NANOSUSPENSION: A NOVEL DOSAGE FORM FOR ENHANCING THE EFFICACY OF AYURVEDIC FORMULATIONS

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ABSTRACT

Ayurveda is a traditional Indian medical system provides formulations like Bhasma, Churna, Vati, Avaleha, medicated ghee, oils, and some fermented extracts like Asava or Arishta. Considering the good effect of formulations they are still having multiple issues like low water solubility, low oral bioavailability, instability, sterility and different quality aspects. Further it will results in international acceptability. The preparation of stable colloidal dispersions of drug particles at the nanoscale range is made possible by current developments in nanotechnology, especially nanosuspension technology, which offers a broad area around those limitations. If it is used in Ayurvedic formulations it will results in improvement of pharmacokinetic properties of ayurvedic formulation based nanosuspensions. Further it resulting in improved therapeutic effectiveness. Improvement in pharmacokinetics as well as targeted delivery and reducing dose are further made possible by the nano size, thus it also reduces systemic toxicity. The review focused on Bhasma, Churna, and Vati like formulations their formulation techniques and technical approaches for formulating nanosuspensions of traditional Ayurvedic medicines. It also discusses issues and safety concerns. Nanosuspension technology in ayurvedic medicines can be a future era towards increasing therapeutic efficacy and wider acceptance for patient in modern healthcare systems.

Keywords: Ayurvedic nanomedicine, Nanosuspension, Polyherbal, Bioavailability, Targeted drug delivery

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1. INTRODUCTION

The traditional Indian medical system named as Ayurveda, is called as one of the most useful and traditional system in the world. Ayurveda, focusing on basically three basic doshas—Pitta, Kapha, and Vata—which regulate both mental and physical processes of the body. Ayurveda underlines that illness results from an imbalance between these doshas, but a healthy balance between them promotes mental, spiritual and physical wellbeing for human. In order to prevent and treat these conditions, Ayurveda has developed over time to consider food advice, lifestyle counselling, therapeutic techniques, and a variety of pharmaceutical formulations for balanced lifestyle. Three types of medicines generally considered like herbal, mineral, and herbomineral medicines are included in its pharmacopoeia. These are further incorporated in a variety of forms, including powders (churna), decoctions (kwatha), tablets (vati), semi-solid pastes (avaleha), medicated ghee and oils (ghrita and taila), and calcined mineral preparations (bhasmas) [1].

Rasashastra is another filed which focuses on use of metals and minerals for therapeutic treatments. Raw metals and minerals undergo a multiple complex procedures that converts them into small, medicinally effective bhasmas, considering śodhana (purification), marana (calcination), and amritikarana (detoxification) [2]. These formulations are long lasting effective, even at minimum dosages and are consistently used in combination with herbal adjuvants to improve therapeutic results [2]. Ayurvedic medicines have been used for thousand years to treat systemic imbalances, inflammation, and chronic illnesses in many diseases. The exact techniques used in their manufacturing processes including consisting heating, levigation and meticulous involvement of herbal elements are also responsible for the preparation of high standard of medicines [2].

Ayurvedic formulations are facing many issues due to modern pharmaceutical needs and regulatory restrictions in india. Further poor water solubility which prevents solubility of active moiety in the gastrointestinal tract and leads to change in absorption further resulting in low oral bioavailability. This is one of the main drawbacks of traditional preparations [3]. Since many mineral-based medicines and herbal extracts contain active phytoconstituents or metallic compounds that are naturally hydrophobic, this is mostly difficult [3]. Furthermore, batch-to-batch difference is increase by the absence of accurate standardization and the tendency for traditional techniques to produce particles of different size. These issues may put risk of safety and decrease therapeutic results [4]. Also, large doses often required for traditional formulations can lead to issues with taste and patient compliance, as many powders and decoctions are bitter, have strong odors and hard to swallow. Additionally, issues about heavy metal contamination, poor purification processes, and toxicity present significant barriers to the broader acceptance of these medicines within modern healthcare system [5].

Nanotechnology has coming up with an innovative and supportive solution to reduce these limitations by improving the solubility, bioavailability, and stability of traditional medicines without compromising their therapeutic properties [6]. Considering various nanotechnological methods, nanosuspension technology has become specifically important for improving the delivery of drugs with low water solubility. Nanosuspensions are micron-sized colloidal dispersions, contains drug particles smaller than 1000 nm. The reduction in particle size may leads to

an increased surface area as well as better wettability for molecules which promote faster dissolution and improved pharmacokinetic properties [6,7]. There are many techniques such as high-pressure homogenization, wet milling and nanoprecipitation are commonly used to prepare these nanosuspensions, considering drug's physicochemical properties.

In Ayurvedic medicine, nanosuspensions underlines multiple advantages. In ayurvedic nanosuspension by reducing particle size it will help in enhancement of solubility further resulting in improved absorption and therapeutic effectiveness. These process reduce dose of a drug which will reduce side effects and improve patient compliance. For mineral as well as herbomineral formulations like bhasmas along with nanosuspension technology will build uniform particle size distribution and ultimately it allow for accurate dosing [7]. By preventing particle aggregation nanaosuspension can show physical stability as well as it will mask unpleasant taste. The benefits of such formulation with considering dosage forms facilitate combination of Ayurvedic medicines with available pharmaceutical standards and requirements.

Scientific studies have shown that traditional Rasashastra processes may have unintentionally prepared nanoparticles in last few centuries. Using advanced characterization methods such as scanning electron microscopy (SEM), transmission electron microscopy (TEM), X-ray diffraction (XRD), and Fourier-transform infrared spectroscopy (FTIR), researchers have found nanoscale aggregation within bhasma preparations. For instance, Lauha Bhasma has been found to contain iron oxide nanoparticles, while Abhraka Bhasma shown nanocrystalline structures [2, 8]. One structural analysis of Lauha Bhasma explored that after multiple rounds of classical heating–cooling, metallic iron converts to iron oxide (magnetite) in nanoparticulate aggregates, visible by SEM and XRD methods [8]. These studies highlights that although ancient practitioners lacked the modern terminology, their methods were capable of preparing therapeutically active nanostructures. By combining this age-old knowledge with current nanosuspension technologies will presents a unique opportunity to standardize, optimize, and scientifically validate Ayurvedic medicines for present time use.

Any ideal nanosuspensions for Ayurvedic formulations should have particle size below 500 nm. In addition to that, a zeta potential more than ±30 mV is required to provide electrostatic stabilization and prevent particle aggregation. These formulations has to maintain chemical stability in presence of herbal phytoconstituents and excipients. For the global acceptance of ayurvedic formulations it must be complies with international pharmacopeial standards, cost-effective, suitable shelf life and must align with AYUSH guidelines [6].

Multiple formulations have numerous bright benefits and difficulties, too. Nanosuspensions production needs special equipment and technical skills, such as high-pressure homogenizers, and milling equipment. The level of stabilization fails to be adequately stabilized since improper selection or concentration of surfactants may result in aggregation of the particles or additional reduction of the crystal in its effectiveness [7]. Also, scaling the process of manufacturing, keeping the size of the particles constant, and stabilized is intricate. Notable is that regulatory frameworks on herbal nanosuspensions are in their early stages of development and that long-term research on toxicity, stability and pharmacokinetics should be more significant to guarantee safety and warrant long-term usage [6].

There is a promising path of Ayurvedic tradition modernization through the nanosuspension technology. Nanosuspensions have demonstrated promise by enhancing solubility, bioavailability, physical stability, and adherence of patients as a way of mediating between the ancient knowledge and the contemporary pharmaceutical need. This new mixture can transform the process of delivery of herbal, mineral, and herbomineral medicines and make it safer, more efficient and acceptable all over the world. Therefore, the integration of the ancient knowledge and new nanotechnology is a new era in the progress of Ayurvedic medicine.

Besides, through green synthesis, which employs Ayurvedic herbs to produce biocompatible environmentally friendly and relevant nanomedicines. The future looks very bright with the use of hybrid formulations, which could involve traditional formulation of bhasmas, in conjunction with the use of modern nanotechnology. Taking into consideration that there have been rigorous scientific approvals and standardized regulatory guidelines, this convergence is open to immense possibilities of innovation in Ayurvedic therapeutics. Moreover, there is a necessity of nanosuspension in the modern world keeping the existing limitations in mind. This has been brought out in Table 1 taking into consideration the possible future dosage forms of ayurvedic formulations.

Table 1. Potential of Nanosuspension in Ayurvedic Formulations

Herbs / Bhasma	Current Limitation	Why Nanosuspension	Potential Future Dosage Form
Brahmi (Bacopa monnieri)	Poor water solubility, slow onset of cognitive benefits	Faster brain delivery, enhanced memory improvement	Brain-targeted oral nanosuspension, intranasal spray
Shankhpushpi (Convolvulus pluricaulis)	Low bioavailability, delayed neuroprotective effect	Increased absorption, quicker action	Pediatric oral drops, cognitive booster drink
Bhumyamalaki (Phyllanthus niruri)	Limited systemic absorption for liver disorders	Enhanced hepatoprotective activity	Oral nanosuspension syrup for liver health
Swarna Bhasma (Gold Ash)	Variable particle size, inconsistent absorption	Uniform nano-size better bioavailability, reduced dose	Nano-gold suspension for immunity, neuroprotection
Abhrak Bhasma (Mica Ash)	Delayed absorption, high doses required	Nanosizing may allow micro-dosing	Respiratory health tonic in nanosuspension
Guduchi + Ashwagandha (Polyherbal)	Synergistic effect but poor solubility of actives	Single nanosuspension with enhanced bioavailability	Immunity-boosting drink, oral suspension

1.1 TYPES OF AYURVEDIC FORMULATIONS AND THEIR POTENTIAL FOR NANOSUSPENSION

1.1.1 BHASMA (CALCINED MINERAL AND METALLIC PREPARATIONS)

Traditionally made by repeatedly purifying metals or minerals (śodhana) and calcining them (marana), which results in fine ashes that have therapeutic potency. Despite being naturally nano- or submicron-sized, pharmacokinetics and therapeutic consistency may be jeopardized by particle aggregation and size fluctuation. Agglomeration is still a major problem, despite the confirmation of nanoscale sizes in bhasmas like Swarna Bhasma and Rajata Bhasma by sophisticated analytical techniques like Transmission Electron Microscopy (TEM) and Dynamic Light Scattering (DLS) [1]. Utilizing stabilizers such as polyvinyl alcohol (PVA) or Tween 80 in nanosuspension formulations decreases aggregation, increases solubility, and boosts bioavailability [6]. Additionally, consistent dispersion, repeatable dosage, and improved stability over time are guaranteed by nanosuspensions. Because of the metallic content, toxicological

evaluation with ICP-MS or AAS is necessary to ensure patient safety and regulatory compliance [11].

1.1.2 CHURNA (POWDERED HERBAL PREPARATIONS)

Prepared using dry plant materials, often containing phytoconstituents, like flavonoids, alkaloids and curcumin, which are insoluble in water. Churna nanosizing enhances the rate of wettability and dissolution which in turn enhances absorption across gastrointestinal membranes [10]. Removes batch to batch variation and provides accurate dosing through standardization of heterogeneous powders. Enhances the systemic availability and bioefficacy of herbal actives, therefore, enhancing pharmacological efficacy.

1.1.3 GHRITA AND TAILA (MEDICATED OILS AND GHEE)

Active ingredients are often limited to the lipophilic matrix of lipid-based semi-solids that are applied topically and orally. Examples of lipid nanosuspensions include solid lipid nanoparticles (SLNs) and nanostructured lipid carriers (NLCs). Lipid nanosuspensions are created in order to enhance solubility, membrane permeability and protect sensitive phytoconstituents against oxidative degradation [11-12]. Enhances stability of shelf life, oral and topical absorption and ensures consistent therapeutic outcomes.

1.1.4 ASAVA AND ARISHTA (FERMENTED DECOCTIONS)

Counterproductive to Hydroalcoholic solutions that can be used to extract bioactives is the variability in batches and unstable chemical compositions. The stability, homogeneity, and repeatability of these preparations are improved by the inclusion in nanoencapsulation or nanosuspension that maintains their bioactive efficacy throughout the time.

1.1.5 AVALEHA AND RASAYANA FORMULATIONS (HERBAL PASTES/CONFECTIONS)

Viscous formulations that are usually semi-solid and mixed with sugar, ghee or honey; this may result in unequal dosing and release. Nanosuspension also enhances the overall bioavailability in addition to enhancing solubility, reduction of dose variability, and stabilization of phytoconstituents. Upholds medicinal purity and converts traditional viscous pastes to the more standardized and easier to use dosage forms. [10]. Nanosuspension can address the limitations of ayurvedic dosage form listed in Table 2 by different ways.

Table 2. Role of Nanosuspension in overcoming Limitations of Ayurvedic Dosage Forms

Category	Examples	Challenges	Nanosuspension Potential
Herbal	Churna, Kwatha, Vati, Avaleha	Poor solubility, slow dissolution, taste issue	Enhanced solubility, faster onset, improved patient compliance
Mineral	Lauha Bhasma, Abhraka Bhasma	Particle size variability, absorption inconsistency	Uniform nanosizing, predictable pharmacokinetics
Herbo-mineral	Rasa Aushadhi. Swarnabhasma	Risk of overdose, safety concerns	Controlled release, dose precision., reduced toxicity

1.2 APPLICATIONS OF NANOSUSPENSION IN AYURVEDA

Introducing nanosuspension technology into Ayurvedic medicine would transform the global homogeneity of conventional formulations, distribution of drugs, efficacy of therapy and patient compliance significantly. One can also transform phytoconstituents that have low solubility into highly accessible forms, in other words, by reducing their particle size to the nanoscale scale without compromising the holistic nature of Ayurvedic treatments. The development provides an opportunity to modernize the traditional treatments and maintain their historical benefits.

The increase in solubility and dissolution rate is among the major benefits of nanosuspensions. The pyytoconstituents that are not highly soluble in water in the traditional Ayurvedic powder and extracts are able to be more wettable and dispersible once they are turned into nanoparticles. The outcomes of this increase in surface area are a faster increase in activity and enhanced contact with biological membranes which accelerates breakdown and promotes efficient absorption at gastrointestinal and mucosal surfaces [9]. Consequently, one of the most important limitations of conventional preparations can be overcome and the medicinal potential of plant actives can be used to the full.

The administration of nanosuspension is also a major improvement in bioavailability and therapeutic outcome. The lipophilic and hydrophilic both bioactive compounds are able to be internalized and widely distributed systemically upon the entire body by the boosting of permeability and dissolution of nanosized preparations. This permits increased plasma concentrations, increased duration of therapeutic effect and faster pharmacological interactions at lower dosages. The nanosuspensions have a higher pharmacokinetics, thus resulting in better clinical outcomes in enhancing performance of Ayurvedic ingredients therapeutic properties [9, 10].

The ayurveda nanosuspensions play a crucial role in adding value to dosage reduction and improved patient compliance, improved absorption and prolonged circulation reduces the occurrence of adverse reactions through demonstrating similar and desirable therapeutic effects using reduced dosages. Besides changing the traditional powders or pills into liquid nanosuspensions improves palatability, this is of especial benefit to patients who are dysphagic, elderly or juvenile. These aspects lead to increased adherence to chronic treatment regimens by patients [11].

The positive effects of the usage of ayurvedic nanosuspensions are standardization and consistency of the formulations. The parameters that can be reflectively controlled include particle size, Polydispersity index and surface charge which minimizes the variation between batches which is repetitively observed in conventional Ayurvedic medicines. Such technical accuracy increases dependability in treatment outcomes, dose consistency and all. Drugs that are based on herb minerals or metals, in such instances the safety and effectiveness is highly founded with uniform particle size, this aspect needs to be taken into consideration [13]. The adaptability is another interesting aspect of administration approaches. Nanosuspensions make it convenient to develop different dosage formulations such as oral liquids, topical gels, nasal sprays, Transdermal patches, ophthalmic formulations, pulmonary aerosols and inject able solutions. This flexibility provides extensive room to therapeutic application of Ayurvedic drugs not in the normal traditional oral or topical preparations but in specific administration to select organs or tissues. In essence, nanosuspensions have been utilized effectively in treating a broad range of disorders in a number of body systems, which include respiratory, gastrointestinal, cardiovascular, and dermatological issues [14].

Ayurvedic nanosuspension strategy makes positive contributions to the formulation stability and shelf life. The biological and physical stability of sensitive bioactive molecules is maintained through the prevention of oxidation, hydrolysis, and aggregation

with the aid of using appropriate surfactants, controlled particle size, and encapsulation methods. Appropriate physical stability ensures the maintenance of the pharmaceutical potency during the entire storage by minimizing precipitation and phase separation based on time phase [13,15].

Use of Ayurvedic drugs is also more acceptable because it is safer to patient than the conventional. Conventional recipes are able to remain loyal to the global thresholds of pharmaceutical quality, like ICH and GMP standards, through incorporating the latest nanotechnology novel solutions. The guarantee of the scientific and regulatory arena is being ensured by day by day through the sustenance of the standard measure and reporting of such parameters as particle size, zeta potential, dissolution rate, mutagenicity, bioavailability in vivo. This evidence-based modernity makes Ayurvedic medicines usable in a broadly globally acceptable and marketable way.Traditional Ayurvedic formulations' pharmacokinetic profile, therapeutic efficacy, and pharmaceutical quality are all noticeably improved nanosuspension technology. Herbal, mineral, and herbo-mineral compounds can be delivered in a targeted, regulated, and repeatable manner by using a variety of illness management areas and administration routes. This approch guarantees both safety and efficacy while opening the door for the worldwide integration of traditional ayurvedic treatments along with traditional Ayurveda with contemporary nanomedicine system [16].

1.3 DRUG SELECTION CRITERIA IN AYURVEDIC NANOSUSPENSIONS

While preparing nanosuspensions for Ayurvedic targeted delivery formulations requires careful drug selection and proper formulation strategies to overcome challenges such as poor solubility, low bioavailability, and variability in raw materials. Ideal and potent candidate for nanosuspension should have low water solubility, stability under processing conditions, and therapeutic significance needs to consider. Drugs candidate with smaller to moderate molecular weight, stability in physiological pH, and compatibility with herbal or mineral matrices are particularly suitable. Along with partially ionized compounds that can cross mucosal or gastrointestinal barriers are suitable to enhance optimal absorption and bioavailability.

Formulation strategies consider under main three methods: top-down, bottom-up, and hybrid methods. In top-down method is reduce coarse particles to nanoscale sizes by mechanical forces. High-pressure homogenization and media or wet milling are mainly work for herbal powders and mineral-based bhasmas. Such methods are highly reproducible, scalable, and appropriate for materials which having poor solubility otherwise it will difficult to process uniformly and smoothly.

In respect with bottom-up approaches directly produce nanoparticles, and prepare molecular solutions, which allow a direct control of the particle size and purity. The process known as antisolvent precipitation consists of dissolving the drug in a solvent system and quickly precipitating it by the addition of a nonsolvent to create homogenized particles of nanosized size. These particles are again stabilized by controlled crystallization and size distribution is reduced. Such perspectives are beneficial to delicate phytochemicals which are likely to be destroyed by mechanical forces.

Combination or hybrid approaches provides the advantages of both approaches. Nanoedging or Smart Crystal methods do not involve combining nanoparticles as they are initially produced by first precipitation followed by homogenizing to refine and stabilize nanoparticles. This manifests in the smaller, more consistent particles which are more stable and therefore very convenient to Ayurvedic drugs, they are primarily characterized by natural variability in raw materials. Stabilizers are complicated to stabilize long-term nanosuspension. To achieve balance between values of tradition and modern value, natural stabilizers, including gum acacia, mucilage, starch, guar gum, and alginate are preferred in Ayurveda. Artificial stabilizers like hydroxypropyl methylcellulose (HPMC), polyvinylpyrrolidone (PVP), poloxamers, and Tween 80 increase stability, prevent aggregation and extend shelf-life. Proper drug choice ensure redispersion, increased activity and consistency between manufacturing batches.

Based on final designs, nanosuspensions onces incorporated into multi-purpose drug delivery system, as lipid-based carriers (solid lipid nanoparticles, nanostructured lipid carriers) of lipophilic herbal actives, or polymeric carriers (chitosan, PLGA) of controlled release system. Such field allow the traditional Ayurvedic medicine delivery methods to be consistent with modern pharmaceutical practice. It took into account the production at an industrial level, optimization of processes is important. Milling duration, homogenization pressure, stabilizer concentration, and temperature are some of the parameters that should be well managed to balance the reproducibility, consistency of particle size, desirable zeta potential, and stability of the suspension in the long term. The choice of appropriate required drug candidates with good solubility, stability, and therapeutic activity, in combination with the improved strategy of particle reduction, stabilization, and administration, underlies the creation of Ayurvedic nanosuspensions. This novel technology enhances the effectiveness, stability and international acceptability of the conventional herbal and mineral drugs.

1.4 EXCIPIENTS

In ayurvedic nanosuspensions it is formulated with a careful selection of excipients, which are necessary to maintaining repeatability, improving bioavailability, and stabilizing the active potent component. Stabilizers and surfactants are the main groups of excipients because they control particle aggregation and preserve a smooth desired distribution of nanosize. It maintain traditional orignal values, steric stabilization, and redispersion upon shaking, Ayurvedic formulations mainly choose natural stabilizers including gum acacia, mucilage, starch, guar gum, and alginate. Artifically produced stabilizers, such as Tween 80, poloxamers, polyvinylpyrrolidone (PVP), and hydroxypropyl methylcellulose (HPMC), are commonly used to improve long-term stability, regulate surface charge, and lower the chance of particle aggregation, especially for metallic and herbomineral bhasmas [1,16].

Solvents and cosolvents are equally important in nanosuspension. The common dispersing medium is water, in consider with cosolvents such as ethanol, glycerin, or propylene glycol aid in the dissolution of lipophilic herbal actives and improve wettability. This makes it simplier to generate stable nanosized suspensions and guarantees uniform desired dispersion. Viscosity modifiers like methylcellulose and xanthan gum are used to reduce sedimentation and make suspension handling easier. Such polymers preserve and maintain the rheological characteristics of the ayurvedic suspension, guaranteeing even dosage and easy administration [6]. To prevent microbiological contamination during storage, preservatives are necessary for aqueous nanosuspensions. The use of synthetic agents such as potassium sorbate or sodium benzoate, as well as natural antibacterial extracts, can prolong shelf life and ensure safety. In same way, to maintain the chemical stability of delicate phytoconstituents and metallic particles, buffers and pH modifiers—such as citrate or phosphate buffers—are useful to stop oxidation or degradation. To conform biocompatibility and patient compliance, osmotic agents like sorbitol and mannitol change tonicity in specific formulations like injectables or ocular nanosuspensions [6, 17].

Lipid-based or polymeric carriers, like solid lipid nanoparticles (SLNs), nanostructured lipid carriers (NLCs), chitosan, or PLGA, may also be incorporated into advanced ayurvedic nanosuspensions in order to focus on certain tissues or organs, allow for regulated release, and safeguard delicate herbal contents. Such carriers improve the pharmacokinetic parameters, stability, and absorption of nanosuspensions, hence increasing their therapeutic efficacy [18]. All the ayurvedic nanosuspensions are safe, effective, repeatable, and patient-friendly because of

proper blending of stabilizers, solvents, viscosity modifiers, preservatives, buffers, osmotic agents, and carriers all while maintaining the holistic tenets of conventional medicine system [1,6]. Ayurvedic nanosuspenion formulations will be formulated by using various excipient. All the excipients are listed in Table 3.

Table 3. Functional Excipients for Ayurvedic Nanosuspension Formulations

Excipient Type	Examples	Role in Ayurvedic Nanosuspension
Stabilizers/Surfactants	Gum acacia, HPMC, PVP, Poloxamers, Tween 80	Prevent aggregation, stabilize nanosized particles, ensure reproducibility
Solvents/Cosolvents	Water, ethanol, glycerin	Solubilize herbal/mineral actives, improve wettability and dispersion
Viscosity Modifiers	Methylcellulose, xanthan gum	Control sedimentation, facilitate handling and dosing
Preservatives	Sodium benzoate, potassium sorbate	Prevent microbial contamination, ensure shelf-life
Buffers/pH Modifiers	Citrate, phosphate buffers	Maintain stability, prevent degradation of active constituents
Osmotic Agents	Sorbitol, mannitol	Adjust tonicity in parenteral or ocular forms for biocompatibility

2. MANUFACTURING OF NANOSUSPENSIONS FOR AYURVEDIC FORMULATION

The production of nanosuspensions for Ayurvedic formulations requires a technical strategy that combines modern nanotechnology with traditional expertise to improve the stability, solubility, and bioavailability of medications derived from minerals and herbs. Top-down, bottom-up, and hybrid approaches are the broad categories into which the preparation methods can be divided; each has unique benefits and factors to take into account [6, 10]. Formulation strategies for the nanosuspension are highlighted in below Figure 1.

2.1 TOP-DOWN METHODS

Top-down methods use mechanical techniques to reduce larger particles to nanoscale levels. These techniques work especially well for materials that are difficult to convert into homogeneous solutions, such as mineral-based Bhasmas and herbal powders [10, 16].

High-pressure homogenization

This method breaks down the drug dispersion into nanoparticles by applying high pressure and forcing it through a small opening. It is scalable and suitable for industrial applications. Research has demonstrated its effectiveness in creating nanosuspensions with controlled particle sizes [6, 19].

Wet milling

This approach uses high-energy milling beads to apply shear and impact forces to drug particles suspended in a liquid medium. It is simple, reproducible, and scalable—ideal for increasing production volume in Ayurvedic nanosuspensions [6, 18].

Medium milling

Similar to wet milling, medium milling employs a milling chamber filled with grinding media. It is commonly used in pharmaceutical industries for producing stable nanosuspensions of phytoconstituents or minerals [6, 19].

2.2 BOTTOM-UP METHODS

By assembling nanoparticles from molecular precursors, bottom-up methods provide more control over particle size and purity, making them especially suitable for thermo labile herbal actives [6, 20].

Antisolvent Precipitation

In this method, the active compound is first dissolved in a suitable solvent and then added to a nonsolvent to induce supersaturation, resulting in nanoparticle formation. It is energy-efficient and ideal for poorly soluble phytoconstituents [18, 19].

Solvent evaporation

This technique forms nanoparticles by evaporating the solvent in which the active compound is dissolved, often yielding uniform particles. It is suitable for formulating hydrophobic herbal actives and integrating them into delivery systems like SLNs or NLCs [20].

Supercritical fluid technology

By considering supercritical fluids like CO2 under controlled conditions which for mild processing and production of nanoparticles without thermal degradation of sensitive herbal constituents [21].

2.3 HYBRID METHODS

Hybrid method combine both top-down and bottom-up techniques to level up the benefits of each while combining for their individual limitations which lacking [10, 16].

Precipitation–high pressure homogenization

It is two-step technique initiate along nanoparticle precipitation, given by size refinement by high-pressure homogenization, it show in more uniform; convenient and stable nanosuspensions form [19, 20].

Co-grinding

This step shows, the potent drug is ground together with stabilizing excipients to produce nanoparticles. It is a solvent-free, measurable technique appropriate for both herbal powders and mineral-based preparations like Bhasmas [21].

3. EVALUATION TECHNIQUES

A prime step is characterization of nanosuspensions considering stability, safety and therapeutic efficacy of nanosuspensions, especially when such are used in Ayurvedic formulations. Such a critical evaluation would ensure that transformation of traditional drugs into nanoscale delivery systems does not render the possible results at the expense of originality.

3.1 PARTICLE SIZE AND SIZE DISTRIBUTION

Particle size and distribution are generally ascertained using methods as Dynamic Light Scattering (DLS) and Laser Diffraction. While Laser Diffraction show a more thorough examination of the size distribution in suspensions, DLS gives information on mean particle size and polydispersity index (PDI). A uniformly tiny particle size improves the solubility and dissolution of poorly soluble Ayurvedic bioactives and give in their desired absorption [23].

3.2 ZETA POTENTIAL ANALYSIS

The physical stability is monitored through the measurement of zeta potential that indicates the surface charge of nanoparticles. In order to maintain Ayurvedic nanosuspensions longer, repulsion among the particles which are based on charge repulsion is signified by large positive or negative values of the zeta potential. To predict long-term stability, it is difficult to use this characteristic [24].

3.3 MORPHOLOGY AND SURFACE ANALYSIS

Investigating the size, shape and surface structure of the particles, advanced imaging methods such as Atomic Force Microscopy (AFM), Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM) are employed. The evaluation techniques provide graphical authentication of nanoscale characteristics and dwell on imperfections on the surface that might influence the rate of drug release and dissolution of herbal source [25].

3.4 CRYSTALLINITY AND PHYSICAL STATE

X-ray diffraction (XRD) analysis provides a nanoparticle with a crystalline or amorphous structure, and in between, the phase changes and thermal conduct of a material is provided by differential scanning calorimetry (DSC). This kind of properties is necessary in Ayurvedic nanosuspensions where crystalline forms can influence stability and solubility and amorphous states can influence to dissolution [26].

3.5 SOLUBILITY AND DISSOLUTION STUDIES

This method which examines the solubility and dissolution rate of the nanosuspensions demonstrate that they are better than conventional herbal preparations. Decreasing particle size to the nanoscale to which it will be accomplished, enhances the scale over which herbal moieties with low solubility to dissolve will have to be increased to cause them to become more bioavailable in medicine [23, 26].

3.6 STABILITY STUDIES

Through testing evaluations parameters such as physical, chemical, and microbiological integrity of nanosuspensions, stability testing under various environmental factors (temperature, humidity and light) are also realised. These parameter evaluation will demonstrate that Ayurvedic nanosuspensions can still maintain therapeutic effects of a longer duration [24, 25].

3.7 FOURIER TRANSFORM INFRARED SPECTROSCOPY (FTIR)

Using FTIR, chemical reactions between stabilizer that is used in nanosuspensions and Ayurvedic effective active ingredients are identified. The methodlogy of formulation does not impair the molecular integrity of the herbal compound according to the compatibility testing [26].

3.8 IN-VITRO BIOAVAILABILITY AND RELEASE STUDIES

Evaluations like diffusion cells or dialysis bags where the release profile of a drug is evaluated. These statistics can guarantee that, in parallel to more traditional Ayurvedic dose preparations, nanosuspensions enhance medication activity and bioavailability, which subsequently can be accepted with enhanced clinical effectiveness [23, 26].

4. SAFETY AND TOXICOLOGY

The high solubility and bioavailability of nanosuspension of Ayurvedic medicine leads to high therapeutic efficacy. However, with the reduction of the nanoscale, conventional formulations lose their safety would also be of concern. The toxicological assessments should be done to ensure that these nanoformulations meet the modern scientific standards with references to safety provisions produced by the traditional Ayurveda.

Bhasma-based nanosuspensions

4.1.1 METAL SPECIATION AND CHARACTERIZATION

Metal ions produced by Ayurvedic metallic/mineral treatments, so-called Bhasma formulations, it modified by nanosizing them compared with the bulk models. Recent methods of analysis such as X-ray fluorescence (XRF), atomic absorption spectroscopy (AAS), and inductively coupled plasma mass spectrometry (ICP-MS) are hence pivotal in the accurate determination of the metal levels and establishment of the chemical forms involved. This ensures the safety profile of the formulation since the presence of toxic units of metals will not arise during the preparation of the nanoparticles [15, 23,24].

4.1.2 SYSTEMIC TOXICITY

The nanoparticles work well in accumulating in other complicated organs such as liver, kidneys, spleen, and the brain due to the fact that they might be absorbed and dispersed easily to the other parts of the body. In order to identify any toxic effects, in-depth in vivo studies of these organs are needed which are supported by clinical chemistry analysis of indicators of organ operationality [25].

Oxidative stress and immunotoxicity

Metal-based nanoparticles have the potential to produce reactive oxygen species (ROS), it is produced during inflammation and oxidative stress. In order to test the risk of the inflammatory or allergic response, the immunotoxicity tests assessing the response of the immune system, including the production of cytokines and indicators of oxidative stress, including superoxide dismutase (SOD) and catalase, are complex [26].

Herbal nanosuspensions

4.2.1 CYTOTOXICITY AND GENOTOXICITY

Herbal extracts are able to modify the way they interact with cells and DNA because they are nanosized. The safety is determined by in vitro tests like the Micronucleus test (chromosomal damage), Comet assay (DNA strand breaks), the LDH release (cell membrane integrity), and the MTT (cell viability) tests. These tests are useful in the exclusion of genotoxic effects or cell toxicity that can compromise safety [23, 27, and 30].

4.2.2 HEMOCOMPATIBILITY

It is vital to ensure that nanosuspensions do not damage the blood components. To avoid the adverse hematological effects, hemolysis tests and coagulation tests are conducted to ensure that these formulations do not destroy red blood cells or disrupt the blood clotting process [23, 28].

4.2.3 MICROBIAL SAFETY AND ALLERGENICITY

Sterilization and quality control measures should be done strictly to minimize microbial contamination. Moreover, allergenicity testing ensures that nanosuspensions will not produce allergic or hypersensitive reactions once they are injected [25, 29].

5. DISCUSSION

There are strengths and weaknesses associated with nanosuspension technology on Ayurvedic preparations. The reason why bhasma is a good candidate to be dispersed by nanosuspension is that the bhasma traditionally is believed to be having a very fine particle size which is better dispersed by nanosuspension which has less aggregation as well as might be better directed therapeutically. However, the metallic characteristics of Bhasma also suggest the formation of high-level toxicological testing, i.e. metal speciation, and long-term safety studies. Churna and Vati are predominantly herberbic and suffer the issue of low aqueous solubility of phytoconstituents, such as flavonoids, alkaloids and terpenes. Nanosuspension offers scientifically proven way of increasing the rate of dissolution, absorption and bioavailability. This comes into play in reducing the dose of therapy, quality control and removing the variability which are still thorns in the flesh in the old fashioned powder and tablet dosing agents. Ghrita, Taila, Asava, Arishta, and Avaleha it have potential through the traditional ayurvedic dosage forms. Their complicated polyherbal properties create formulation and stability difficulties, and the selected nanosuspension systems can partially address them by stabilizing delicate molecules and providing a uniform distribution of bioactives. Meanwhile, the use of nanosuspension should be done

with consideration of Ayurvedic philosophy of synergy in whole and without excessive reductionist emphasis on principal actives. The most important thing that Ayurvedic nanosuspensions demand is that strict quality control, preclinical safety review, and adherence to the current international regulations are all necessary. In the meantime that nanotechnology is able to produce Ayurveda and make it more credible throughout the world, balance needs to be taken between the old and the new technology. With regard to safety, or the failure to consider the holistic points of Ayurveda, it may accorded the approbation of these ingenious targeted nanosuspension in ayurveda.

6. CONCLUSION

The Ayurveda nanosuspension technology provides additional room to develop as far as research is concerned and clinical usage is concerned. A significant field in the formulation of polyherbal nanosuspensions, has been the case where more than one herb can be combined without interfering with the natural origninal synergy of the herb. The other important measure of transitioning between the experimental and preclinical phases and highly designed clinical trials, which will demonstrate satisfactory, therapeutic outcome and suitable dosage, was taken. The new approaches such as ligand -decorated Nanosuspension can enable the treatment of particular organs and tissues with ayurvedic agents because the delivery will be more accurate. Meanwhile, the fact that green nanao technology is involved, and that a stabilizer is used that is environmentally safe also indicates the main idea of Ayurveda. Individualized practices, in which nanosuspensions are taken into consideration based on an individual prakruti and disease profile which are new thrilling opportunities. It will be necessary to further entrench a clear regulatory framework in cooperation with international standards to guarantee quality, standardization and international appreciation of ayurvedic nanomedicines. The integration of nanosuspension based formulations as adjuvant or adjunctive therapy with the traditional allopathic drugs. This may be establish a link between old and new in the field of healthcare.

Author contribution

Swapnil Patil: Conceptualization and supervision, Aishwarya Jadhav: Preparation, data compilation, literature, Shivam Patil: data compilation, literature, Anuja Gaikwad: writing original draft, formatting, Prakash Nargatti: Manuscript editing, and formatting

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