Journal of Neonatal Surgery
ISSN(Online): 2226-0439
Vol. 14, Issue 28s (2025)
https://www.jneonatalsurg.com

OPEN ACCESS

A Comprehensive Review on Solid Lipid Nanoparticle Using Herbal Plant Extract

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Cite this paper as: Himanshu Adhikari, Manoj Bhardwaj, Manoj Bisht, Shalini Rawat, (2025) A Comprehensive Review on Solid Lipid Nanoparticle Using Herbal Plant Extract, *Journal of Neonatal Surgery*, 14 (28s), 872-882

ABSTRACT

Drug delivery systems have seen a revolution because to nanotechnology, which provides precise, regulated, and targeted treatment solutions with the fewest possible negative effects. This study examines several nanocarriers that are essential for improving medication efficacy, such as dendrimers, liposomes, solid lipid nanoparticles (SLNs), nanoparticles, nanosuspensions, and polymeric nanoparticles. SLNs provide a better option than the others because of their physiological lipid content, which reduces toxicity and maximizes medication absorption. Solvent evaporation, emulsification-diffusion, polymerization, and ultrasonication are some of the preparation techniques that guarantee the structural soundness and functional effectiveness of SLNs. Their flexibility in pharmaceuticals is demonstrated by their broad variety of uses, which include oral, parenteral, transdermal, topical, and cosmetic formulations. Additionally, extracts from ashwagandha, eugenol, neem, aloe vera, and curcumin have been shown to have improved bioavailability and therapeutic efficacy in herbal-loaded SLNs, especially in anti-inflammatory, antibacterial, antioxidant, and anti-tumor therapies. The stability and effectiveness of SLN are continuously being improved by formulation technology innovations, despite obstacles such burst drug release and fast systemic clearance. This research demonstrates the enormous potential of medication delivery powered by nanotechnology in improving contemporary medical treatments and offering creative ways for improved therapeutic results

Keywords: *Nanotechnology, Drug Delivery Systems, Solid Lipid Nanoparticles, Nanocarriers, Controlled Release, Bioavailability*

1. INTRODUCTION

With the profound knowledge acquired in the various sectors of biotechnology, biomedical engineering, and nanotechnology, the field of novel drug delivery systems is developing at an exponential rate [1] Nanotechnology, or the creation of nanosized objects containing the AP, is used in many of the most modern formulation techniques [2]. According to the National Nanotechnology Initiative (NNI), nanotechnology is the study and application of structures that are approximately between 1 and 100 nm in size. The general objective of nanotechnology is the same as that of medicine: to use a controlled and targeted medication delivery technique to diagnose as correctly and early as possible and to cure as effectively as possible without causing any side effects [3] . Nanoparticles, Solid Lipid Nanoparticles, Nanosuspension, Nanoemulsion, and Nanocrystals are a few of the significant Drug Delivery Systems created utilizing nanotechnology concepts [4].

1.1 Types of Nanotechnology in Drug Delivery Systems

1. **Nanosuspension**: Nanosuspension is the term used to describe a suspension of drug nanoparticles in a liquid. The size of nanoparticles ranges from 200 to 500 nm, and the remarkable characteristic of nanosuspension are the compound's enhanced solubility, saturation, and rate of dissolution. [5], Another characteristic of nanosuspension is its ability to alter the crystalline structure, raise the percentage of amorphous particles, or even produce entirely amorphous particles. Increased tissue adhesion is demonstrated by nanoparticles and nanosuspensions [6].
2. **Solid lipid nanoparticles**: Dispersed in water or an aqueous surfactant solution, the solid lipid nanoparticles are submicron colloidal carriers (50–1,000 nm) made of physiological lipid. To get over the drawbacks of oil droplets in their liquid state, liquid lipid was substituted with solid lipid, which finally turned into solid lipid nanoparticles [7].
3. **Liposomes**: liposomes are a effective way in biochemistry, biology, and medication. Small, synthetic, spherical vesicles known as liposomes can be created from cholesterol and naturally occurring, non-toxic phospholipids. Spherical carrier with a phospholipid bilayer help to encapsulated drug and better their delivery. Liposomes can fuse with cell

4. membranes, releasing their payload directly into the target cells [8].
5. **Polymeric nanoparticles**: The medication dissolves, becomes stuck, absorbs, attaches itself to, or is encased in the matrix of nanoparticles. The qualities and release characteristics of encapsulated medicinal agents can vary depending on the preparation procedure used to create nanoparticles, nanospheres, or nanocapsules.In contrast to nanospheres, which are matrix systems where the drug is evenly and physically distributed, nanoparticles are vesicular systems where the drug is contained within a cavity encircled by special polymer membranes. The two primary characteristics of nanoparticles are what make them advantageous for medication delivery.First, due to their small size, nanoparticles can enter narrower capillaries and be absorbed by cells, enabling effective drug accumulation at the intended locations. Second, the production of nanoparticles using biodegradable materials permits prolonged drug release within the periods of day or week [9].
6. **Dendrimers:** its regulated polymerisation that results in a highly branched, virtually monodisperse polymer system with three primary components: the core, branch, and surface extended circulation, regulated bioactive delivery, macrophage-specific bioactive delivery, and liver targeting [10].

1.2. SOLID LIPID NANOPARTICLES

SLNs, or solid lipid nanoparticles. A superior and substitute for conventional colloidal carriers such emulsions, liposomes, and polymeric micro and nanoparticles, SLNs were first introduced in 1991 [11].

In contrast to other colloidal carriers, SLNs use solid lipid in place of liquid lipid. Lipid pellets for oral medication delivery have made the use of solid lipid as a matrix material for drug delivery widely known [12].Triglycerides, partial glycerides, fatty acids, hard fats, and waxes are all included in the broad definition of the term "lipid." The fact that the lipid matrix of SLN is composed of physiological lipids, which lowers the risk of acute and chronic toxicity, is an obvious benefit [13].

It has been demonstrated that using solid-lipid rather than liquid-lipid improves the stability of added chemically sensitive lipophilic components and increases control over the release kinetics of encapsulated API. Numerous physicochemical properties connected to the physical state of the lipid phase are responsible for these potentially advantageous effects. First, the pace of chemical degradation reactions

may be slowed down because reactive chemicals have less mobility in solid matrices than in liquid ones. Second, the carrier lipid and active compounds' microphase separations is done by controlling individual liquid particles, the buildup of active chemicals at the lipid surface can be avoided.. Several studies have also state that using a solid matrix instead of liquid one might slow down lipid breakdown, enabling a longer-lasting release of the encapsulated chemical [14].

High pressure homogenisation or microemulsification are the primary methods used to make SLNs. Any technique can produce SLNs in dispersion form, which becomes unstable over time due primarily to hydrolysis reactions. To improve their stability, lyophilization can be used to turn them into solid dry reconstitutable powders; spray drying is an inexpensive and simple alternative to lyophilization [15].

1.3. Merits and Demerits of solid Lipid Nanoparticles

1.3.1. Merits

1. Improving oral bioavailability [16].
2. Cutting down on the liver's first-pass metabolism [17].
3. P-glycoprotein efflux pumps are passed [18].
4. Controlled and sustained drug release [19].
5. Low dose due to improve physicochemical properties of drug.

1.3.2. Demerits

1. Burst drug release from these nanocarriers may induce toxic effects [20].
2. Rapid clearance of IV administered drug-loaded SLNs from systemic circulation [21].
3. Their small particle size makes them unsuitable for deep lung distribution; instead, they should be encapsulated in lipid microparticles. [22].

1.4. Excipients used in solid lipid nanoparticles preparation:

1.4.1. Lipids -Triglycerides, Tricaprin, Trilaurin, Acyl glycerols, Glyceryl monostearate , Waxes, Fatty Acids, Stearic acid.

1.4.2. Surfactants- Phospholipids- Soy lecithin, Egg lecithin, Phosphatidylcholine.

Ethylene oxide- Poloxamer 188, Poloxamer 182, Poloxamer 407, Poloxamine 908 .

Sorbitan ethylene oxide- Tween80,60

Bile salts- Sodium cholate, Sodium glycocholate, Sodium taurocholate, Sodium

taurodeoxycholate.

1.4.3. **Alcohols**-Ethanol, Butyl-alcohol, Butyric

Monooctylphosphoric acid sodium.[23,24]

2. PREPARATION METHODS OF SLNS

2.1 Solvent Evaporation Method: This method involves two steps:

The polymer solution is first emulsified into an aqueous phase, and then the polymer solvent evaporates, causing the polymer to precipitate as nanospheres**.**

First dissolved the drug in an organic solvent, To create anoil in water (o/w) emulsion, this aqueous solution comprises an emulsifying agent or surfactant. [25].

High-speed homogenisation or ultrasonication are frequently used to create particles with a small size [26]. After being recovered by ultracentrifugation, the nanoparticles are lyophilised for storage and cleaned with distilled water to get rid of any remaining stabilizer residue or free medication [27] .This method's modifications are referred to as high pressure emulsification and solvent evaporation method [28] .This technique entails creating an emulsion, homogenising it under high pressure, and then swirling it thoroughly to get rid of the organic solvent [29].

2.2 Emulsification or Solvent Diffusion Method:

This technique was developed from the solvent evaporation method [30], which uses an oil phase consisting of a water-miscible solvent and a tiny amount of an organic solvent (water immiscible). An interfacial turbulence is created during the spontaneous diffusion of solvents between the two phases, which may eventually result in the creation of tiny particles. Increasing the concentration of a water-miscible solvent can result in smaller particle sizes. Drugs that are hydrophilic or hydrophobic can be treated with this technique. When a medication is hydrophilic, it must dissolve in the internal aqueous phase to generate a multiple w/o/w emulsion.

2.3 Double Emulsion and Evaporation Method:-

Poor entrapment of hydrophilic medicines is a short coming of the majority of emulsion and evaporation-based techniques. Thus, the double emulsion technique—which entails adding aqueous drug solutions to organic polymer solutions while vigorously swirling to create w/o emulsions—is used to encapsulate hydrophilic drugs. To create the w/o/w emulsion, this w/o emulsion is continuously stirred when introduced to the second aqueous phase. The emulsion is then exposed to evaporation to remove the solvent, and high-speed centrifugation can be used to separate the nanoparticles. Prior to lyophilization, the generated nanoparticles need to be properly cleaned [31]. The variables influencing this approach include the volume of the aqueous phase, the concentration of the polymer, the amount of hydrophilic drug to be added, and the concentration of stabiliser utilised.

2.4 Emulsions-Diffusion Method:

To guarantee the initial thermodynamic equilibrium of both liquids, the encapsulating polymer is dissolved in a solvent that is somewhat water-miscible (such as propylene carbonate or benzyl alcohol) and then saturated with water. Following the emulsification of the polymer-water saturated solvent phase in an aqueous solution containing stabiliser, the solvent diffuses to the exterior phase and, depending on the oil-to-polymer ratio, forms nanospheres or nanocapsules. Lastly, depending on its boiling point, the solvent is removed by evaporation or filtration [32].

2.5 Polymerization Method:

Using this technique, monomers are polymerised to create nanoparticles in an aqueous solution. Drugs are integrated into polymerisation at two distinct stages: either by dissolving in the polymerisation solution or by adhering to the nanoparticles once the polymerisation process is finished [33][34].

2.6 Ultrasonication:

Melted lipids are dispersed into tiny droplets in a continuous phase by ultrasonication. This process is quick, easy, and effective in producing SLNs without the use of organic solvents. However, it is sometimes hampered by the presence of microparticles and has the drawback of requiring an extra filtration step of the prepared SLN emulsion to remove contaminants like metal produced by ultrasonication [35]. This method's concept is to use sound waves to decrease particle size [36]. As mentioned below in **Fig-1**.

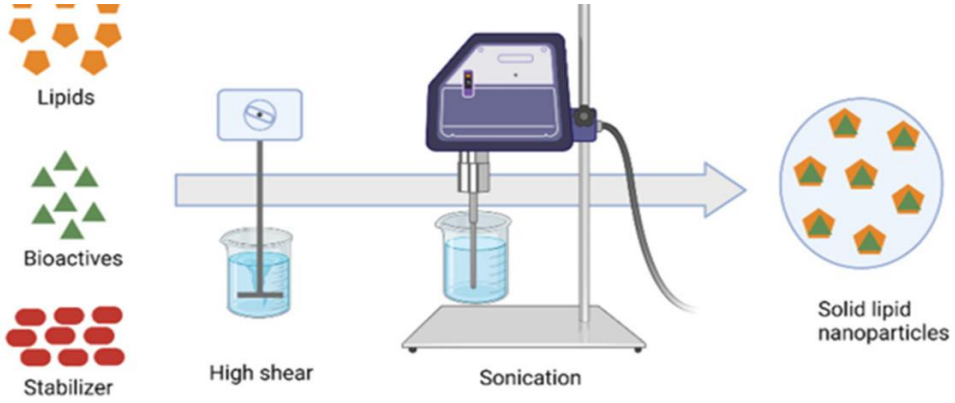

Fig.1:- Diagramatic representation of Ultrasonication

Preparation of SLN using the sonication technique. This method creates emulsions with smaller droplets by melting the lipids and then using a probe sonicator to sonicate the aqueous phase containing surfactants. The production of the SLNs dispersions is done by the emulsion slowly cooling down the temperature to obtain solidifying the nanoparticles[37].

3. APPLICATION OF SLNS

3.1 Pre oral administration

SLN-loaded old dosage forms, such as tablets, pellets, or capsules are part of pre oral administration forms of SLN. The stomach's high ionic strength and acidity create a microenvironment that encourages particle agglomeration. It is reasonable to assume that eating will significantly affect SLN performance [11].

3.2 Parenteral administration

Intravenous injection in rats, doxorubicin integrated into SLN demonstrated greater blood levels than a commercial drug solution, according to pharmacokinetic studies. In terms of bodily distribution, it was discovered that SLN increased drug concentrations in the brain, spleen, and lung, whereas the solution caused a distribution that was more concentrated in the liver and kidneys. For SLN, parenteral application is a fairly broad range [11].

3.3 Transdermal application

The SLN dispersions with the lowest lipid content t the smallest particle sizes. For cutaneous administration, the decrease viscosity and small concentration of the dispersed . To create a formulation that can be applied to the skin, the SLN dispersion must typically be incorporated into an ointment or gel.

A further decrease in the lipid content is implied by the integration stage. Semesolid, gel-like systems are produced when the solid lipid content of the SLN dispersion is increased; these systems may be suitable for direct skin application [38].

3.4 Cosmetic application

Lipid nanoparticle-containing face cosmetics can also be created. They provide a smooth matt finish, conceal flaws, add new colour, and enhance colouring consistency. Given the significant aesthetic value of the face and the fact that it is the single body part most exposed to climate change, protection is very necessary.

SLNs and NLCs can be used to develop cleansing creams, which are oil-miscible treatments that are helpful in removing makeup remnants without the energetic degreasing that may come from using soap and water. Lipid nanoparticles stick to the skin to protect it, while the aqueous portion of the dispersion possesses surfactant qualities to remove makeup [39].

3.5.Topical administration

Topical application presents little challenges in terms of regularity. The main benefits of topical products are the occlusion effect brought on by film formation on the skin and the protective qualities of SLN against degradation of chemically labile medications. Many substances, particularly in the cosmetics industry, such vitamin C and retinol, cannot be used due to their poor chemical stability. Retinol can only be incorporated when specific protective measures are used during manufacture (such as noble gasing) and when specific packing materials are used [40].

4. SLNS WITH HERBAL PLANT:-

4.1 Curcumin

By encasing curcumin in lipid matrix, SLNs improve its solubility and prevent degradation, hence increasing its

bioavailability. SLNs loaded with curcumin exhibit enhanced stability and regulated release, which makes them useful for anti-inflammatory and anti-cancer applications. They also show improved therapeutic effectiveness and cellular absorption. Research indicates that they may be used to treat a range of malignancies and inflammatory conditions. Ultrasonication and high-pressure homogenization are two methods used in the encapsulation process [41].

4.2 Eugenol

Its stability and regulated release are improved by eugenol-loaded SLNs, which also strengthen its antibacterial and anti-inflammatory qualities. Eugenol is shielded from oxidation and destruction by these nanoparticles. They effectively decrease inflammation and specified bacterial infections. Eugenol's ability to enter deeper tissues is likewise improved by SLNs. For the best encapsulation, emulsification techniques are used in the preparation [42].

4.3 Holoptelea integrifolia

SLNs loaded with an extract from this plant exhibit prolonged drug release and improved antifungal efficacy. The bioavailability of its active ingredients is enhanced by these nanoparticles. They work very well against *Candida albicans* and other fungal infections. Long-lasting therapeutic effects are guaranteed by the encapsulation procedure. Research indicates that they may be used to treat infections and skin conditions [43].

4.4 Malva sylvestris

also known as mallow, By encasing the plant's medicinal ingredients, SLNs enhance its therapeutic potential for the treatment of cancer. The stability and bioavailability of its phytochemicals are improved by these nanoparticles. They have anti-inflammatory and antioxidant qualities. Additionally, SLNs offer regulated release, guaranteeing long-lasting therapeutic benefits. Advanced nanotechnology techniques are used in the preparation process [44][45][46].

4.5 Punica granatum

[Pomegranate]**:** SLNs improve pomegranate extracts' antioxidant qualities, increasing their efficacy in cosmetic products. The stability and bioavailability of its polyphenols are enhanced by these nanoparticles. They have anti-inflammatory and anti-cancer qualities. Because of their controlled release, SLNs guarantee long-lasting therapeutic benefits. Hot homogenization and ultrasonication procedures are used in the preparation [47].

4.6.Azadirachta indica

SLNs enhance the transport of neem extracts for antibacterial and anti-inflammatory applications. The stability and bioavailability of its active ingredients are improved by these nanoparticles. They work well against parasitic and bacterial illnesses. Additionally, SLNs offer regulated release, guaranteeing long-lasting therapeutic benefits. Techniques for homogenization and emulsification are used in the preparation [48].

4.7.Aloe barbadensis Miller

SLNs improve the bioactive chemicals in aloe vera's stability and absorption, which promotes wound healing. The phytochemicals' bioavailability is enhanced by these nanoparticles. They have anti-inflammatory and antioxidant qualities. further, SLNs offer regulated release, confirming long durable therapeutic benefits. Microemulsification techniques has been helping the encapsulation process [49][50].

4.8.Withania somnifera

ashwagandha is a well-known adaptogenic herb that is used extensively for its immunomodulatory, neuroprotective, and anti-stress effects. Its bioactive components, including withanolides, show improved stability and bioavailability when added to SLNs. With their regulated release, SLNs guarantee enhanced cellular absorption and long-lasting therapeutic benefits. These nanoparticles hold great promise for use in cancer treatment, neurological diseases, and stress management. Ashwagandha-loaded SLNs are prepared using methods such as emulsification and high-pressure homogenization [51].

4.9.***Phyllanthus emblica L***.

For thousands of years, Tibetans have utilised Phyllanthus emblica L., a traditional medicinal herb, in therapeutic settings. Phyllanthi Tannin-SLNs greatly increased . Phyllanthi Tannin water solubility while enabling high drug incorporation. Desired physicochemical characteristics, such as favourable control effect of in vitro drug release and good physical stability with small particle size, were demonstrated by the characterisation results of Phyllanthi Tannin -SLNs. According to the pharmacodynamics of both in vitro and in vivo investigations, . Phyllanthi Tannin -SLNs demonstrated a more potent anti-tumor impact. As versatile nanomedicines for a range of drug delivery strategies, solid lipid nanoparticles have gained popularity. The thin-film hydration technique has been effectively used to create PTF-SLNs, which improve lung cancer treatment outcomes. SLNs improve its bioavailability, Its active extracts' high tannin and polyphenol content has anti-tumor, anti-inflammatory, antibacterial, antiviral, and other properties, according to current pharmacological study. [52].

4.10.Calendula officinalis

Carotenoids (β-carotene, γ-carotene, lycopene, flavoxanthin, lutein, and rubixanthin) and faradiol make up the majority of the active component in calendula officinalis L., a medicinal plant. A natural substance used in ocular formulations for its anti-inflammatory, emollient, and wound-repairing properties, calendula officinalis extract, was added to the mixture. Loading capacity and entrapment efficiency were assessed by characterising calendula-loaded SLN formulations. A safe and solvent-free calendula extract administration method, the SLN formulation may offer a regulated treatment option for lowering symptoms of illness and enhancing ocular surface epithelium restoration [53]

4.11.Talinum portulacifolium

The pharmacological action and many biological activities of Talinum portulacifolium (Forssk.), a well-known traditional medicinal herb, include lowering blood glucose, serum lipids, and antioxidant enzymes. At a dosage of 250 mg/kg body weight, the ethanolic extract of Talinum portulacifolium (Forssk.) and Nano formulation SLN shown notable antidiabetic action in Streptozotocin and high-fat diet-induced Rats with diabetes. SLNs of Talinum help to reduce increase blood glucose with better bioavailability amd its antidiabetic property. It has been applied to the treatment of diabetes. When combined with young stem sections, Talinum portulacifolium leaves can be consumed fresh in salads or cooked. 500 species make up the genus Talinum , an inhibitor of the onset and advancement of potential cardiovascular problems in diabetes mellitus. Furthermore, flavonoids and tannins, the plant's active ingredients, may be responsible for the anti-diabetic effect [54].

4.12. Annona muricata

In vitro models of breast cancer are used to investigate the cytotoxic potential of solid lipid nanoparticles (SLNs) loaded with Annona muricata fruit extract. Extract-loaded SLNs were effectively made using the ultrasonication method after high-pressure homogenisation. A member of the Annonaceae family, Annona muricata has been used in traditional medicine to cure a number of illnesses, such as bacterial, viral, and cancerous infections. Alkaloids, flavonoids, lactones, anthraquinones, cardiac glucosides, phenols, phytosterols, and acetogenin substances have been discovered from studies on the chemical components of the leaves and seeds. Acetogenins work particularly well against cancer because they prevent the high energy demand of cancer cells from receiving adenosine triphosphate (ATP), which disrupts the mitochondrial electron transport mechanism and causes apoptosis [55].

4.13. Kaempferia parviflora

Traditional folk medicine has utilised Kaempferia parviflora (KP), a herbaceous plant of the Zingiberaceae family, to cure and prevent a variety of ailments. According to reports, KP's crude extracts exhibit anti-inflammatory, antimicrobial/antiviral, anti-mutagenic, anti-oxidative, and estrogenic-like properties. SLNs were synthesised using extracts of Kaempferia parviflora to betterment their ermeability. There has been a lot of interest in formulating herbal health products with a better of quality control using KP rhizomes. Flavonoid derivatives were found as the 1st ingredients contributing to the biological activities observed in KP rhizomes after the chemical constituents of these plants were recently identified [56].

4.14. Matricaria chamomilla

The study demonstrated the critical function that solid lipid nanoparticles play in enhancing chamomile oil's ability to pass through biological barriers and, consequently, speeding up the rate of wound healing activity. Their improved re-epithelialization grade, greater collagen deposition, improved skin architecture, increased tensile strength, and improved wound area contraction all served to validate this.The heat homogenisation process was used to create solid lipid nanoparticles of CM . In short, stearic acid lipid phases with varying CM ratios were heated to 60 °C. An aqueous phase heated at the same temperature that contains 5%w/w Tween 80 Because of its anti-inflammatory, antibacterial, antioxidant, and anti-irritating properties as well as its beneficial occlusive effect through its function as a skin protective barrier, chamomile oil (CM) is one of the most widely utilised herbs [57].

4.15. Prunus persica (L.)

leaf extract in ethanol is used to prepare cosmeceutical anti-aging and skin-whitening creams that are put into solid lipid nanoparticles (SLNs) to improve skin delivery. Polyphenols are well-known antioxidants found in food. Recently, there has been a lot of interest in their potential applications to stop skin ageing and hyperpigmentation brought on by UV radiation from the sun. Because of their high polyphenol content, Prunus persica(L.) leaves, which are regarded as by- products, have been shown to have extraordinary antioxidant exertion. A chemical analysis of PPEE revealed a notably high amount of flavonoids and total phenolics with considerable antioxidant properties. There have been reports of in- vitro antiwrinkle and skin- decolorizing activators and in- vivo defensive conditioning against UV- convinced photoaging in PP seeds, fruits, flowers, and other species [58].

5. CHARACTERIZATION OF SLNS

Its quality control requires that the SLNs be adequately and correctly characterised. However, the complexity and dynamic nature of the delivery mechanism, as well as the colloidal size of the particles, make characterising SLN a significant

difficulty. Particle size, size distribution kinetics (zeta potential), degree of crystallintity and lipid modification (polymorphism), coexistence of other colloidal structures (miscelles, liposomes, super cooled melts, drug nanoparticles), time scale of distribution processes, drug content, in-vitro drug release, and surface morphology are among the crucial parameters assessed for the SLNs [59].

5.1 Particle size

There are several methods for studying nanoparticle size, including as tracking analysis, dynamic light scattering, and microscopy.

5.2 Microscopy

• Transmission electron microscopy (TEM): A fundamental technique that generates pictures of nanoparticles for the purpose of determining their size and distribution Analysing the size, shape, and surface of nanoparticles is done via scanning electron microscopy (SEM).

• STM [Scanning tunneling microscopy]: A technique for examining the size, shape, and surface of nanoparticles.

5.3.Zeta potential

Zeta potential can be measured with a zetameter or a zeta potential analyser. SLN dispersions are diluted 50 times using the original dispersion preparation media prior to measurement in order to determine their size and evaluate their zeta potential Advanced zeta eventuality values, in the absence of other complicating rudiments like hydrophilic face accessories or steric stabilisers, may beget patches to deaggregate. Predictions regarding the storage stability of colloidal dispersions are made possible by zeta potential measurements [60].

5.4. Electron microscopy

Direct observation of nanoparticles is possible by transmission electron microscopy (TEM) and scanning electron microscopy (SEM). However, SEM performs better in morphological analysis. The size limit of detection with TEM is tiny [61].

5.5.Atomic force microscopy (AFM)

This method creates a topological map based on the forces acting between the probe tip and the surface by rastering a probe tip with atomic scale sharpness across a sample. To differentiate between the various sub-techniques, the precise type of force used determines whether the probe is dragged across the sample (contact mode) or left hovering slightly above it (non-contact mode). Together with the capability to map a sample based on characteristics other than size, such as colloidal attraction or resistance to deformation, this method allows for ultrahigh resolution, which makes AFM a useful tool [62].

5.6.Fourier Transform Infrared Spectroscopy

By directly placing the snap- dried phrasings onto the vertical ATR accessory's demitasse, a Spectrum Two PE instrument fitted with the universal ATR accessory(UATR, Single Reflection Diamond/ ZnSe) was used to assay pure accoutrements and SLN samples. [63].

5.7. Differential scanning calorimetry (DSC)

To ascertain the degree of crystallinity of the particle dispersion, DSC and powder X-ray diffractometry (PXRD) are used. The melting enthalpy/g of the dispersion and the melting enthalpy/g of the bulk material are compared to estimate the rate of crystallinity using DSC [64].

5.8.Drug entrapment

After the aqueous dispersion is centrifuged, the spectrophotometric technique is used to estimate the entrapment efficiency (EE). To put it briefly, the amount of integrated drug was calculated by subtracting the amount of free drug from the amount of drug that was discovered in the supernatant[6

5.9.TGA

Temperature-dependent physical and chemical changes of the nanoparticles were measured using thermogravimetric analysis (TGA). A sample of PQ-free medication, empty nanoparticles, and drug-loaded nanoparticles were heated at a rate of 10°C per minute and linked to an inert nitrogen gas flow for analysis[66].

6. CONCLUSION

Significant improvements in drug delivery systems have been made possible by nanotechnology, which guarantees controlled, targeted, and prolonged medication release with few adverse effects. Since solid lipid nanoparticles (SLNs) have a physiological lipid content that improves bioavailability, stability, and absorption, they have become one of the most successful and adaptable drug delivery systems among other nanocarriers. Solvent evaporation, emulsification-diffusion,

polymerization, and ultrasonication are some of the advanced preparation methods used by SLNs to create structurally optimized formulations for use in pharmaceutical and cosmetic applications. These nanoparticles provide regulated drug release, less toxicity, and enhanced therapeutic results, therefore circumventing the constraints of conventional formulation. The widespread use of SLNs in topical, oral, parenteral, transdermal, and cosmetic formulations highlights their importance in contemporary medicine. Their therapeutic efficacy in anti-inflammatory, antibacterial, antioxidant, and anti-tumor therapies has been further increased by their capacity to encapsulate herbal extracts, such as curcumin, eugenol, neem, aloe vera, and ashwagandha. These herbal-loaded SLNs show improved bioavailability and sustained drug release, which makes them attractive options for sustainable and natural treatment modalities.

Notwithstanding their outstanding benefits, SLNs have drawbacks, including formulation stability, burst drug release, and quick systemic elimination. Further investigation into targeted delivery methods, drug encapsulation effectiveness, and nanoparticle optimization will be essential to improving SLN applications. SLNs have the potential to revolutionize pharmaceutical strategy by providing more effective, accessible, and patient-friendly drug delivery methods thanks to advancements in nanotechnology. With precision-driven nanotechnology solutions, SLNs have the potential to transform treatment methods and influence the direction of medicine and cosmetics as science develops.

Acknowledgement

The authors express their gratitude towards Head and Faculty members and research scholars of Department of Pharmacy, Devsthali Vidyapeeth College of Pharmacy, Lalpur Rudrapur , Uttarakhand, India, for providing research environment and all necessary facility for conducting research.

Author Contributions:- Conceptualization, H.A., and M.B., **Validation**, H.A, M.B., **Investigation**: H.A., M.B, M.B R**esources**, M.B., H.A, S.R **Data Curation;** H.A, and M.B,. **Writing—original draft preparation;** H.A, S.R **Review and Editing, and Visualization;** H.A.; **Supervision;** M.B., All the authors read and approved the final version of the manuscript. No paper mill and artificial intelligence was used for preparation of this manuscript.

Statements and declarations:-

No potential conflict of interest was reported by the author(s) and ethics approval and consent to participate Not applicable.

Named funding statement

The author(s) did not receive any potential funding for their review project work.

Conflict of Interest

The authors declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent

This article does not contain any studies with human or animal subjects performed by any of the authors

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