

# Formulation And Characterization of Solid Lipid Nanoparticles Loaded with *Dioscorea Bulbifera* Extract for Enhanced Bioavailability

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## ABSTRACT

The present study aimed to formulate and characterize solid lipid nanoparticles (SLNs) loaded with *Dioscorea bulbifera* fruit extract to enhance its bioavailability, stability, and antimicrobial efficacy. Fruit of *Dioscorea bulbifera* were subjected to methanolic and petroleum ether extraction to obtain polar and non-polar phytoconstituents. The methanolic extract exhibited a higher yield (5.0%) compared to petroleum ether extract (3.27%), indicating the predominance of polar bioactive compounds. Phytochemical investigations confirmed the presence of flavonoids, phenolics, saponins, glycosides, and alkaloids, with significant phenolic (55.3 mg/g gallic acid equivalent) and flavonoid content (53.1 mg/g rutin equivalent), supporting its antioxidant and antimicrobial potential. The methanolic extract was successfully encapsulated into SLNs using suitable lipids and surfactants. Characterization studies revealed a homogeneous milky suspension with off-white to light brown appearance and faint odor. Among the developed formulations, batch F5 showed the smallest particle size (151.00 nm) and highest negative zeta potential (-42.9 mV), indicating excellent colloidal stability. Scanning electron microscopy confirmed spherical morphology. Antimicrobial evaluation demonstrated enhanced, concentration-dependent activity of F5 SLNs against *Escherichia coli* and *Staphylococcus aureus* compared to the crude extract. Stability studies conducted for 90 days under room temperature (25 °C) and accelerated conditions (40 °C) showed no significant changes in physical appearance, particle size, or formulation integrity. Overall, the study highlights SLNs as a promising nanocarrier system for improving the bioavailability, stability, and therapeutic performance of *Dioscorea bulbifera* fruit extract.

**Key words:** *Dioscorea bulbifera*, Solid Lipid Nanoparticles (SLNs), Phytochemical Analysis, Antimicrobial Activity, Stability Studies.

## I. INTRODUCTION

Solid lipid nanoparticles (SLNs) represent a promising drug delivery system composed of active drug molecules, solid lipids, surfactants, and/or co-surfactants. These nanoparticles can be safely formulated for diverse routes of administration, including oral, injectable, and topical applications (ScioliMontoto *et al.*, 2020). The scope of SLN applications is extensive, offering the potential to enhance the treatment of various diseases through judicious physicochemical modifications. Their versatility extends to loading both lipophilic and hydrophilic drugs, thereby improving the drug characteristics, extending action duration, and prolonging drug release profiles (Tan *et al.*, 2017). Consequently, this enables a reduction in administration frequency while concurrently enhancing therapeutic efficacy. Beyond their ability to enhance drug oral bioavailability and sustain drug release, the heightened precision of drug targeting is a paramount advantage of SLNs when compared to conventional delivery methods (Zhao *et al.*, 2022).

*Dioscorea bulbifera*, commonly known as air potato, is a medicinal plant widely used in traditional medicine for its anti-inflammatory, antimicrobial, antioxidant, and anticancer properties (Narzary *et al.*, 2025). The bioactive constituents present in *Dioscorea bulbifera* extract, such as flavonoids, saponins, and phenolic compounds, contribute to its therapeutic potential. Despite these benefits, the clinical application of this extract is hindered by poor solubility, low permeability, and rapid metabolism, leading to reduced bioavailability. Incorporating *Dioscorea bulbifera* extract into solid lipid nanoparticles presents a novel approach to overcome these limitations (Yadav *et al.*,

2024). SLNs can encapsulate the bioactive compounds within a lipid matrix, thereby protecting them from degradation, enhancing their solubility, and improving their absorption across biological membranes. Additionally, the small particle size of SLNs increases surface area, promoting better interaction with biological tissues and facilitating controlled drug release. This ultimately leads to improved therapeutic efficacy and reduced dosing frequency (Son *et al.*, 2017).

The formulation of SLNs involves the selection of suitable lipids, surfactants, and preparation methods such as high-shear homogenization, ultrasonication, solvent evaporation, or microemulsion techniques. Optimization of formulation parameters is essential to achieve desired characteristics such as small particle size, uniform distribution, high drug loading, and physical stability (Khairnaret *et al.*, 2022).

Characterization of SLNs is a critical step in evaluating their performance and suitability for pharmaceutical use (Kathe *et al.*, 2014). Important parameters include particle size and polydispersity index (PDI), zeta potential, surface morphology using scanning electron microscopy (SEM) or transmission electron microscopy (TEM), drug content, entrapment efficiency, in vitro drug release profile, and stability studies under various environmental conditions. These evaluations provide valuable insight into the formulation's behavior, stability, and drug delivery efficiency (Danaei *et al.*, 2018).

Overall, the formulation and characterization of solid lipid nanoparticles loaded with *Dioscorea bulbifera* extract represent a promising strategy to enhance its bioavailability and therapeutic effectiveness. This approach integrates the benefits of herbal medicine with modern nanotechnology, offering a potential pathway for the development of safe, stable, and efficient drug delivery systems.

## II. MATERIAL AND METHODS

### 2.1 Chemicals

*Dioscorea bulbifera* extract was procured from Authenticated herbal source. Stearic Acid, Ethanol, Methanol and Phosphate buffer (pH 7.4) was received from Merck. Tween 80 (Polysorbate 80) was acquired from Sigma-Aldrich while, Methyl paraben was sourced from HiMedia Laboratories. Distilled water obtained from Laboratory grade. All other solvents, Chemicals and reagents used were of analytical (AR) grade and purchased from

Balrampur Chini Mills, and Shree Bajrang Chemicals.

### 2.2 Plant Material Collection

The plant material of *Dioscorea bulbifera* was collected from a suitable habitat during its optimal season, and healthy, disease-free parts were selected. The material was washed, shade-dried at room temperature, and then coarsely powdered using a mechanical grinder. The powder was sieved for uniformity and stored in airtight containers for further extraction and formulation studies.

### 2.3 Plant Material Extraction process

The powdered plant material of *Dioscorea bulbifera* was subjected to successive solvent extraction to obtain the bioactive constituents. About 400 g of the coarsely powdered plant material was placed in a clean Soxhlet apparatus.

#### 1. Petroleum Ether Extraction:

Petroleum ether was used first to remove non-polar constituents such as fats, waxes, and oils. The plant material was extracted with petroleum ether at a temperature of 40–60 °C for 6–8 hours until the solvent in the siphon tube became colorless. The extract was filtered through Whatman No. 1 filter paper and concentrated under reduced pressure using a rotary evaporator. The petroleum ether extract was collected and stored in an airtight container for further studies.

#### 2. Methanol Extraction:

The residue obtained after petroleum ether extraction was dried and then subjected to methanol extraction to obtain polar bioactive compounds such as alkaloids, glycosides, flavonoids, and phenolics. Methanol was used in a Soxhlet apparatus at 55–60 °C for 8–10 hours. After extraction, the methanol extract was filtered, concentrated under reduced pressure using a rotary evaporator, and stored in an airtight container at 4 °C until further use (Krawowska-Sieprawska *et al.*, 2022).

This successive extraction method ensured maximum recovery of phytoconstituents from the plant material, separating non-polar and polar compounds effectively for formulation and characterization studies.

Weighing dried extract and extract's % yield was computed using formula that follows:

$$\% \text{ Yield} = \frac{\text{Weight of extract}}{\text{Weight of Plant Material used}} \times 100$$

### 2.4 Quantitative Estimation of Phytoconstituents in *Dioscorea bulbifera*

After preliminary phytochemical screening confirmed the presence of phenols, flavonoids, saponins, tannins, and alkaloids in *Dioscorea bulbifera* tuber extracts, quantitative analysis was performed to determine the total phenolic and flavonoid content (Kaur and Sharma, 2022).

#### 2.4.1 Determination of Total Phenolic Content

The total phenolic content of *Dioscorea bulbifera* tuber extract was estimated using the Folin–Ciocalteu method and expressed as mg gallic acid equivalents per gram of dry extract. In this procedure, 0.2 mL of the extract was mixed with 5 mL of diluted Folin–Ciocalteu reagent and allowed to react for 4 minutes. Subsequently, 4 mL of 7.5% sodium carbonate solution was added, and the final volume was adjusted to 25 mL with distilled water. The mixture was kept at room temperature for 90 minutes, after which the absorbance was measured at 760 nm using a UV–visible spectrophotometer. A calibration curve was prepared using gallic acid standard solutions in the range of 20–100 µg/mL, and the total phenolic content of the extract was calculated from this standard curve (Mololeet *et al.*, 2022).

#### 2.4.2 Determination of Total Flavonoid Content

The total flavonoid content of *Dioscorea bulbifera* tuber extract was determined using a colorimetric method and expressed as mg rutin equivalents per gram of dry extract. In this method, 0.5 mL of the extract prepared in 45% ethanol was mixed with 0.15 mL of 10% aluminum chloride and 4 mL of 0.15 M sodium nitrate solution. The mixture was then diluted to a final volume of 25 mL with deionized water and allowed to react at room temperature for 30 minutes. The absorbance was measured at 510 nm using a UV–visible spectrophotometer. A calibration curve was

constructed using rutin standard solutions in the concentration range of 20–100 µg/mL, and the total flavonoid content of the extract was calculated from the standard curve (Orsavová *et al.*, 2023).

### 2.5 Preformulation studies of *Dioscorea bulbifera*

#### 2.5.1 Organoleptic evaluation

The organoleptic properties of *Dioscorea bulbifera* tuber extract were evaluated by observing color, odor, texture, and appearance. The powdered sample was assessed visually and by touch to determine its physical characteristics and uniformity. These observations confirmed the quality and suitability of the material for further formulation and phytochemical studies (Sarfraz *et al.*, 2024).

#### 2.5.2 Solubility study

The qualitative solubility of *Dioscorea bulbifera* tuber powder was evaluated in various solvents such as water, methanol, chloroform, acetone, and DMSO. The samples were mixed and observed for clarity or residue formation. The results provided preliminary insight into the solubility behavior and polarity of the phytoconstituents (Sodeifian and Usefi, 2023).

#### 2.6 Formulation of SLNs

Solid lipid nanoparticles (SLNs) loaded with *Dioscorea bulbifera* extract were prepared using the melt emulsification followed by low-temperature solidification method. The extract was dissolved in methanol, and stearic acid was dissolved in acetone to form the lipid phase. Both phases were mixed and sonicated, then added dropwise into a hot aqueous phase containing Tween 80 under continuous stirring to form an emulsion. The mixture was then rapidly cooled in an ice bath to solidify the lipid and form SLNs. The dispersion was further stirred to ensure stability, and different formulations were prepared by varying lipid concentration for further evaluation (Kesharwaniet *et al.*, 2016).

Table 1: Composition of Solid lipid nanoparticle formulation

Batch	<i>Dioscorea bulbifera</i> extract (mg)	Solid Lipid Stearic acid (mg)	Tween 80 (% w/v)	Preservatives Methyl Paraben (%)	Aqueous phase (mL)	Sonication Time (Min.)	Stirring time (Hrs)
SLN-1	500	500	1.0	0.02%	20.0	15.0	1-3
SLN-2	500	400	1.0	0.02%	20.0	15.0	1-3
SLN-3	500	300	1.0	0.02%	20.0	15.0	1-3
SLN-4	500	200	1.0	0.02%	20.0	15.0	1-3
SLN-5	500	100	1.0	0.02%	20.0	15.0	1-3

## 2.7 Characterization Parameters of extract loaded SLNs

### 2.7.1 Visual observation

The prepared extract-loaded solid lipid nanoparticles were visually evaluated for color, clarity, homogeneity, and any signs of aggregation, phase separation, or sedimentation. Observations were made under normal light conditions and monitored over time to assess preliminary stability and uniformity of the formulations (Chutoprapatet *et al.*, 2022).

### 2.7.2 UV-Visible spectrophotometric analysis

UV-Visible spectrophotometric analysis of the SLNs was carried out in the range of 200–800 nm using a suitable blank. The diluted dispersion was analyzed to identify the characteristic  $\lambda_{max}$  and compare it with the pure extract. The absence of significant peak shifts confirmed compatibility and successful encapsulation of the extract (Guemariet *et al.*, 2022).

### 2.7.3 Scanning electron microscopic

Scanning electron microscopy (SEM) was employed to examine the surface morphology and shape of the extract-loaded solid lipid nanoparticles (SLNs). A small amount of the SLN dispersion was suitably diluted and mounted onto an aluminum stub using double-sided adhesive carbon tape. The sample was then air-dried at room temperature to remove excess moisture. Prior to analysis, the dried sample was sputter-coated with a thin layer of gold under vacuum to render the surface electrically conductive. SEM analysis was performed at an appropriate accelerating voltage, and micrographs were recorded at different magnifications to assess particle shape, surface characteristics, and degree of aggregation (Rehman *et al.*, 2022).

### 2.7.4 Zeta potential

The zeta potential of extract-loaded solid lipid nanoparticles was measured using a Zetasizer based on electrophoretic light scattering. The samples were diluted with distilled water and analyzed at room temperature in triplicate. The values obtained

indicated surface charge and stability, where higher absolute zeta potential suggested better resistance to aggregation (Németh *et al.*, 2022).

### 2.7.5 Particle size

The particle size of extract-loaded solid lipid nanoparticles was measured using dynamic light scattering after suitable dilution with distilled water. The average particle size (Z-average) was recorded at room temperature in triplicate. This analysis helped assess size distribution, uniformity, and factors influencing stability and drug release (Álvarez-Chimalet *et al.*, 2022).

## 2.8 Anti-microbial activity through Well diffusion assay

The antibacterial activity of *Dioscorea bulbifera* extract-loaded solid lipid nanoparticles (SLNs) was evaluated against *Escherichia coli* and *Staphylococcus aureus* using the agar well diffusion method. Mueller–Hinton agar plates were inoculated with bacterial cultures standardized to 0.5 McFarland turbidity. Wells of 6–8 mm diameter were prepared, and samples including control (blank SLN/solvent), plant extract (1 mg/mL), and F5 SLNs at different concentrations (1 and 1.5 mg/mL) were introduced. A standard antibiotic was used as a positive control. After incubation at 37 °C for 18–24 hours, the zones of inhibition were measured, and the antibacterial efficacy of SLNs was compared with the extract and controls (Tenoc, 2025).

### 2.9 Stability study

The stability of the extract-loaded solid lipid nanoparticles was evaluated under ICH accelerated conditions ( $25 \pm 2$  °C/60 ± 5% RH and  $40 \pm 2$  °C/70 ± 5% RH) for three months. Samples were analyzed at regular intervals for particle size and entrapment efficiency, and results were compared with initial values. The minimal changes observed indicated good physical and chemical stability of the formulation (Agnishet *et al.*, 2022).

## III. RESULT AND DISCUSSION

### 3.1 Plant Collection

Table 2: Plant collection

Plant name	Plant part used	Weight
<i>Dioscorea bulbifera</i>	fruit	400 gm

### 3.2 Percentage Yield determination

Table 3: Percentage Yield of crude extracts of *Dioscorea bulbifera* extract

Plant name	Solvent	Color of extract	Theoretical weight	Yield (gm)	% yield
<i>Dioscorea bulbifera</i>	Methanol	Dark brownish	290	14.52	5.00%
	Pet ether	Pale yellow	300	9.82	3.27%

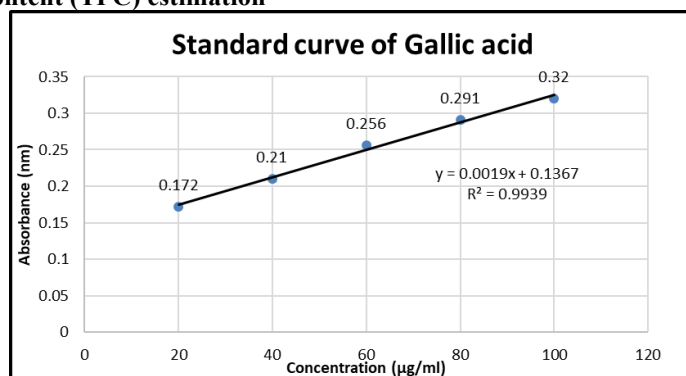
### 3.3 Preliminary Phytochemical study

Table 4: Phytochemical testing of *Dioscorea bulbifera* fruit extract

Experiment	Presence or absence of phytochemical test	
	Pet. Ether extract	Methanolic extract
<b>Test for Carbohydrates</b>		
Molisch's Test	(-)	(+)
Fehling's Test	(-)	(+)
Benedict's test	(-)	(+)
Barfoed's Test	(+)	(+)
Iodine Test	(-)	(+)
<b>Glycoside</b>		
Borntrager test	(+)	(+)
Killer-Killiani test	(+)	(+)
<b>Tests for Alkaloids</b>		
Dragendorff's Test	(+)	(+)
Mayer's Test	(+)	(+)
Wagner's Test	(-)	(+)
Hager's Test	(+)	(+)
<b>Test for Flavonoids</b>		
Shinoda Test	(-)	(+)
<b>Test for Triterpenoids and Steroids</b>		
Salkowski Test	(+)	(+)
Liebermann-Burchard Test for Triterpenoids and Steroids	(-)	(+)
<b>Tannin and Phenolic Compound Test</b>		
Ferric Chloride Test	(+)	(+)
Lead Acetate Test	(+)	(+)
Gelatin Test	(+)	(+)
<b>Test for Saponin</b>		
Foam Test	(+)	(+)
Froth Test	(+)	(+)

### 3.4 Quantitative Estimation of Phytoconstituents

#### 3.4.1 Total Phenolic content (TPC) estimation



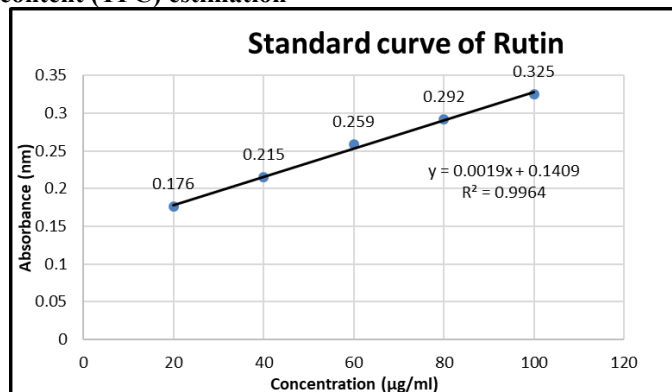
Graph 1: Represent standard curve of Gallic acid

#### 3.4.1.1 Total Phenolic Content (TPC)

Table 5: Total Phenolic Content in *Dioscorea bulbifera* extract

Absorbance	TPC in mg/gm equivalent of Gallic Acid
0.180	55.3 mg/gm
0.193	
0.203	

### 3.4.2 Total Flavonoids content (TFC) estimation



Graph 2: Represent standard curve of Rutin

#### 3.4.2.1 Total Flavonoid Content (TFC)

Table 6: Total Flavonoid Content in *Dioscorea bulbifera* extract

Absorbance	TFC in mg/gm equivalent of Rutin
0.182	53.1 mg/gm
0.192	
0.210	

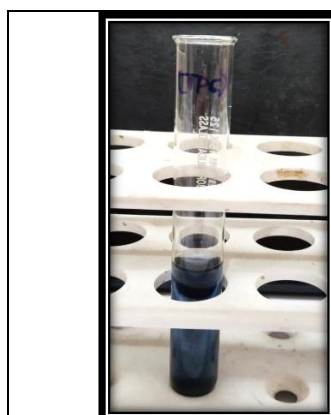


Figure 1: Total Phenolic Content of extract *Dioscorea bulbifera*

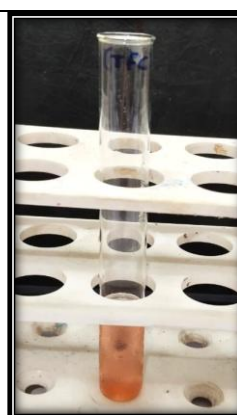


Figure 2: Total Flavonoid Content of extract *Dioscorea bulbifera*

### 3.5 Preformulation studies

#### 3.5.1 Organoleptic evaluation

Table 7: Organoleptic evaluation of *Dioscorea bulbifera* extract

Parameter	Observation
Colour	Dark brown (methanolic extract), Pale yellow (petroleum ether extract)
Odour	Characteristic, slightly earthy
Appearance/Texture	Viscous, sticky
State	Semi-solid or paste-like

### 3.6 Characterization parameters of SLNs

#### 3.6.1 Visible observation

Table 8: Visible observation of SLNs

Formulation	Parameters	Observation
SLNs	Colour	Light brown
	Odour	Characteristic faint
	Appearance	Powder

### 3.6.2 Scanning Electron Microscopic (SEM)

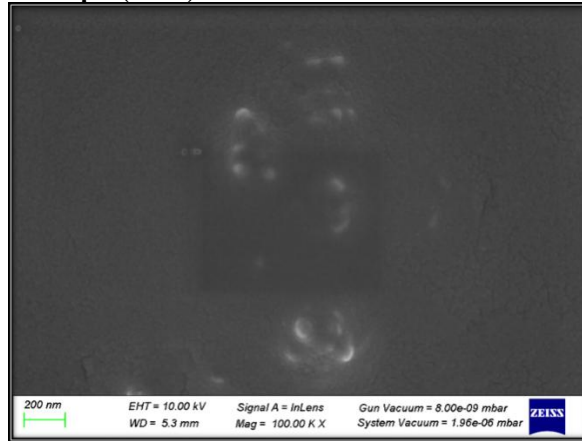
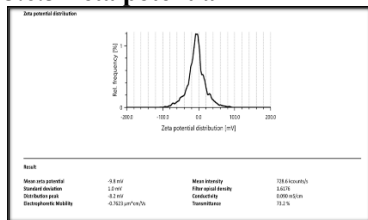
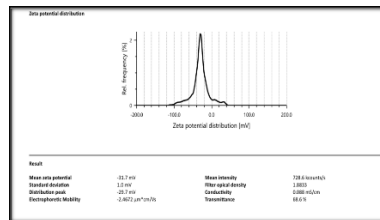


Figure 3: SEM (F2)

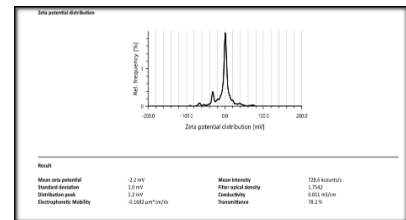
### 3.6.3 Zeta potential



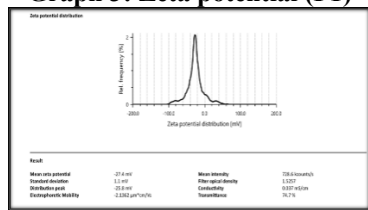
Graph 3: Zeta potential (F1)



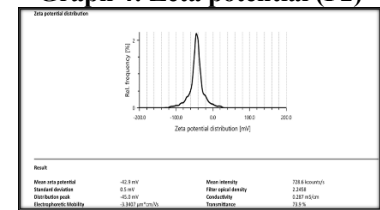
Graph 4: Zeta potential (F2)



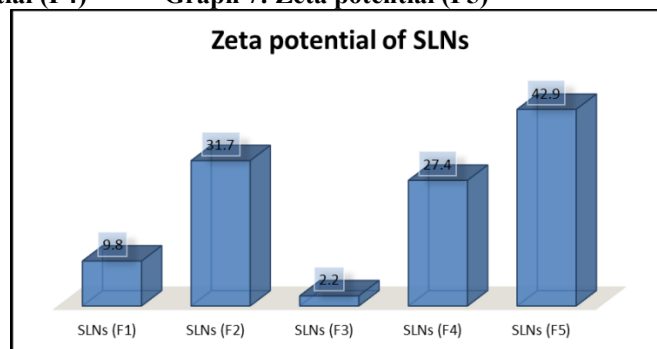
Graph 5: Zeta potential (F3)



Graph 6: Zeta potential (F4)

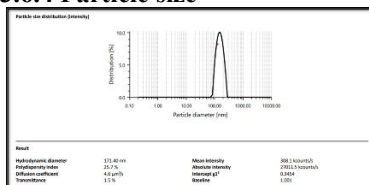


Graph 7: Zeta potential (F5)

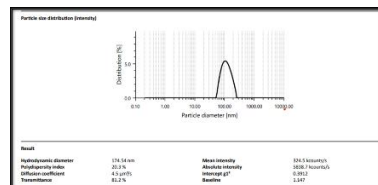


Graph 8: Graphical representation of Zeta potential of SLNs

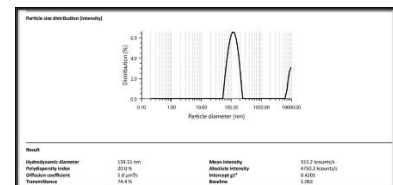
### 3.6.4 Particle size



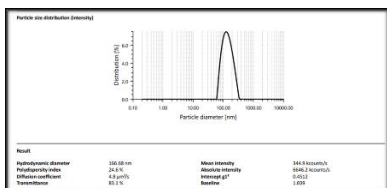
Graph 9: Particle size (F1)



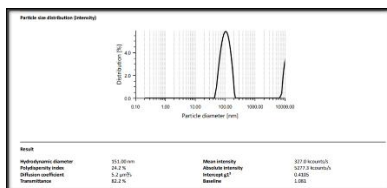
Graph 10: Particle size (F2)



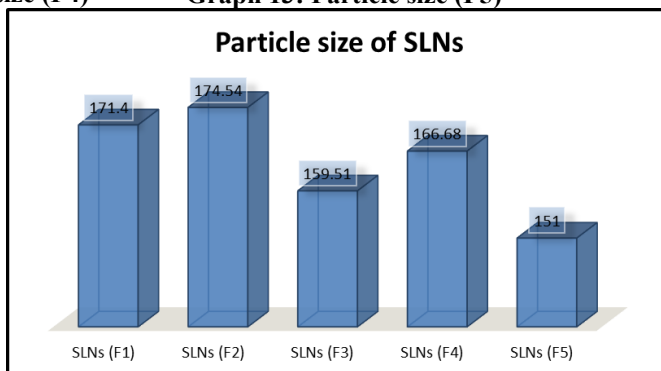
Graph 11: Particle size (F3)



Graph 12: Particle size (F4)



Graph 13: Particle size (F5)



Graph 14: Graphical representation of Particle size of SLNs

### 3.7 Results of antimicrobial activity of SLNs F5 formulation

#### 3.7.1 Antimicrobial activity of SLNs

Table 9: Antimicrobial activity of SLNs against *E.coli* and *S.aureus*

Sample Name	Zone of Inhibition (mm)of <i>E. coli</i>	Zone of Inhibition (mm)of <i>S. aureus</i>
Control	0.0	0.0
Extract (1mg/ml)	2.2	2.5
SLNs F5 (1mg/ml)	4.6	4.9
SLNs F5 (1.5 mg/ml)	6.2	7.4



Figure4: Photograph showing zone of inhibition of SLNs A: *Escherichia coli* and *S. aureus*

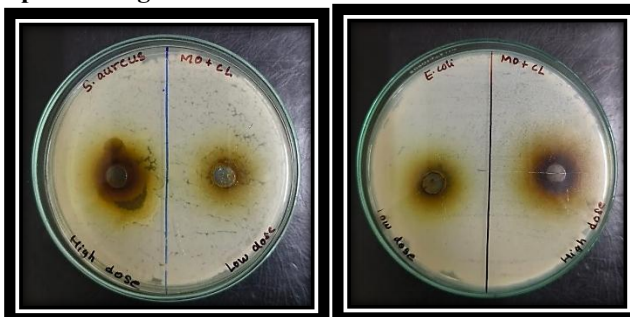
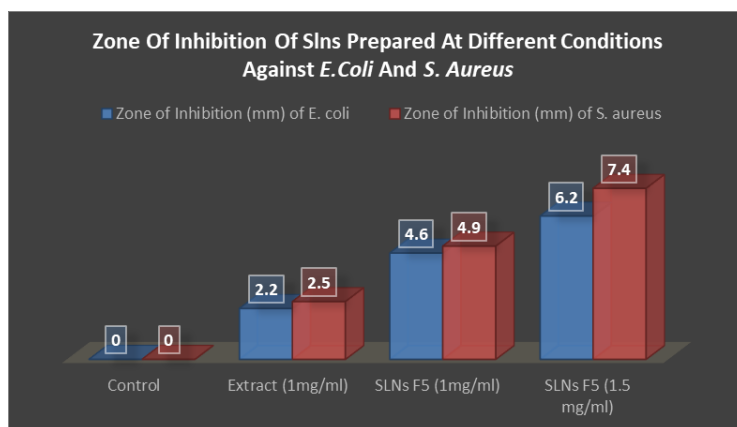


Figure 5: Zone of Inhibition Study of Combined Plant Extracts (low dose and High dose) against *S. aureus* and *E. coli*



Graph15: Zone of inhibition of SLNs prepared at different conditions against *E. coli* and *S. aureus*

### 3.8 Stability study

Table 10: Stability Study of SLNs (F5) formulation

Time (Days)	25°C±2 °C and 60 ± 5% RH				40°C±2 °C and 70 ±5% RH			
	Colour	Odour	Appearance	Particle size nm	Colour	Odour	Appearance	Particle size nm
0	light brown	Characteristic	Powder	151.00 nm	light brown	Characteristic	Powder	151.00 nm
30	light brown	Characteristic	Powder	151.23 nm	light brown	Characteristic	Powder	150.02 nm
45	light brown	Characteristic	Powder	150.02nm	light brown	Characteristic	Powder	154.06 nm
60	light brown	Characteristic	Powder	153.10 nm	light brown	Characteristic	Powder	151.34 nm
90	light brown	Characteristic	Powder	156.08 nm	light brown	Characteristic	Powder	155.15 nm

## IV. Discussion

The study on *Dioscorea bulbifera* extract-loaded solid lipid nanoparticles (SLNs) demonstrated successful formulation and promising pharmaceutical performance. The extraction results confirmed that methanol yielded a higher amount of bioactive constituents compared to non-polar solvents, indicating the predominance of polar phytochemicals such as phenolics and flavonoids, which was further supported by significant total phenolic and flavonoid content. Preformulation studies, including organoleptic properties and solubility analysis, verified the suitability of the extract for formulation development.

The prepared SLNs exhibited desirable physical characteristics, including uniform appearance, nanoscale particle size (188.54–261.9 nm), and acceptable surface morphology. Among all formulations, F5 showed optimal properties with the smallest particle size and highest zeta potential (–42.9 mV), indicating excellent stability due to strong electrostatic repulsion. Enhanced antibacterial activity of SLNs compared to the crude extract

confirmed that nanoencapsulation improved the bioavailability and efficacy of the plant extract, with a clear concentration-dependent effect against both Gram-positive and Gram-negative bacteria.

Furthermore, stability studies conducted under both normal and accelerated conditions revealed minimal changes in particle size and no significant alterations in physical appearance, confirming the robustness of the optimized formulation. Overall, the study highlights that SLNs are an effective delivery system for improving the stability, bioavailability, and therapeutic potential of *Dioscorea bulbifera* extract, making them a promising candidate for future pharmaceutical applications

## V. CONCLUSION

The study successfully formulated and characterized solid lipid nanoparticles loaded with *Dioscorea bulbifera* fruit extract. Methanolic extraction efficiently obtained bioactive phenolics and flavonoids, which were effectively encapsulated into SLNs. Among all formulations, F5 emerged as

the optimal batch due to its small particle size, high negative zeta potential, homogeneous morphology, and enhanced antimicrobial activity. Stability studies demonstrated that F5 maintained physical integrity under both ambient and accelerated conditions, indicating good shelf-life potential. These results suggest that SLNs are a promising carrier system for improving the bioavailability, stability, and therapeutic efficacy of *D. bulbifera* extract, supporting its future development as a phytopharmaceutical.

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