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Review Article

Novel Herbal Drug Delivery System: Emerging Trends and Technologies Towards Safer and more Effective Drug Delivery

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ABSTRACT

The growing demand for effective and safer drug delivery systems has driven significant research into alternative methods, with a particular focus on herbal-based systems. This project explores the development of a novel herbal drug delivery system (HDDS) aimed at improving the bioavailability, controlled release, and targeted delivery of therapeutic compounds derived from medicinal plants. Herbal drugs are known for their therapeutic benefits, but their clinical efficacy is often limited due to poor solubility, rapid metabolism, and inconsistent absorption. These systems are designed to enhance the pharmacokinetics of herbal compounds, ensure sustained release, and minimize side effects. Through a combination of in vitro and in vivo models, the project assesses the performance of these herbal drug delivery systems in terms of drug release profiles, stability, and targeted action, with a particular emphasis on their ability to cross biological barriers like the blood-brain barrier and gastrointestinal tract. Furthermore, the project evaluates the safety and toxicity of the formulated systems, ensuring that they meet the regulatory standards for clinical applications. The findings from this research are expected to contribute to the development of more efficient, eco-friendly, and patient-compliant herbal drug delivery systems, thus expanding the therapeutic potential of herbal medicines in modern healthcare.[1].

INTRODUCTION

Herbal treatments have been utilized in healthcare for thousands of years, and many plants have notable medicinal benefits. Despite the numerous therapeutic uses of herbal compounds, their clinical use has frequently been limited by pharmacokinetic issues, such as low solubility. Poor bioavailability, quick metabolism, and erratic absorption. These constraints may lead to less-than-ideal therapeutic consequences, making it challenging to attain the intended clinical results. Therefore, there is increasing interest in creating

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innovative drug delivery systems (DDS) that can meet these difficulties, especially those associated with herbal therapies. The goal of a novel herbal drug delivery system (NHDDS) is to increase the effectiveness of plant-based treatments making derived chemicals better by enhancing their stability, solubility, and regulated release, as well as allowing for targeted distribution to particular tissues or organs. The concept behind such a approach involves using cutting-edge technology, like hydrogels, dendrimers, liposomes, and nanoparticles, to encapsulate the active herbal components. These systems can shield the active molecules. Maximize their absorption, protect them from degradation, and guarantee a sustained release, all of which are essential for preserving therapeutic levels over time.[2]

Main Points of Emphasis:

a. Boosting Bioavailability**:** Improving the solubility and absorption of herbal substances.

b. Controlled Release: Creating mechanisms that provide a sustained drug release for lasting therapeutic benefit.

c. Targeted Delivery**:** creating methods to deliver herbal chemicals to particular tissues or organs, thereby enhancing their therapeutic index.

d. Safety and Biocompatibility: Making sure the systems are nontoxic and compatible with the body's natural processes.

e. Environmentally Friendly Formulations: Examining the application of natural and biodegradable substances in delivery systems.[3]

Herbal medicines require NDDS:

Multiple variables make unique drug delivery systems (NDDS) essential in herbal medicines. The goal of these systems is to improve the therapeutic efficacy, bioavailability, and safety of these organic products.

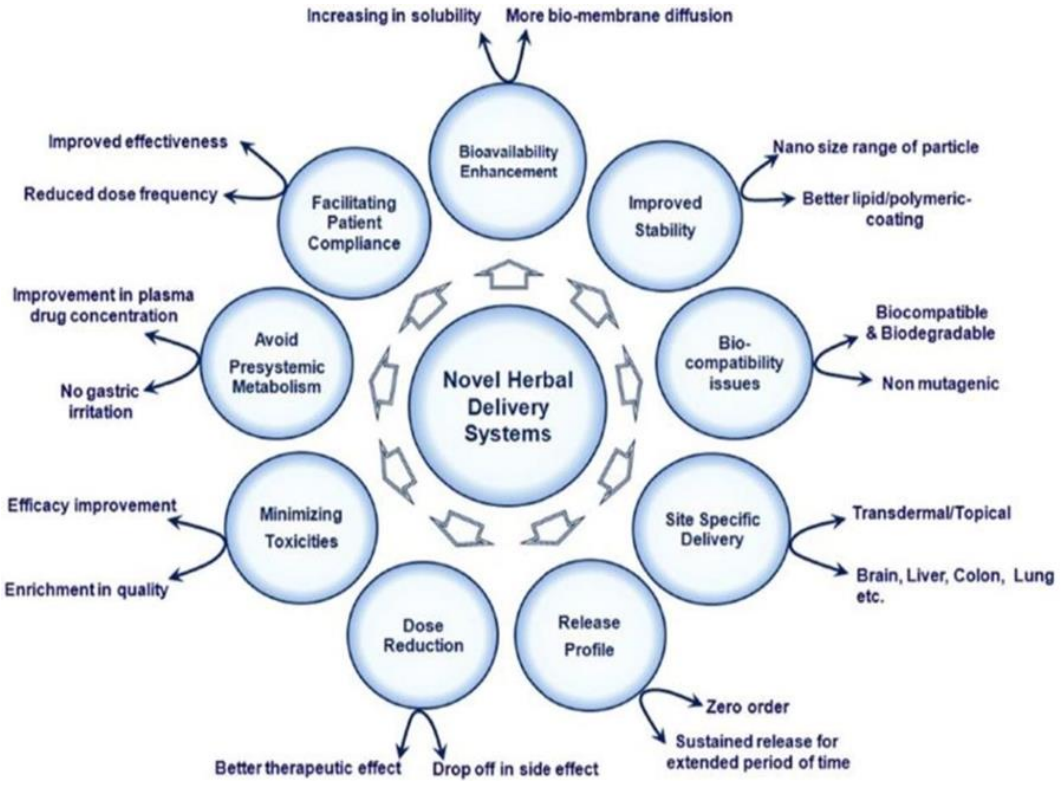

Fig.1 Silent features of Novel Herbal Delivery System

A. Increased Bioavailability

a.problem: The issue is that many plant substances have limited bioavailability because they are poorly soluble, poorly absorbed in the digestive system, or quickly metabolized in the liver.

b. Solution: Herbal substances can be encapsulated by NDDS, such as liposomes, nanoformulations, and micelles, which enhances their stability and solubility, ultimately resulting in increased absorption.

b. Targeted Delivery

Herbal medicines can have side effects because they frequently act on several bodily systems, and their distribution can be nonspecific.

Advanced delivery methods may target certain tissues or organs, increasing therapeutic outcomes while minimizing adverse effects.[4]

c. Continuous and Regulated Release

The issue with conventional herbal treatments is that they frequently have a quick release and a limited duration of effect, resulting in fluctuating plasma levels and diminished therapeutic outcomes.

Approach: Over a longer period of time, herbal medications can be administered in a regulated manner using NDDSs, such as hydrogels or polymeric microspheres, which maintain therapeutic levels.

d. Increased Stability

The effectiveness of several herbal substances may be reduced by hydrolysis, photodegradation, and oxidation.

Herbal medicines can be protected from environmental factors like light and oxygen by encapsulating them in protective materials using the NDDS method. For instance, polymeric or solid lipid nanoparticles can extend the shelf life of delicate herbal components by stabilizing them.

f. Lowered Adverse Effects and Toxicity

Due to their bad pharmacokinetics, certain herbal chemicals can have negative effects when taken in large doses or without adequate preparation.

The answer is that by lowering the systemic exposure to high concentrations, NDDS can enhance the pharmacokinetic profile of herbal medications, which in turn lowers toxicity and adverse effects. For instance, Herbal ingredients can be encased in biocompatible carriers to guarantee a slow and targeted release, which lowers the risk of toxicity.[5]

❖ **The biological and physicochemical characteristics of herbal medicines:**

The physicochemical properties of herbal medicines are those of plant-derived compounds that influence their safety, efficacy, quality, and stability as therapeutic goods.

a. Attributes of Morphology:

The quality, identification, and consumer acceptance of the herb or its processed form (powder, extract, etc.) can be impacted by its shape, size, and color.

b. Moisture Content:

Because it impacts their shelf life, stability, and vulnerability to microbial development, the moisture level of herbal medicines is essential. Inadequate moisture might cause hard, brittle material, whereas too much moisture can cause deterioration.

c. Solubility:

The water solubility of many herbal medicinal bioactive chemicals, like alkaloids and flavonoids, varies. When ingested, the drug's solubility influences its bioavailability and absorption.

d. Polarity and Lipophilicity:

Lipophilic Compounds: Numerous active substances in herbs, such as essential oils, terpenes, and fatty acids, are lipophilic and may need oil-based solvents for extraction.

Polarity: key to overcoming challenges like poor water solubility, improving bioavailability, and achieving targeted delivery.[6]

❖ **Selecting an herbal remedy and an NDDS:**

The selection of herbal therapies and their integration into Novel Drug Delivery Systems (NDDS) is a key area of research in modern herbal and pharmaceutical medicine. Many herbal medicines suffer from problems such poor solubility and variable absorption; this approach aims to increase their bioavailability, stability, and efficacy. It also decomposes fast in the body. The use of NDDS provides a means of improving these characteristics, which in the end leads to better therapeutic outcomes.

Pharmacological Consequences:

The herbal remedy must have a proven therapeutic effect. Withania somnifera (ashwagandha) and Curcuma longa (turmeric) are two popular examples.

Bioavailability issues include:

Many herbal remedies have restricted bioavailability because they are either poorly soluble or unstable in the digestive system. NDDS may improve the solubility of these chemicals, leading to better absorption and efficacy. For instance, curcumin, which comes from turmeric, has low oral bioavailability, making it a great candidate for NDDS enhancement.

Safety and Toxicity:

It's essential to select herbal treatments that are widely regarded as safe and have minimal toxicity profiles. Standardized extracts, which deliver consistent amounts of active ingredients, can also help lower safety risks.

Mode of Administration:

Herbal treatments can be given orally, topically, or parenterally. The NDDS is selected depending on the preferred method of administration. Herbal remedies may be incorporated into transdermal systems for topical administration, and solubility-enhancing systems (such as nanoformulations) can be used for oral delivery.[7]

❖ **Creative Drug Delivery Systems (NDDS) for Herbal Medicines**

NDDS are designed to overcome the limitations of conventional medication delivery systems by controlling the rate of release, increasing the solubility of the drug, and ensuring targeted delivery. Some of the NDDS techniques often utilized to increase the potency of herbal treatments are listed below:

a. Systems Based on Nanotechnology:

a) Nanoparticles: Active herbal constituents can be encapsulated in nanoparticles, such as liposomes, solid lipid nanoparticles, and poly(lactic-co-glycolic acid) (PLGA) nanoparticles, which enhances their solubility, stability, and bioavailability. For example, curcumin-loaded

nanoparticles significantly improve the oral bioavailability of curcumin.

b) Nanosuspensions: These are colloidal dispersions of minute herbal drug particles that enhance the solubility of drugs with low water solubility. This is beneficial for plant ingredients like resveratrol, quercetin, and curcumin.

b. Hydrogels and Polymers:

a) Hydrogels: These 3D networks are made of hydrophilic polymers that have a high capacity for water retention. They can be used in herbal medicine compositions for sustained release. For instance, hydrogels loaded with Calendula officinalis extract or Aloe vera might provide sustained therapeutic benefits for wound treatment.

b) Polymeric Micelles: These micelles can solubilize hydrophobic herbal medicines in water since they are composed of amphiphilic block copolymers. They are able to increase the bioavailability of resveratrol and curcumin, two compounds that are not particularly soluble.[8]

c. Systems for regulated and sustained release:

a) Matrix Tablets: These tablets are designed to release herbal remedies gradually over time, which helps maintain a steady therapeutic concentration of the medicine in the bloodstream. For example**,** Ashwagandha or ginseng might be turned into extended-release formulations to guarantee consistent results.

b) Nanocapsules: These have a core-shell design that can be used to encapsulate herbal medications, allowing for controlled release. By changing the outer shell, the herbal remedy inside the nanocapsules can be released in specific conditions, such as the acidic stomach or the alkaline intestine.[8]

d. Transdermal Systems:

a) Transdermal Patches: Herbal remedies such Capsicum or Mentha can be administered via the skin in a controlled manner using patches. Particularly beneficial for herbal treatments that alleviate pain and swelling, this method is.

b) Microneedles: These very small needles are able to deliver herbal remedies like Cannabis or CBD straight into the bloodstream by bypassing first-pass metabolism.

f. Methods of Targeted Drug Delivery:

a) Targeted liposomes: Liposomes can be functionalized with ligands, such antibodies or specific peptides, that target specific cells or tissues. Herbal compounds like ginseng, for example, can be targeted toward certain organs, like the liver or brain, to boost their therapeutic benefits.

b) Polymeric Nanoparticles with Targeting Ligands: To deliver herbal medicines to the, polymeric nanoparticles can be decorated with targeting ligands. The site of action, such as targeting cancer cells for a more localized impact, uses turmeric orginger for cancer treatment.

The advantages of herbal therapy

1. Increased Bioavailability
2. Controlled and sustained release
3. Targeted medication delivery
4. Greater Stability
5. Improved Patient Compliance
6. Reduced Metabolism During the First Pass

The drawbacks of herbal remedies include:

- ❖ No Standards.
- ❖ Not Enough Clinical Information.
- ❖ Problems with Safety

- ❖ Issues with Quality Control and Regulation
- ❖ The interplay between herbs and drugs
- ❖ Questions Pertaining to the Environment and Sustainability
- ❖ Common Misunderstandings Among Consumers [9].

- ❖ **Key Challenges in Modernization of Herbal Formulations**

- ➢ **Raw Material Quality & Standardization**

Genetic / Species Variation: Even within the same "plant" species, there may be subspecies, chemotypes, or genetic variability that influence active compound content.

Growing Conditions & Harvesting: Soil, climate, altitude, time of harvest, season, maturity stage affect phytochemical profile.

Adulteration & Misidentification: Wrong species (plant), substitution, mix-ups; intentional or accidental adulteration (e.g. other plant parts, fillers, low quality raw material).

Contamination: Heavy metals, pesticide residues, microbial or fungal contamination, mycotoxins.

Post-harvest handling, storage, transport: Degradation of active compounds, moisture, light, etc.

- ➢ **Analytical & Science-Based Validation**

Marker-based Standards / Fingerprinting: Identifying reliable, relevant chemical markers; developing methods (chromatographic, spectroscopic, etc.) to measure them. Many herbs lack such standardized markers.

Complexity of Herbal Mixtures: Multiple constituents, with possible synergistic effects. It is harder to attribute efficacy to one compound; difficult to establish dose-response relationships.

Pharmacokinetics / ADME: Absorption, distribution, metabolism, excretion of herbal compounds often poorly understood; interactions among compounds; interactions with conventional drugs.

Efficacy, Safety and Clinical Trials: Well-designed clinical trials (randomized, double blind etc.) are costly; it is challenging to standardize the formulation used in trial to what will be marketed; placebo controls; long term safety data; adverse interactions; toxicological studies.[10]

- ➢ **Regulation & Harmonization**

Inconsistent Regulatory Standards: Different countries have varying requirements for herbal medicines vs. pharmaceuticals, or classify them differently (supplements, traditional medicines, etc.). Harmonization is limited.

Implementation & Enforcement: Even where regulations exist (e.g. Good Manufacturing Practices (GMP), Good Agricultural & Collection Practices (GACP)), their awareness, adoption, and enforcement are variable.

Registration / Approval Process: Dossier requirements, timelines, licensing can be inconsistent and burdensome. Export approvals face additional layers of complexity.

- ➢ **Formulation / Manufacturing Challenges**

Stability, Shelf-life: Many herbal products degrade over time; sensitive to light, heat, humidity; loss of potency.

Bioavailability: Many herbal actives are poorly soluble or poorly absorbed in their natural form. Enhancing delivery (e.g. nano-formulations,

encapsulation, phytosomes, etc.) adds cost and technical complexity.

Scale-up: Moving from small laboratory/traditional batches to industrial scale: reproducibility, maintaining consistency, scalability of novel delivery systems.

Cost of Modern Technologies: Sophisticated analytical instrumentation, modern extraction/delivery technologies, R&D for clinical trials demand investment. Smaller manufacturers may find this prohibitive.

- **Intellectual Property, Traditional Knowledge & Ethical Issues**

1. Protecting and recognizing traditional knowledge; biopiracy; benefit sharing; ensuring communities whose knowledge is used are credited/rewarded.
2. Difficulties in patenting complex natural mixtures; many components may not be new, or are in public domain.
3. Sustainability & Environmental Concerns
4. Overharvesting of wild medicinal plants; loss of biodiversity.
5. Unsustainable cultivation practices: soil degradation, water usage, pesticide use, etc.
6. Marketing & Branding Challenges: distinguishing quality products; regulatory compliance may limit claims; competition from cheaper, less regulated/herbal products.
7. Limited infrastructure: labs capable of advanced analysis; stability testing; clinical trial sites.
8. Funding and incentives: R&D funding is often limited; return on investment uncertain.[11]

- **Novel herbal formulation currently available in market**

Table referred from (Advances in Novel Phytopharmaceuticals Edited by Durgesh Nandini Chauhan, Madhu Gupta, Vikas Sharma, Nagendra Singh Chauhan) [12]

Product / Brand	Herb / Active Ingredient	Novel Formulation / Delivery Technology	Key Benefits / What Makes It Novel
Meriva (Healthy Origins etc.)	Curcumin	Phytosome® / Phospholipid-complex & sustained release versions	Much higher bioavailability than regular curcumin; better absorption; sustained plasma levels.
Green Tea Phytosome (GreenSelect®)	Green tea polyphenols (epigallocatechin etc.)	Phytosome complex	Improved absorption; marketed for antioxidant benefits, weight management etc.
Ginkgo bilobaPhytosome	Ginkgo biloba extract	Phytosome tech by Indena etc.	Enhanced delivery; used in geriatric, cognitive support products.
Milk Thistle (Silybummarianum) Phytosome (SILIPHOS™)	Silymarin	Phytosome particulate / complex formulation	Improved antioxidant, hepatoprotective action; better bioavailability.
BerberinePhytosome	Berberine	Phytosome (phospholipid complex)	Enhanced absorption, marketed particularly for metabolic health / blood sugar support.
Herbal Liposomal / "Herbasec®" cosmetics by Cosmetochem	Various herbal antioxidants (white tea, green tea, aloe vera etc.)	Liposomal delivery in cosmetics (skin / anti-aging applications)	Better skin penetration; more potent antioxidant action; improved stability in cosmetics.

❖ Introduction:

Nanomedicine uses nanoscale materials to improve medical treatments, diagnostics, and monitoring. A key application within this field is the development of novel drug delivery systems (DDS), which are engineered to carry therapeutic agents precisely to target sites. This approach can increase drug efficacy, reduce systemic side effects, and overcome biological barriers. Nanomedicine DDS can be broadly categorized by their composition and structure. Lipid-based nanocarriers,Polymeric nanocarriers,Biological nanocarriers

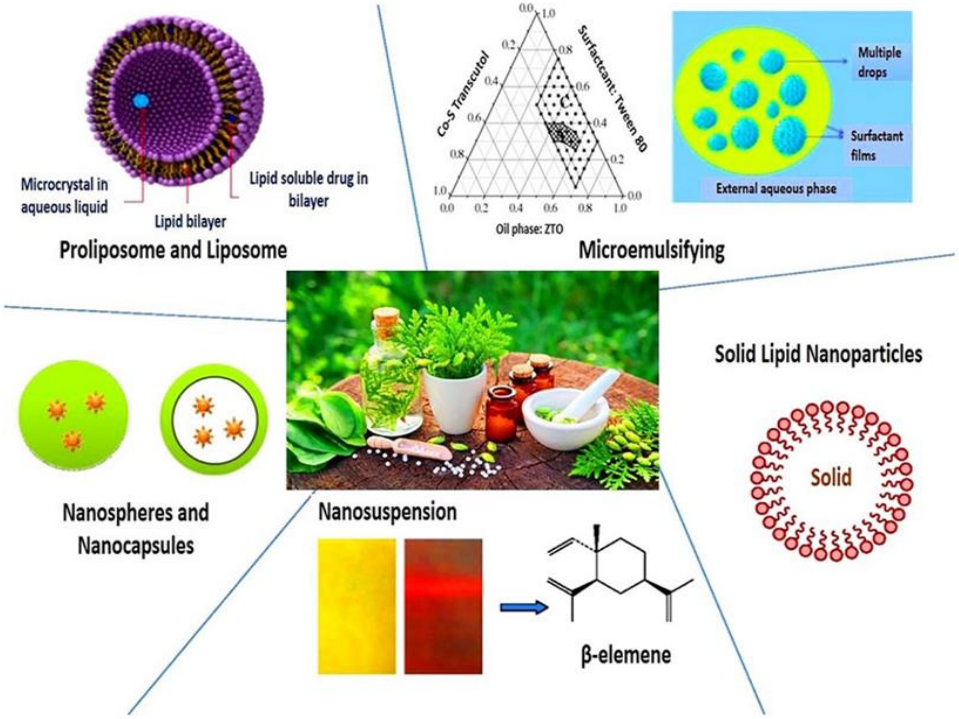

Fig. Types of nanomedicines and drug delivery system

Neosomes

Niosomes are microscopic lamellar structures formed by non-ionic surfactants and cholesterol. They exhibit a bilayer structure, with hydrophilic ends facing outward and hydrophobic ends facing inward. Their unique structure makes them ideal for diverse applications, notably in drug delivery systems. Niosomes excel in encapsulating both hydrophilic and hydrophobic drugs, enhancing drug stability and bioavailability. They are adaptable for tailored drug release and have garnered interest across pharmaceuticals, cosmetics, and agriculture for their biocompatibility and versatile properties.

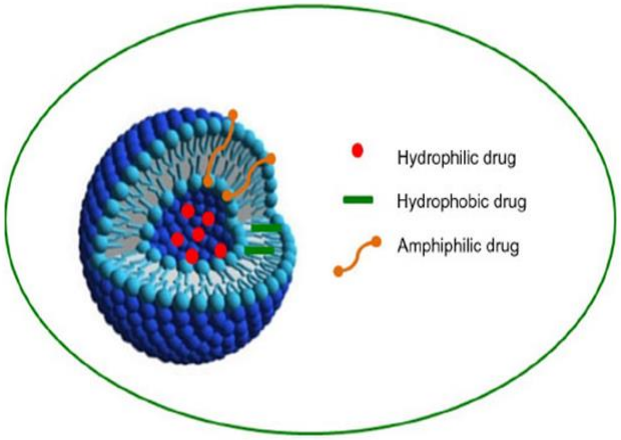

Fig. Structure of Neosome

🧪 Physicochemical Properties:

a. Surfactant-based vesicles

b. Biodegradable and non-toxic

c. Size: 100 nm to a few microns

d. High entrapment efficiency

🧫 Method of Preparation:

a. Thin film hydration

b. Ether injection method

c. Reverse phase evaporation

🌟 Advantages:

1. Cost-effective alternative to liposomes
2. Chemical stability
3. Better shelf life

⚠️ Disadvantages:

1. Less biocompatible than liposomes
2. Possible drug leakage
3. Scale-up challenges[13]

🧩 Phytosomes

Phytosomes are complexes of herbal extracts and phospholipids. They improve the absorption and bioavailability of poorly soluble herbal compounds like flavonoids and terpenoids.

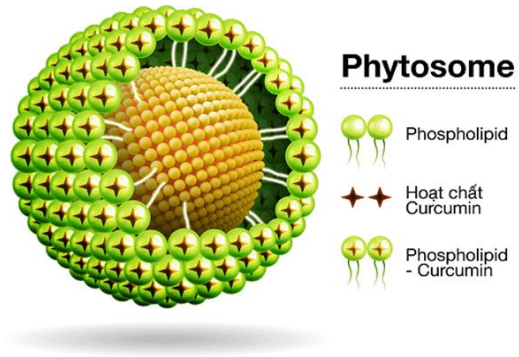

Fig. Phytosome

🧪 Physicochemical Properties:

a. Amphiphilic in nature (hydrophilic + lipophilic)

b. Better lipid solubility than plain extract

c. Enhanced membrane permeability

d. Stable complex with improved dissolution

🧫 Method of Preparation:

a. Mixing standardized herbal extract with phospholipids in an organic solvent (like ethanol).

b. Evaporating solvent to get a thin film.

c. Hydration of the film → forms phytosomal complex.

🌟 Advantages:

1. Enhanced oral absorption and bioavailability
2. Better therapeutic effect at lower doses Easy to formulate in capsules or tablets.

⚠️ Disadvantages:

1. Costlier than conventional extract
2. Requires specialized equipmentLimited stability if not stored properly.[14]

❖ Introduction of herbal excipients

Herbal excipients are natural substances derived from plants that are used in pharmaceutical formulations not for their therapeutic action, but to aid in the formulation, stability, delivery, or administration of the active pharmaceutical ingredients (APIs).Excipients are vital non-active ingredients in drug formulations, playing a significant role in achieving stability, bioavailability, and ease of administration. They are traditionally synthetic or semi-synthetic in nature. The use of herbal excipients derived from natural plant sources has been stimulated in recent years. Interests have shown an upsurge, driven by concerns over safety, biocompatibility, and environmental sustainability of synthetic excipients. The pharmaceutical industry's demand for more natural and green formulations also contributes to this trend.

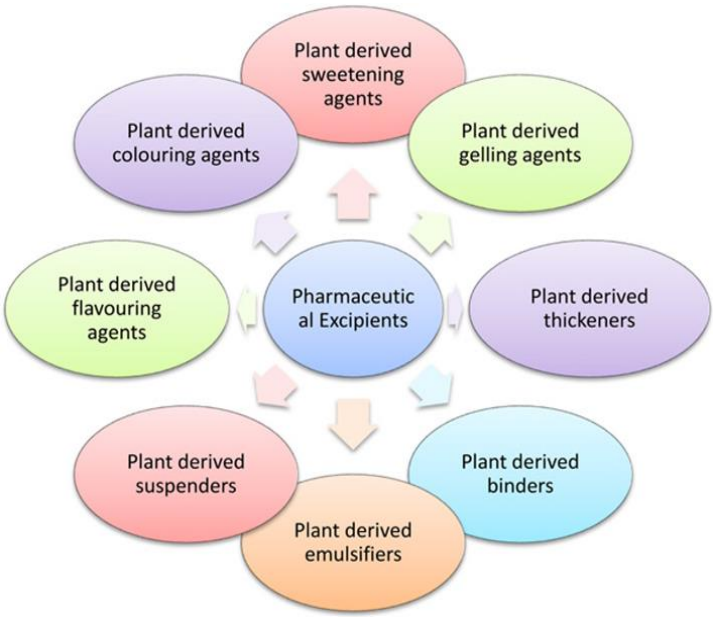

Fig. Types of Herbal Ecipients

➢ Classification of Herbal Excipients

Herbal excipients can be classified based on their functional roles in pharmaceutical formulations:

1. Binders

Used to hold the ingredients of a tablet together.

Examples: Acacia (Gum arabic), Tragacanth, Guargum, Starch (from maize, potato, etc.) Mucilage of Isapgol.

2. Diluents (Fillers)

Used to increase the bulk of a tablet or capsule so that the dose is easily handled.

Examples:Starch,Cellulose (Microcrystalline cellulose),Mannitol (from seaweed),Lactose (although not strictly herbal, some plant-based alternatives are used)

3. Disintegrants

Help break down tablets into smaller fragments in the digestive tract to ensure better absorption.

Examples:Plantago ovata (Isapgol husk),Starch,Alginates (from brown algae),Gum karaya

4. Lubricants

Reduce friction during tablet manufacturing.

Examples:Rice bran wax,Stearic acid (plant-derived),Hydrogenated castor oil

5. Glidants

Improve the flow of powder during tablet or capsule manufacturing.

Examples:Starch,Colloidal silica (from plant ash or silica-rich plants). [15]

6. Thickening / Suspending Agents

Used in liquid formulations to suspend insoluble particles.

Examples: Gumtragacanth, Xanthangum, Guargum, Pectin

7. Emulsifying Agents

Stabilize emulsions (oil and water mixtures).

Examples: Lecithin (from soy), Acacia, Pectin

8. Sweeteners / Flavoring Agents

Enhance the taste and palatability of formulations.

Examples:Liquorice(Glycyrrhizaglabra),Stevia,Honey,Menthol,Essentialoils (peppermint,orange, etc.)

9. Coloring Agents

Used to improve aesthetic appeal; often from plant pigments.

Examples: Curcumin (from turmeric), Chlorophyll (from green leaves),Beetroot red

Annatto (Bixaorellana)

10. Preservatives / Antioxidants

Prevent microbial growth or oxidation.

Examples: Neem (Azadirachtolides),Clove oil (Eugenol), Turmeric Rosemary extract (carnosic acid),Ascorbic acid (Vitamin C from citrus fruits)

❖ Difference between herbal excipients and synthetic excipients

Feature	Herbal Excipients	Synthetic Excipients

Origin	Natural (plant-based)	Man-made (chemical synthesis)
Biocompatibility	High	Variable
Toxicity	Low (mostly safe)	Potential for adverse effects
Cost	Lower	Higher
Availability	Easily available in nature	Depends on industrial production
Stability	Less stable, variable	More stable and uniform
Regulatory Status	Limited standardization	Well-established regulatory approval
Environmental Impact	Eco-friendly	May be harmful to environment

➢ **Advantages of Herbal Excipients**

🌿Natural & Biodegradable

🧬 Biocompatible & Non-toxic

💰Cost-effective.

🌎 Sustainable & Renewable

🛡 Safe for Long-term

🧪 Multifunctional Properties

📦 Availability

🌱Public Preference

➢ **Disadvantages of Herbal Excipients**

🦠 Batch-to-Batch Variability

🦠 Microbial Contamination

🦠 Limited Shelf Life .

📉Poor Flow and Compressibility

📊Lack of Standardization

Difficult to ensure uniformity in chemical composition without strict controls.

📜Regulatory Challenges

Not all herbal excipients are officially listed in pharmacopeias or approved by drug regulatory agencies.

🧪 Difficult to Purify Isolation and purification of some herbal excipients can be labor-intensive.[16]

📄•**Analytical Aspects of Novel Herbal Formulation**

1]Visualization: –Observing the physical appearance and structure of the formulation.

Method: -

a)Microscopy:– (SEM, TEM)

b) Spectroscopy

c)X-ray diffraction (XRD) etc.

2]Particle Size:–Measuring particle size and surface charge for stability studies.

Method:-

a)Dynamic Light Scattering (DLS)

b)Laser Diffraction

c)Microscopy etc.

3]Zeta Potential:-Indicates stability of colloidal dispersions.

Method:- Measured using a Zeta Potential Analyzer

4]Entrapment Efficiency:– Determining the amount of active ingredient entrapped in the formulation.Measures % of drug encapsulated in carriers like nanoparticles.

Method:-

a)Centrifugation

b)Ultrafiltration

5]Transition Temperature:– Studying thermal behavior and stability of the formulation.

Example-Gel to Sol Transition

Method:-Defferncial Scanning Colorimetry (DSC)

6]Vesicle Stability:–Evaluating stability over time under different conditions.

Method :-Monitored via size distribution and zeta potential.

In-vitro Drug Dissolvation Apparatus:–

Simulates drug release in conditions like stomach/intestine using a dissolution apparatus.

Method:-

a)USP Type I:-Basket apparatus

b)USP Type II:-Paddle apparatus

c)USP Type IV:-Flow-through cell (common for NDDS)

d)Franz diffusion cell:- For transdermal/nanocarrier studies

📜**~Excipient Compatibility Study:-**

✅ Purpose:-

•Ensure stability and efficacy of the drug.

•Select suitable excipients.

✅ Method:-Prepare binary mixtures (API + excipient).

~Spectroscopic AndChromatograpic Analysis:-

•Spectroscopic Analysis:-

Identifies and quantifies compounds by light–matter interaction (e.g., UV, IR, NMR, MS).

•Chromatographic Analysis:-

Separates and analyzes components in a mixture (e.g., TLC, HPLC, GC) Used for purity testing, identification, and quantification of drugs.[17]

🌿**Application of Novel Herbal Drug Delivery System: -**

1. **Application Of Novel Herbal Drug Delivery System for Diabetes: -**

1]Targeted Delivery: -

Herbal drugs can be delivered directly to pancreatic β-cells to improve insulin secretion.

2]Improved Bioavailability: - Novel systems like nanoparticles, liposomes, and transdermal patches increase absorption of herbal antidiabetic compounds (e.g., gymnemic acid, berberine).

3]Controlled Release: -

Sustained drug release helps maintain stable blood glucose levels for a longer period.

4]Reduced Side Effects: -

Targeted and controlled delivery minimizes gastrointestinal irritation and toxicity.

5]Enhanced Stability:

Protects sensitive herbal molecules from degradation, improving therapeutic effect.

6]Better Patient Compliance:

Easy-to-use formulations (patches, oral strips, gels) improve adherence to therapy.

- **Herbal Actives in NDDS For Diabetes: -**

1)Gymnemasylvestre – nanoparticle for better absorption

2)Fenugreek – sustained-release tablets

3)Curcumin – nanoformulation for insulin sensitivity

4)Bitter melon – oral controlled release system[18]

2. Application of Novel Herbal Drug Delivery System (NDDS) in Hepatoprotective Therapy: -

1]Targeted Liver Delivery – NDDS helps deliver herbal drugs directly to liver tissues.

2]Improved Bioavailability – Enhances absorption of poorly soluble hepatoprotective herbs.

3]Sustained& Controlled Release – Maintains constant drug level for better liver protection.

4] Reduced Side Effects – Lower dose needed due to targeted action.

5] Protection of Active Compounds – Prevents herbal actives from degradation in the GIT.

•Herbal Actives in NDDS For Hepatoprotective: –

1)Silymarin nanoparticles

2)curcumin liposomes

3) flavonoid phytosomes.

3. Application of Novel Herbal Drug Delivery System (NDDS) in Antioxidant Therapy: -

1. Enhanced Absorption – NDDS improves bioavailability of herbal antioxidants.

2. Controlled & Sustained Release – Provides long-lasting antioxidant effect.

3. Targeted Delivery – Delivers antioxidants to specific tissues or organs.

4. Protection from Degradation – Prevents oxidation and loss of herbal active compounds.

5. Reduced Dosage Frequency – Increases patient compliance and effectiveness.

•Herbal Actives in NDDS For Antioxidant therapy: -

1)Curcumin liposomes

2)Green tea catechin nanoparticles,

3)Resveratrol phytosomes.[19]

Importance of Targeted Herbal Drug Delivery in Cancer:-

🎯Site-Specific Delivery – Herbal anticancer agents are delivered directly to tumor cells, reducing harm to normal cells.

💊Enhanced Bioavailability – Many herbal compounds have poor solubility; targeted systems improve absorption and effectiveness.

📉Reduced Side Effects:– Lower toxicity compared to synthetic chemotherapy drugs.

🧠Controlled & Sustained Release – Ensures continuous therapeutic action at the cancer site.

🧍Improved Patient Compliance – Natural origin + targeted action leads to better tolerance.

🧪 Overcomes Limitations of Herbal Drugs – Protects herbal actives from degradation in the body.

4. Approaches of Targeted Herbal Drug Delivery in Cancer

1]Nanoparticle-Based Delivery:-

Herbal actives are encapsulated in polymeric or metallic nanoparticles.

Improves solubility, stability, and tumor targeting.

Example:-Curcumin nanoparticles for breast cancer.

2] Liposomes and Phytosomes:-

Lipid-based vesicles carry herbal drugs to tumor sites.

Enhance permeability and retention (EPR effect).

Example:-Liposomal delivery of paclitaxel (from Taxus plant).

3]Ligand-Mediated Targeting:-

Ligands (antibodies, sugars, peptides) guide herbal drug carriers to specific cancer cell receptors.

4]Magnetic Targeting:-

Magnetic nanoparticles loaded with herbal extracts can be directed to tumors using external magnetic fields.

5]Stimuli-Responsive Systems:-

Herbal drugs released at tumor site based on pH, temperature, or enzymes.Ensures controlled and targeted therapy.[20]

❖ Case Study: Curcumin-Loaded Nanoparticles for Cancer Treatment

Curcumin, the principal bioactive compound in Curcuma longa (turmeric), has been widely studied for its potent anticancer properties. However, its clinical application has been limited due to its poor bioavailability, rapid metabolism, and low solubility. To overcome these limitations, novel drug delivery systems (NDDS), such as nanoparticles, have been developed to enhance curcumin's effectiveness in cancer therapy.

Study Overview:

A notable case study investigates the development and evaluation of curcumin-loaded nanoparticles for the treatment of breast cancer. This case study specifically focuses on the polymeric nanoparticle formulation of curcumin, designed to overcome curcumin's bioavailability issues and enhance its therapeutic efficacy in targeted cancer treatment.

Objective:

i. Enhanced bioavailability and stability of curcumin.

ii. Targeted delivery to cancer cells.

iii. Improved anticancer activity with reduced systemic toxicity.

Formulation and Design of Curcumin-Loaded Nanoparticles:

Nanoparticle Carrier: The curcumin was encapsulated in PLGA (Poly(lactic-co-glycolic acid)) nanoparticles, a biodegradable and biocompatible polymer commonly used in drug

delivery systems Size and Surface Modification: The nanoparticles were designed to have a size range of 100-200 nm, an ideal range for tumor targeting through enhanced permeability and retention (EPR) effect. The surface of the nanoparticles was modified with PEG (polyethylene glycol) to enhance their circulation time and stability in the bloodstream [21]

CONCLUSION

In conclusion, the development of a novel herbal drug delivery system represents a significant advancement in the field of pharmaceutical formulations, particularly for enhancing the therapeutic efficacy and bioavailability of herbal medicines. Herbal drugs have long been recognized for their therapeutic potential, but their clinical use is often limited by challenges such as poor solubility, low bioavailability, and inconsistent pharmacokinetics. By utilizing advanced drug delivery systems, these limitations can be addressed, thereby maximizing the medicinal benefits of herbal formulations. The novel drug delivery system explored in this project has demonstrated the ability to improve the solubility, stability, and controlled release of herbal compounds, offering a promising solution for overcoming the traditional barriers associated with herbal medicine. Whether it is through nanotechnology. lipid-based vesicles (like liposomes or ethosomes), or other cutting-edge technologies, these systems allow for targeted delivery, enhanced absorption, and better therapeutic outcomes, all while minimizing potential side effects.[22]

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