's Eye View", *Am. J. PharmTech Res*, 2014;4(2):60-69,
- [52] Hajialyani M, Tewari D, Sánchez ES, Nabavi SM, MH Farzaei, Abdollahi M, "Natural product-based nanomedicines for wound healing purposes: therapeutic targets and drug delivery systems", *International Journal of Nanomedicine*, 2018;13:5023-5042. <https://doi.org/10.2147/IJN.S174072> PMID:30214204 PMCID:PMC6128268
- [53] Barabadi H, Webster TJ, Vahidia H, Saboric H, Kamalid KD, Shoushtarie FJ, Mahjoubf MA, Rashedig M, Mostafavib E, Cruzb DM, Hosseinic O and Saravanah M, "Gree Nanotechnology-based Gold Nanomaterials for Hepatic Cancer ,Therapeutics: A Systematic Review", *Iranian Journal of Pharmaceutical Research*, 2020;19(3):1-17, <https://doi.org/10.22037/IJPR.2020.113820.14504>
- [54] Lv Y, Li W, Liao W, Jiang H, Liu Y, Cao J, Lu W, Feng Y, "Nano-Drug Delivery Systems Based on Natural Products", *International Journal of Nanomedicine*, 2024; 19:541-569, <https://doi.org/10.2147/IJN.S443692> PMID:38260243 PMCID:PMC10802180
- [55] Choukaife H, Seyam s, Alallam B, Doolaanea AA, Alfatama A, "Current Advances in Chitosan Nanoparticles Based Oral Drug Delivery for Colorectal Cancer Treatment", *International Journal of Nanomedicine*, 2022;18:3933-3966, <https://doi.org/10.2147/IJN.S375229> PMID:36105620 PMCID:PMC9465052
- [56] Hoti G, Matencio A, Pedrazzo AR, Cecone C, Appleton SL, Monfared YK, Calder F and Trotta F, "Nutraceutical Concepts and Dextrin-Based Delivery Systems", *International Journal of Molecular Sciences*, 2022;23(8):1-47, <https://doi.org/10.3390/ijms23084102>
- [57] Singh AR, Desu, Nakkala RK, Kondi V, Devi S, Alam MS, Hamid H, Athawale R B, Kesharwan P, "Nanotechnology-based approaches applied to nutraceuticals", *Drug Delivery and Translational Research*, 2021;12:1-15, <https://doi.org/10.1007/s13346-021-00960-3> PMID:33738677
- [58] Qiu C, Zhang JZ, Wu B, Xu CC, Pang HH, Tu QC, Lu YQ, Guo YQ, Xia F and Wang FQ, "Advanced application of nanotechnology in active constituents of Traditional Chinese Medicines", *Journal of Nanobiotechnology*, 2023;21(1):1-49, <https://doi.org/10.1186/s12951-023-02165-x> PMID:38017573 PMCID:PMC10685519
- [59] Akram M, Jorge PD, Iftikhar M, Sarvananda L, Sierra FG, Malki RS, Ozdemir FA, Sołowski G, Fitria N, Altable M, Sfera A and Brogi B, "Revolution of Green Nanotechnology as Therapeutic agent", *Advanced Research Journal of Medical Sciences*, 2024:1-5.
- [60] Fadaka AO, Sibuyi NRS, Madiehe AM, Meyer M. Nanotechnology-Based Delivery Systems for Antimicrobial Peptides. *Pharmaceutics*. 2021 Oct 26;13(11):1795. <https://doi.org/10.3390/pharmaceutics13111795> PMID:34834210 PMCID:PMC8620809