

GREEN SYNTHESIZED *PTEROCARPUS MARSUPIUM* SILVER NANOPARTICLES LOADED TOPICAL GEL: FORMULATION, CHARACTERIZATION, MOLECULAR DOCKING AND ANTI-INFLAMMATORY STUDIES

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ABSTRACT

The present study aimed to synthesize silver nanoparticles (AgNPs) using the aqueous stem extract of *Pterocarpus marsupium* Roxb and formulate them into a topical gel for anti-inflammatory applications. The plant extract was prepared by aqueous extraction and utilized as a reducing and stabilizing agent for the green synthesis of silver nanoparticles. Preliminary phytochemical screening confirmed the presence of carbohydrates, alkaloids, steroids, glycosides, saponins, flavonoids, terpenoids, tannins, phenolic compounds, and gums and mucilage. The synthesized nanoparticles were characterized by UV-Visible spectroscopy, FTIR, SEM, and particle size analysis. UV analysis showed a characteristic surface plasmon resonance peak around 410 nm, confirming nanoparticle formation. SEM analysis revealed nanosized particles with sizes ranging from 194.3 to 410.8 nm. The nanoparticles were incorporated into Carbopol 940 gel formulations (F1, F2, and F3). Evaluation studies demonstrated acceptable physicochemical properties, including suitable pH, viscosity, spreadability, homogeneity, and absence of skin irritation. In-vitro drug release studies showed sustained release behavior, with maximum release observed in formulation F3. Anti-inflammatory activity evaluated by the egg albumin denaturation method revealed significant inhibition, with formulation F3 exhibiting the highest activity (81.95%). Molecular docking studies further supported the anti-inflammatory potential of phytoconstituents present in *Pterocarpus marsupium*. The findings indicate that silver nanoparticle-loaded topical gel possesses promising anti-inflammatory activity and may serve as an effective herbal nanoformulation for topical therapeutic applications.

KEYWORDS: *Pterocarpus marsupium*, Silver nanoparticles, Topical gel, Green synthesis, Anti-inflammatory activity, Molecular docking, Phytochemical screening.

1. INTRODUCTION

Nanotechnology is one of the most rapidly advancing fields of science and technology, involving the design, development, characterization, and application of materials at the nanoscale. The term nano is derived from the Greek word *nanos*, meaning "dwarf," and refers to one-billionth (10^{-9}) of a meter. Materials with dimensions ranging from 1 to 100 nanometers (nm) are known as nanomaterials, and the particles within this size range are called nanoparticles. At this extremely small scale, materials exhibit unique physical, chemical, optical, electrical, magnetic, and biological properties that are significantly different from those of their bulk counterparts.

The Major Classes of Inorganic Nanoparticles Include

- ✚ Gold nanoparticles
- ✚ Silver nanoparticles
- ✚ Iron oxide nanoparticles
- ✚ Silica nanoparticles
- ✚ Quantum dots
- ✚ Titanium dioxide nanoparticles
- ✚ Zinc oxide nanoparticles
- ✚ Calcium phosphate nanoparticles

Table 1: Comparison of Inorganic Nanoparticles.

Nanoparticle	Typical Size (nm)	Major Property	Principal Applications
Gold nanoparticles	2–100	Surface plasmon resonance	Cancer therapy, biosensors, imaging
Silver nanoparticles	10–100	Antimicrobial activity	Wound healing, antimicrobial coatings
Iron oxide nanoparticles	10–150	Magnetic behavior	MRI, magnetic targeting, hyperthermia
Silica nanoparticles	20–500	High porosity	Drug delivery, biosensors
Quantum dots	2–10	Fluorescence	Imaging, diagnostics
Titanium dioxide nanoparticles	10–100	Photocatalytic activity	Sunscreens, coatings
Zinc oxide nanoparticles	10–100	UV protection, antimicrobial activity	Dermatology, wound healing
Calcium phosphate nanoparticles	20–200	Biocompatibility	Bone regeneration, dental delivery

2. PLANT PROFILE

2.1 Taxonomic Classification

Table 2: Taxonomic Classification.

Category	Classification
Kingdom	Plantae
Division	Magnoliophyta
Class	Magnoliopsida
Order	Fabales
Family	Fabaceae
Genus	<i>Pterocarpus</i>
Species	<i>Pterocarpus marsupium</i> Roxb.

2.2 Common Names

- ✚ Indian Kino Tree
- ✚ Malabar Kino

- ✚ Vijaysar (Hindi)
- ✚ Asana (Sanskrit)
- ✚ Vengai (Tamil)
- ✚ Bijasal (Bengali)
- ✚ Honne (Kannada)

2.3 Botanical Description

Pterocarpus marsupium Roxb. is a large deciduous tree reaching 15–30 m in height. The bark is grayish-brown, rough, and exudes a reddish gum known as kino. Leaves are alternate, imparipinnate, and consist of 5–7 leaflets. Flowers are yellow, fragrant, and arranged in terminal panicles. Fruits are orbicular, winged pods containing one or two seeds.

2.4 Chemical Constituents

Major phytoconstituents include:

- ✚ Pterostilbene
- ✚ Marsupsin
- ✚ Pterosupin
- ✚ Liquiritigenin
- ✚ Epicatechin
- ✚ Catechin
- ✚ Flavonoids
- ✚ Tannins
- ✚ Phenolic compounds

2.5 Medicinal Uses

- ✚ Anti-diabetic activity
- ✚ Anti-oxidant activity
- ✚ Anti-inflammatory activity
- ✚ Anti-microbial activity
- ✚ Hepato-protective activity
- ✚ Wound healing property
- ✚ Cardio-protective effects



Fig. 1: *Pterocarpus Marsupium* Roxb.

3. MATERIALS AND METHODS

3.1 Plan of Work

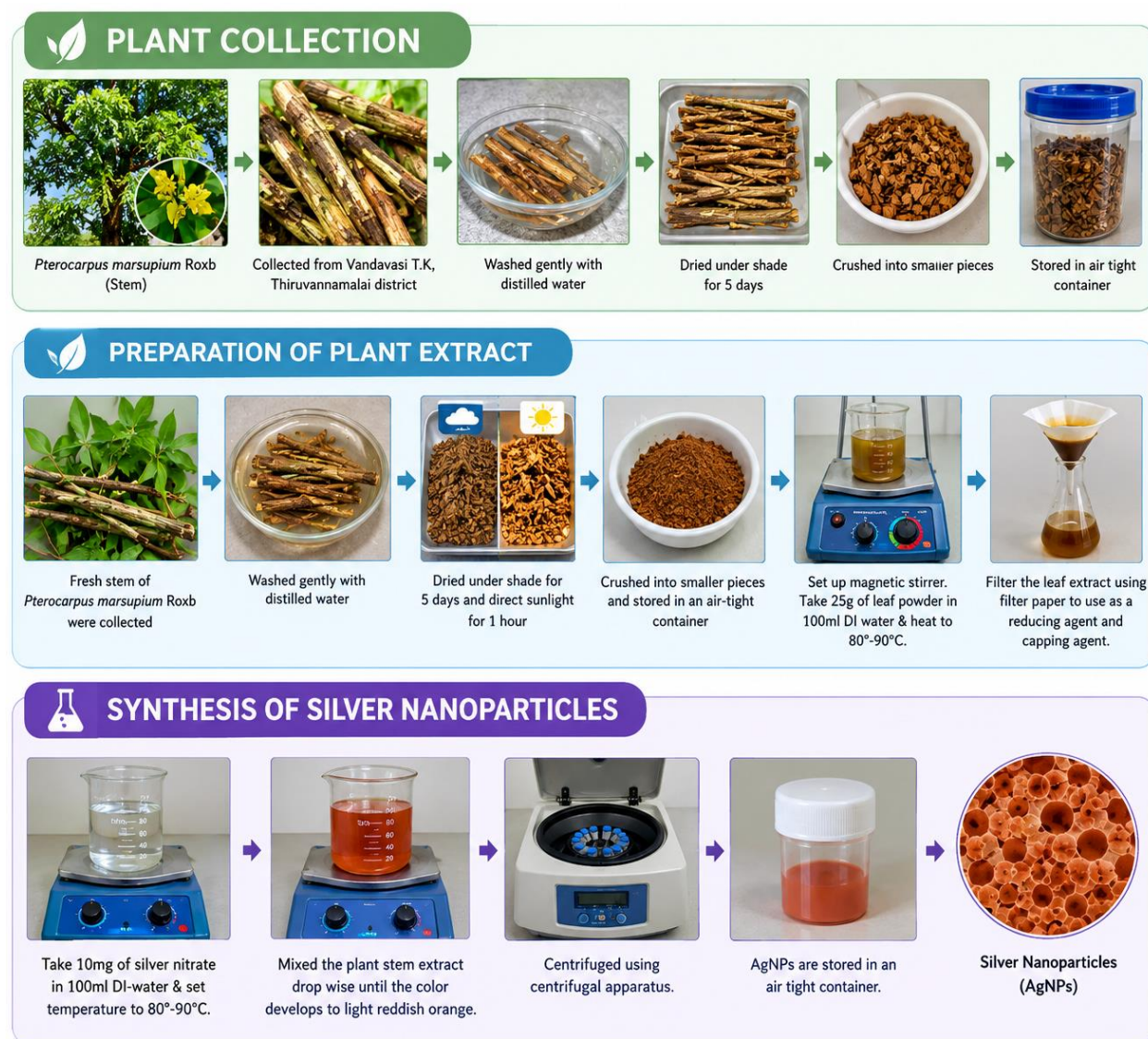


Fig. 2: Plan of Work.

3.2 Molecular Docking Study

Auto Dock 4 Procedure

1. Ligand preparation
2. Protein preparation
3. Docking
4. Analysis

3.3 Phyto-Chemical Test

The extracts of *Pterocarpus Marsupium Roxb* were subjected to the following preliminary phytochemical analysis.

- Test For Carbohydrates: Molisch Test
- Test For Alkaloids: Mayer's Test
- Test For Steroids And Sterols: Salkowski Test

- ✚ Test For Glycosides: Legal's Test
- ✚ Test For Saponins: Foam Test
- ✚ Test For Flavonoids
- ✚ Test For Tri-Terpenoids
- ✚ Test For Terpenoids: Copper Acetate Test
- ✚ Tests For Tannins And Phenolic Compounds
- ✚ Test For Gums And Mucilage: Ruthenium Red Test
- ✚ Test For Proteins And Amino Acids: Biuret Test, Ninhydrin Test
- ✚ Test For Fixed Oils And Fatty Acids: Saponification Test, Litmus Test

3.4 Evaluation of Silver Nanoparticles (AgNPs)

Before using silver nanoparticles (AgNPs) for any application, their formation must be confirmed. A simple way to identify AgNP formation is by observing the color change of the solution from yellow to brown. UV-Visible spectroscopy is commonly used to confirm nanoparticle formation by detecting characteristic peaks between 400–450 nm. Other techniques such as SEM help determine the size, shape, and surface structure of nanoparticles, while FTIR analysis identifies the biomolecules responsible for nanoparticle formation and stability.

- ✚ UV-Visible Spectrophotometry of AgNPs
- ✚ SEM Imaging of Nanoparticles
- ✚ Drug Content and Encapsulation Efficiency
- ✚ In-Vitro Drug Release Study

3.5 Formulation of Silver Nanoparticles Loaded Gel

Table 3: Formulation of Silver Nanoparticles Loaded Gel.

S. No.	Ingredients	F1	F2	F3
1	<i>Pterocarpus Marsupium Roxb</i> Nanoparticle	1.5 g	1.5 g	1.5 g
2	Carbopol 940	1 g	2 g	4 g
3	Propylene glycol	10 ml	10 ml	10 ml
4	Glycerin	5 ml	5 ml	5 ml
5	Methyl paraben	180 mg	180 mg	180 mg
6	Propyl paraben	20 mg	20 mg	20 mg
7	Triethanolamine	q.s.	q.s.	q.s.
8	Distilled water	q.s. to make 100 g	q.s. to make 100 g	q.s. to make 100 g

Procedure: The nanoparticle-loaded gel was prepared using the dispersion method. Initially, the required quantity of Carbopol 940 (1 g, 2 g, and 4 g for formulations F1, F2, and F3, respectively) was slowly dispersed in a portion of distilled water and allowed to hydrate and swell completely for 2–4 hours. Methyl paraben (180 mg) and propyl paraben (20 mg) were dissolved in propylene glycol (10 mL) with gentle heating, followed by the addition of glycerin (5 mL) to obtain a uniform preservative solution. Subsequently, 1.5 g of *Pterocarpus marsupium* nanoparticles were incorporated into the hydrated Carbopol dispersion under continuous stirring to ensure uniform distribution. The preservative solution was then added gradually to the nanoparticle dispersion and mixed thoroughly until a homogeneous mixture was obtained. Triethanolamine was added drop wise with continuous stirring to neutralize the dispersion and facilitate gel formation. The pH of the formulation was adjusted to 6.5–7.0. Finally, distilled water was added to make up the final weight to 100 g, and the resulting gel was stirred until a smooth and uniform consistency

was achieved. The prepared nanoparticle-loaded gels were transferred into airtight containers and stored at room temperature for further evaluation.

3.6 Evaluation of Topical Gel

Evaluating Topical gel involves assessing their properties, performance, and suitability for specific applications. This evaluation typically includes various physical, chemical, and mechanical tests. Below is an overview of the key aspects considered when evaluating Topical gel.

- + Appearance
- + Color
- + Odor
- + Determination of PH
- + Rheology
- + Spreadability study ($S = (m \times l) / t$)
- + Viscoelastic Properties
- + Gel Fraction ($GF (\%) = W_g / W_o \times 100$)
- + Scanning Electron Microscopy (SEM)
- + Homogeneity
- + Irritancy Test
- + *In-Vitro* Diffusion Study (Cellophane Membrane Treatment for Permeation study)
- + Stability Studies

3.7 Drug Release

To study kinetics, data obtained from in vitro release were plotted in various kinetic models.

- + Zero order equation: $C = K_0 t$
- + First order equation: $\log C = \log C_0 - Kt / 2.303$
- + Higuchi kinetics: $Q = Kt^{1/2}$
- + Hixson and Crowell erosion equation: $Q_0^{1/3} - Q_t^{1/3} = K_{HCT}$
- + Korsmeyer – Peppas equation: $M_t / M_\infty = Kt^n$

3.8 Anti Inflammatory Study

Egg Albumin Assay: The anti-inflammatory activity of unknown crude extracts can be determined in vitro for inhibition of the denaturation of egg albumin (protein).

0.2 mL of 1-2% egg albumin solution (from fresh hen's egg/ or commercially available egg albumin powder), 2 mL of sample extract or standard (Diclofenac sodium) at varying concentrations, and 2.8 mL of phosphate buffered saline (pH 7.4) were mixed to form a reaction mixture of a total volume of 5 mL. A total volume of 5 mL of the control was created by combining 2 mL of triple-distilled water, 0.2 mL of 1-2% egg albumin solution, and 2.8 mL of phosphate-buffered saline. The reaction mixtures were then incubated at $37 \pm 2^\circ\text{C}$ for 30 min and will be heated in a water bath at $70 \pm 2^\circ\text{C}$ for 15 min. After cooling, the absorbance was measured at 280 nm by a suitable UV/Vis spectrophotometer using triple distilled water as the blank. The following equation was used to determine the % inhibition of protein denaturation.

$$\text{Percentage of Inhibition} = \frac{\text{Absorbance of control} - \text{Absorbance of test sample}}{\text{Absorbance of control}} \times 100$$

4. RESULTS AND DISCUSSION

4.1 Chemical Test

Table 4: Chemical Test.

S. No.	Phytochemical Constituent	Test Performed	Observation	Result
1	Carbohydrates	Molisch Test	Purple/reddish violet ring formed at the junction	+
2	Alkaloids	Mayer's Test	Dull white precipitate formed	+
3	Steroids and Sterols	Salkowski Test	Bluish-red to cherry-red color with green fluorescence	+
4	Glycosides	Legal's Test	Pink-red color developed	+
5	Saponins	Foam Test	Persistent foam layer (>1 cm) observed	+
6	Flavonoids	Alkaline Reagent Test	Dark yellow color appeared	+
7	Tri-terpenoids	Tin and Thionyl Chloride Test	Pink color developed	+
8	Terpenoids	Copper Acetate Test	Emerald green color observed	+
9	Tannins	Lead Acetate Test	White precipitate formed	+
10	Phenolic Compounds	Litmus Test	Blue litmus turned red	+
11	Gums and Mucilage	Ruthenium Red Test	Pink coloration observed	+
12	Proteins	Biuret Test	Violet color developed	-
13	Amino Acids	Ninhydrin Test	No characteristic blue color observed	-
14	Fixed Oils and Fats	Saponification Test	Soap formation absent	-
15	Fixed Oils and Fats	Litmus Test	No significant change observed	-

4.2 Evaluation of Nanoparticle

UV Analysis

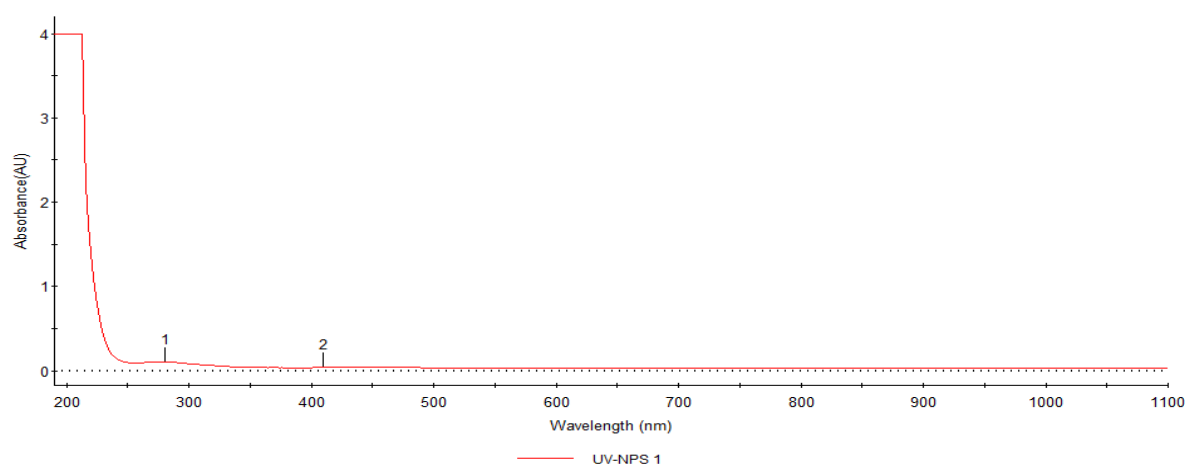


Fig. 3: UV Analysis of Nanoparticle.

Name	No.	Peak(nm)	Peak(AU)	No.	Valley(nm)	Valley(AU)
UV-NPS	1	279.9	0.110			
	2	410.0	0.041			

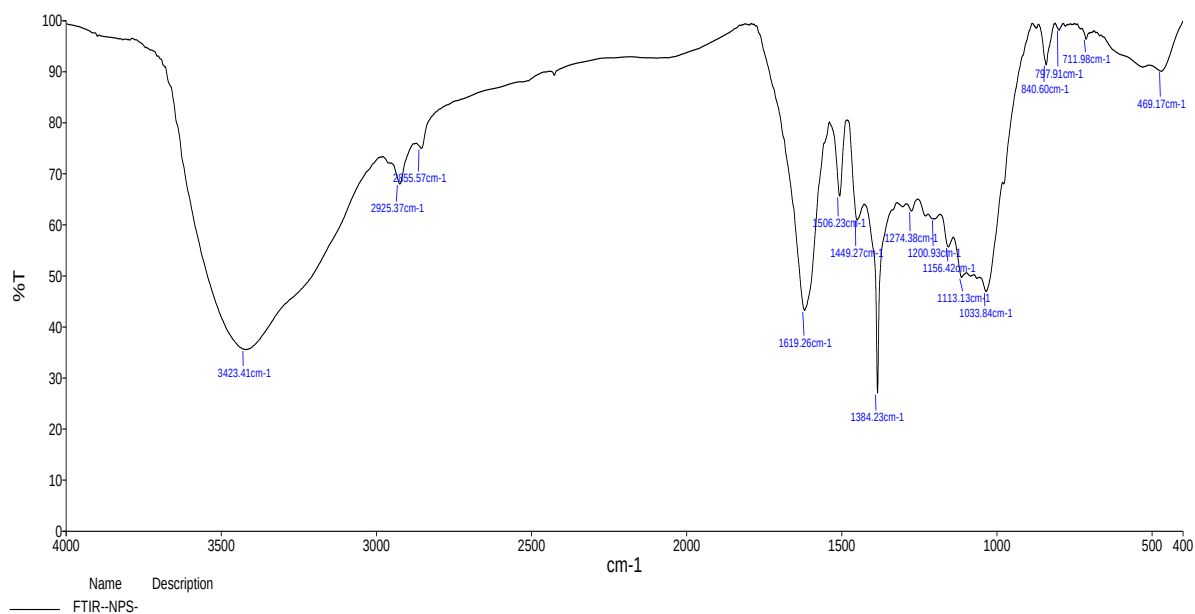
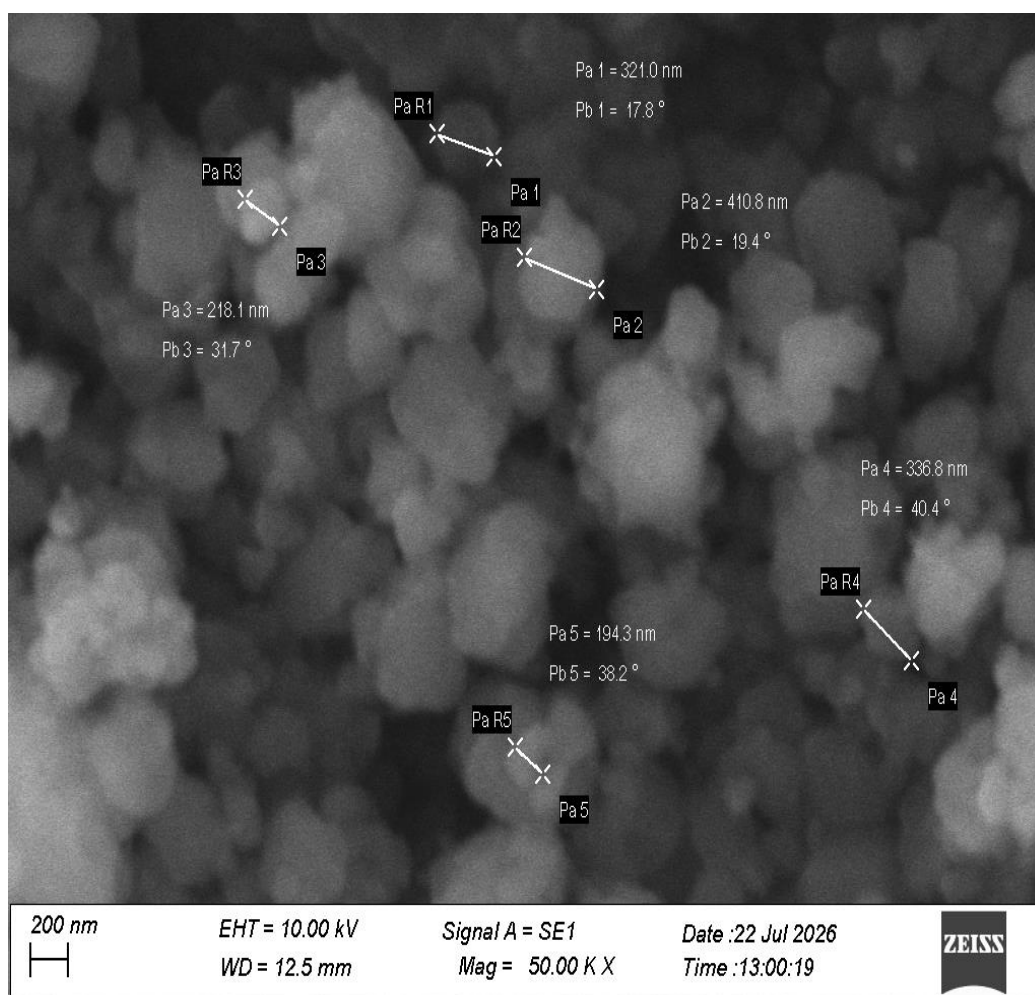
FTIR Analysis**Fig. 4: FTIR Analysis of Nanoparticle.****SEM Analysis****Fig. 5: SEM Analysis.**

Table 5: Particle Size of Nanoparticle.

Particles	Size
1	321.0nm
2	410.8nm
3	218.1nm
4	336.8nm
5	194.3nm

Particle Size Distribution Analysis



NanoPlus
Common

Intensity Distribution		S/N : 411615	
User	: Common	Group	: Repetition : 1/1
Date	: 23-Jul-26	File Name	: DLS-NPS
Time	: 09:03:44	Sample Information	:
SOP Name : SJC Size Method		Security : No Security	
Version 5.22 / 3.00			

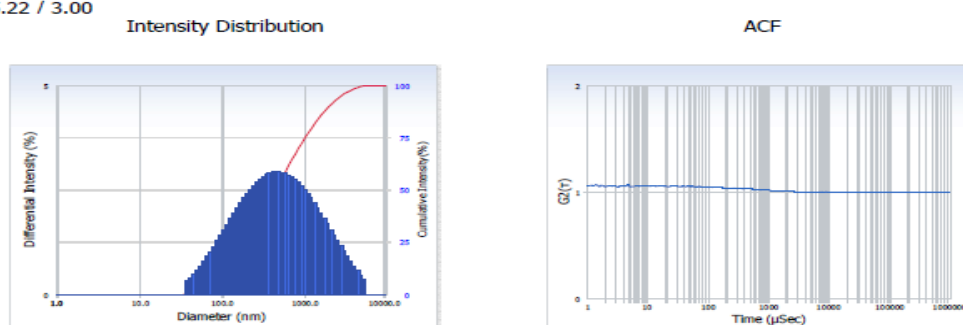


Fig. 6: Particle Size Distribution of Nanoparticle.

Table 6: Distribution Table.

Distribution Results (Contin)			Cumulants Results		
Peak	Diameter (nm)	Std. Dev.	Diameter (d)	: 458.3	(nm)
1	889.9	1,035.8	Polydispersity Index (P.I.)	: 0.383	
2	0.0	0.0	Diffusion Const. (D)	: 1.073e-008	(cm ² /sec)
3	0.0	0.0	Measurement Condition		
4	0.0	0.0	Temperature	: 25.0	(°C)
5	0.0	0.0	Diluent Name	: WATER	
Average	889.9	1,035.8	Refractive Index	: 1.3328	
Residual	: 1.206e-002	(O.K)	Viscosity	: 0.8878	(cP)
			Scattering Intensity	: 31512	(cps)
			Attenuator 1	: 1.01	(%)

Table 7: Intensity Distribution Table.

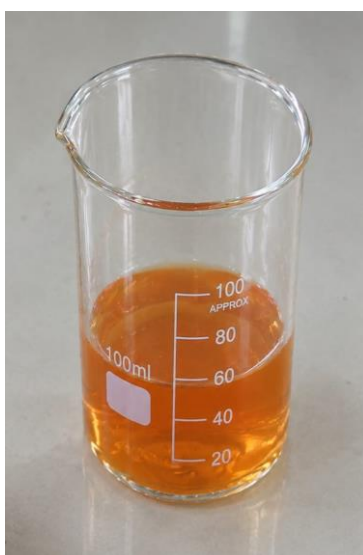
Intensity Distribution Table											
d (nm)	f(%)	f(cum.%)	d (nm)	f(%)	f(cum.%)	d (nm)	f(%)	f(cum.%)	d (nm)	f(%)	f(cum.%)
9.4	0.0	0.0	96.9	1.4	9.1	998.8	2.6	72.7	10300.0	0.0	100.0
D (10%): 102.30 (nm)			D (50%): 471.10 (nm)			D (90%): 2,150.80 (nm)					

In-vitro Dissolution Study**Table 8: In-Vitro Dissolution Study For Nanoparticle.**

Time	Absorbance	mcg/ml	mg/ml	% Drug Release
0	0	0	0	0
1	0.180	1.86	1.68	16.77
2	0.260	2.76	2.49	24.86
3	0.372	4.02	3.62	36.18
4	0.414	4.49	4.04	40.43
5	0.589	6.46	5.81	58.13
6	0.650	7.14	6.43	64.29
8	0.790	8.72	7.85	78.45

4.3 Evaluation of Nanoparticle Loaded Gel**Physical Evaluation of Nanoparticle Loaded Gel****Table 9: Physical Evaluation of Gel.**

S.NO	PARAMETERS	F1	F2	F3
1.	State	Semi Solid	Semi Solid	Semi Solid
2.	Color	Colorless	Colorless	Colorless
3.	Odor	Aroma	Aroma	Aroma
4.	pH	8.44	8.31	8.35
5.	Grittiness	Smooth	Smooth	Smooth
6.	Viscosity	7321	7897	7993
7.	Sensitivity Test	No Irritation	No Irritation	No Irritation
8.	Irritation Test	No Irritation	No Irritation	No Irritation
9.	Spreadability	6.8 cm	6.6 cm	6.9 cm
10.	Homogeneity	Homogenous	Homogenous	Homogenous
11.	Gel Fraction	63%	71%	68%
12.	Viscoelastic	Elasticity Gel-Like Behaviour	Higher Elasticity Gel-Like Behaviour	Higher Elasticity Gel-Like Behaviour

**Extract****Nanoparticle****Gel****Fig. 7: Product Images.**

UV Analysis

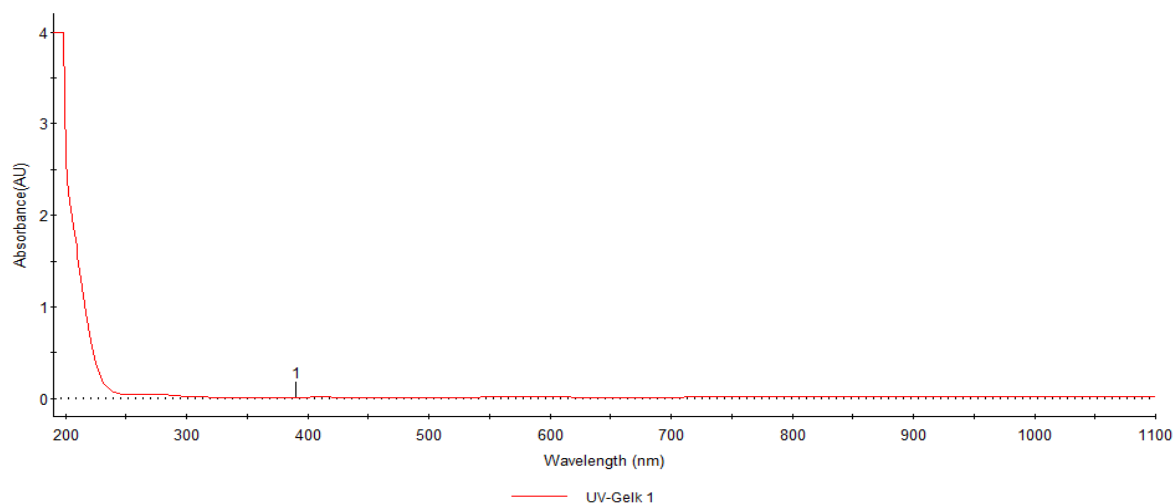


Fig. 8: UV Analysis of Nanoparticle Loaded Gel.

Name	No.	Peak(nm)	Peak(AU)	No.	Valley(nm)	Valley(AU)
UV-Gel	1	390.1	0.009			

FTIR Analysis

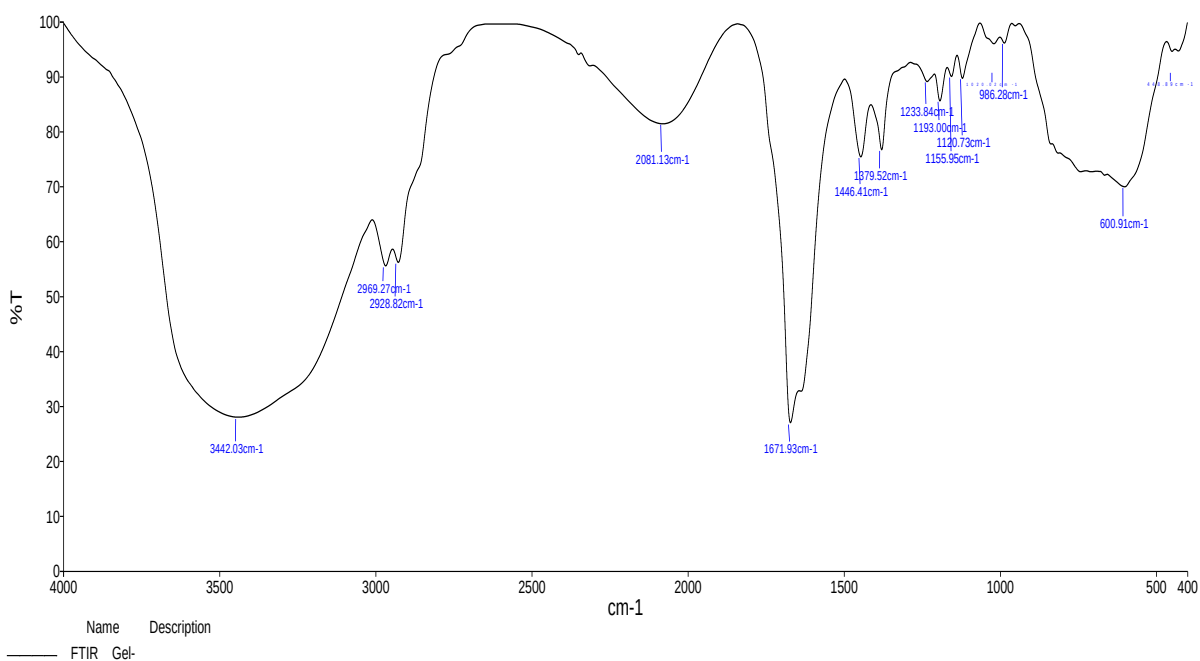


Fig. 9: FTIR Analysis of Nanoparticle Loaded Gel.

SEM Analysis

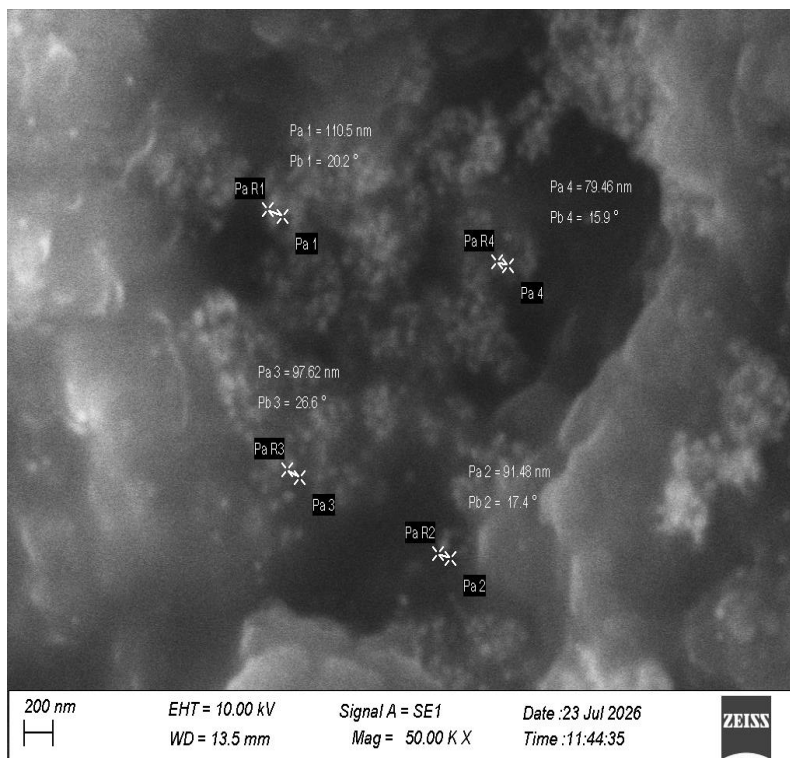


Fig. 10: SEM Analysis.

Table 10: Particle Size of Nanoparticle Loaded Gel.

Particles	Size
1	110.5nm
2	91.48nm
3	97.62nm
4	79.46nm

Particle Size Distribution Analysis

NanoPlus
Common

Intensity Distribution		S/N : 411615	
User	: Common	Group	: Repetition : 1/1
Date	: 23-Jul-26	File Name	: DLS-GD
Time	: 10:22:50	Sample Information	:
SOP Name	: SJC Size Method	Security	: No Security

Version 5.22 / 3.00

Intensity Distribution

ACF

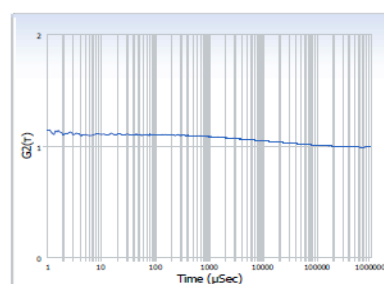
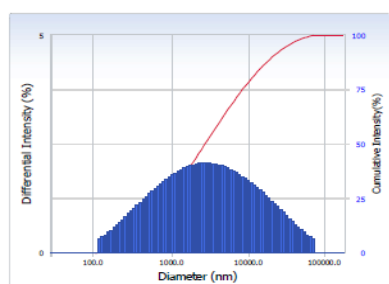


Fig. 11: Particle Size Distribution of Nanoparticle Loaded Gel.

Table 11: Distribution Table.

Distribution Results (Contin)			Cumulants Results	
Peak	Diameter (nm)	Std. Dev.	Diameter (d)	(nm)
1	7,952.3	12,082.1	Polydispersity Index (P.I.)	: 1.511
2	0.0	0.0	Diffusion Const. (D)	: 1.245e-009 (cm ² /sec)
3	0.0	0.0	Measurement Condition	
4	0.0	0.0	Temperature	: 25.0 (°C)
5	0.0	0.0	Diluent Name	: WATER
Average	7,952.3	12,082.1	Refractive Index	: 1.3328
Residual :	1.963e-002	(O.K)	Viscosity	: 0.8878 (cP)
			Scattering Intensity	: 17680 (cps)
			Attenuator 1	: 2.71 (%)

Table 12: Intensity Distribution Table.

Intensity Distribution Table											
d (nm)	f(%)	f(cum.%)	d (nm)	f(%)	f(cum.%)	d (nm)	f(%)	f(cum.%)	d (nm)	f(%)	f(cum.%)
245.5	0.8	4.9	2193.1	2.1	43.6	19590.7	1.3	88.8	175000.0	0.0	100.0
D (10%) : 387.10 (nm)			D (50%) : 2,879.80 (nm)			D (90%) : 21,368.20 (nm)					

In-vitro Dissolution Study**Table 13: In-Vitro Dissolution Study for Nanoparticle Loaded Gel F1.**

Time	Absorbance	mcg/ml	mg/ml	% Drug Release
0	0	0	0	0
1	0.212	2.22	2.00	20.00
2	0.359	3.87	3.49	34.87
3	0.426	4.63	4.16	41.64
4	0.562	6.16	5.54	55.40
5	0.665	7.31	6.58	65.81
6	0.721	7.94	7.15	71.47
8	0.812	8.96	8.07	80.68

Table 14: In-Vitro Dissolution Study for Nanoparticle Loaded Gel F2.

Time	Absorbance	mcg/ml	mg/ml	% Drug Release
0	0	0	0	0
1	0.198	2.07	1.86	18.59
2	0.290	3.10	2.79	27.89
3	0.360	3.89	3.50	34.97
4	0.480	5.23	4.71	47.10
5	0.554	6.07	5.46	54.59
6	0.690	7.59	6.83	68.34
8	0.810	8.94	8.05	80.47

Table 15: In-Vitro Dissolution Study for Nanoparticle Loaded Gel F3.

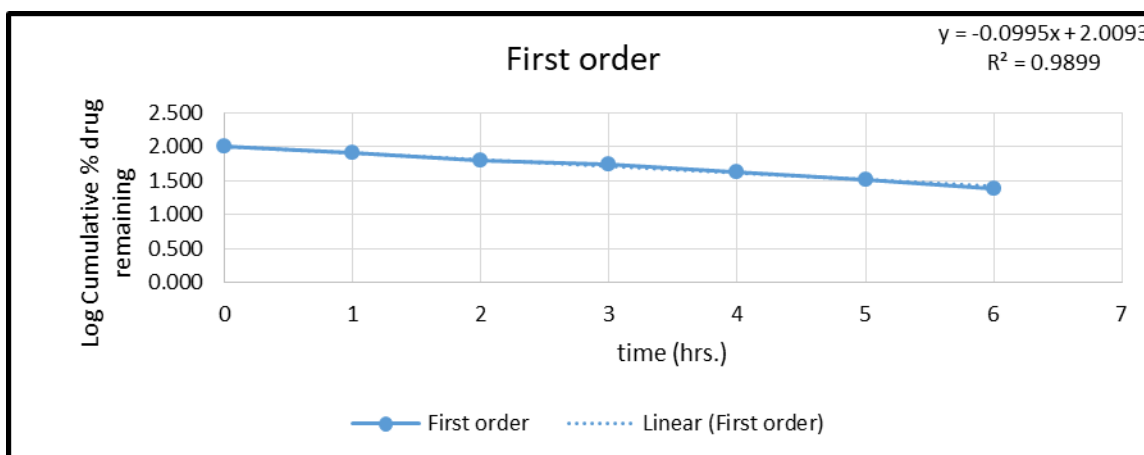
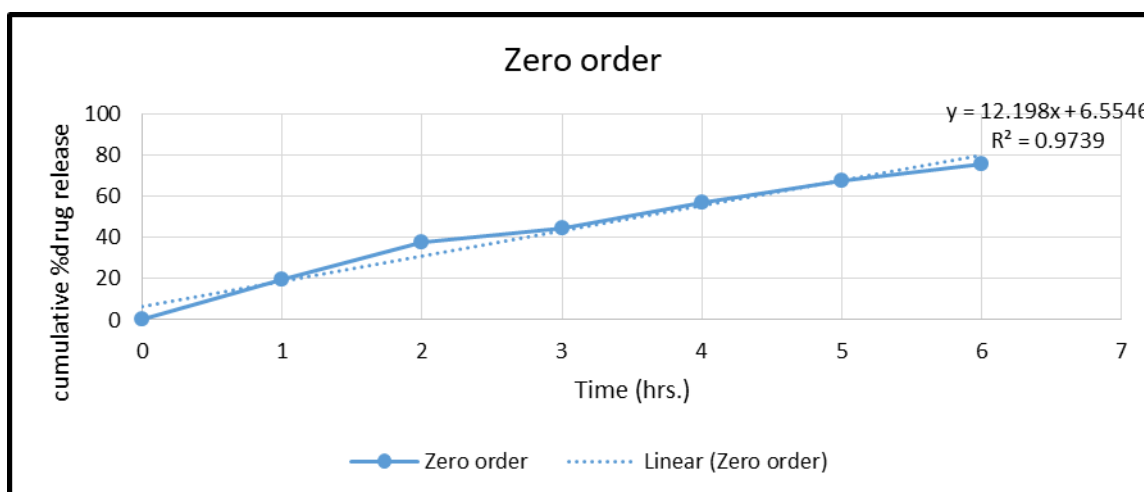
Time	Absorbance	mcg/ml	mg/ml	% Drug Release
0	0	0	0	0
1	0.210	2.20	1.98	19.80

2	0.388	4.20	3.78	37.80
3	0.452	4.92	4.43	44.27
4	0.579	6.35	5.71	57.11
5	0.680	7.48	6.73	67.33
6	0.763	8.41	7.57	75.72
8	0.898	9.93	8.94	89.37

Drug Release Study

Table 16: Drug Release Study For Nanoparticle Loaded Gel F3.

Time (Hr)	cumulative % drug released	% drug remaining	Square root time	log Cumu % drug remaining	log time	log Cumu % drug released	% Drug released	Cube Root of % drug Remaining(Wt)	Wo-Wt
0	0	100	0.000	2.000	0.000	0.000	100	4.642	0.000
1	19.8	80.2	1.000	1.904	0.000	1.297	19.8	4.312	0.330
2	37.8	62.2	1.414	1.794	0.301	1.577	18	3.962	0.680
3	44.27	55.73	1.732	1.746	0.477	1.646	6.47	3.820	0.822
4	57.11	42.89	2.000	1.632	0.602	1.757	12.84	3.500	1.142
5	67.33	32.67	2.236	1.514	0.699	1.828	10.22	3.197	1.445
6	75.72	24.28	2.449	1.385	0.778	1.879	8.39	2.896	1.746
8	89.37	10.63	2.828	1.027	0.903	1.951	13.65	2.199	2.443
		100	0.000	2.000	#NUM!	#NUM!	-89.37	4.642	0.000



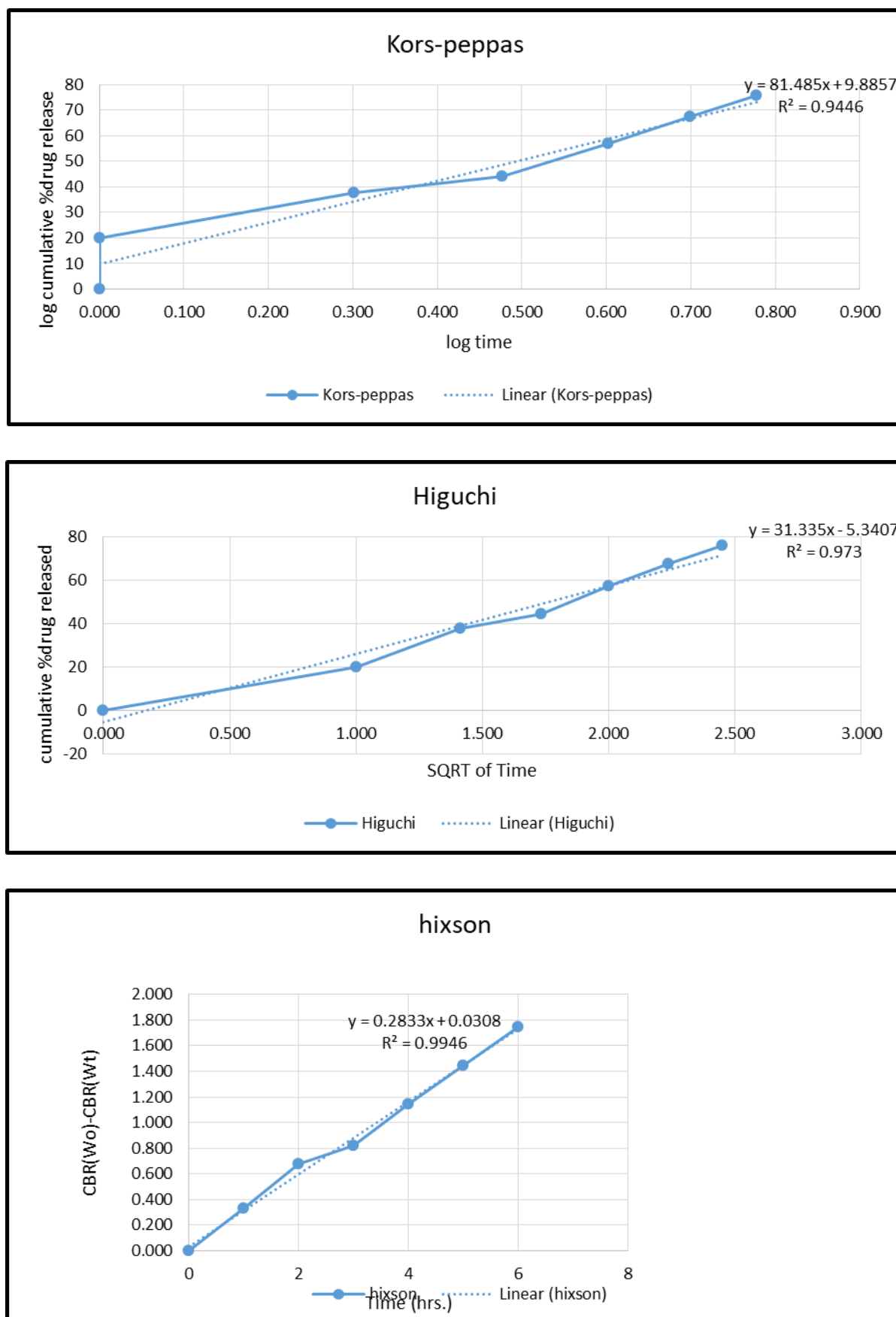


Fig. 12: Drug Release Order for Nanoparticle Loaded Gel F3.

Stability Studies

Table 17: Stability Study of Sliver Nanoparticle Loaded Topical Gel F3.

S.No	Parameter	Observation				
		Initial	At the end of 1 st month		At the end of 2 nd month	
			RT	40 ± 2oC & RH 70 ± 5%	RT	40 ± 2oC & RH 70 ± 5%
1.	Appearance	Smooth	Smooth	Smooth	Smooth	Smooth
2.	pH	8.35	8.35	8.31	8.31	8.30
3.	Spreadability	6.9 cm	6.9 cm	6.8 cm	6.9 cm	6.9 cm
4.	Extrudability	Excellent	Excellent	Excellent	Excellent	Excellent
5.	% drug content	89.37	89.35	89.36	89.33	89.35

3.4 Anti-Inflammatory Activity

Table 18: Anti-Inflammatory Activity.

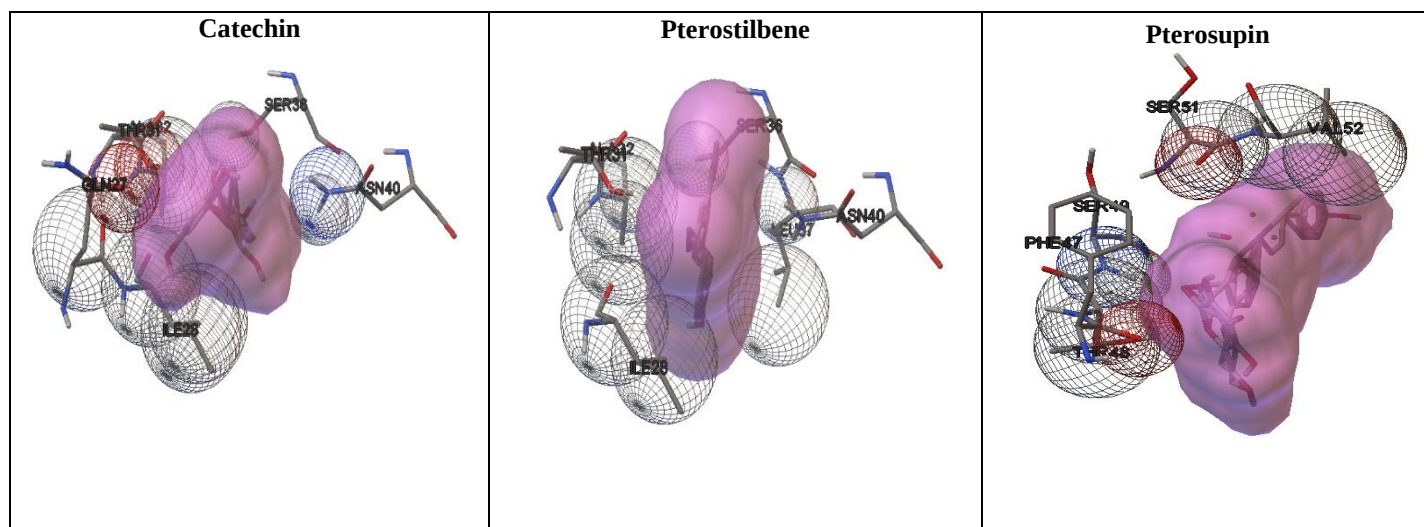
S.NO	SLIVER NANOPARTICLE LOADED TOPICAL GEL	OD VALUE	% OF INHIBITION
1	DISTILLED WATER	0.00	-
2	CONTROL	0.449	-
3	STANDARD	0.146	67.48
4	Nanoparticle	0.129	71.26
5	F1	0.123	72.60
6	F2	0.117	73.94
7	F3	0.131	81.95

3.5 Molecular Docking Study

Table 19: Anti-Inflammatory Activity (5LOX).

Catechin	Pterostilbene	Pterosupin	Formononetin	Marsupin	Standard (Diclofenac)
-4.52	-4.52	-4.24	-3.94	-1.88	-1.90
-4.64	-4.64	-4.19	-3.55	-2.21	-1.90
-4.85	-4.85	-4.22	-3.79	-2.37	-1.90
-4.46	-4.46	-5.69	-3.20	-2.13	-1.90
-4.84	-4.84	-3.61	-4.28	-2.31	-1.90
-4.82	-4.82	-4.02	-4.14	-2.19	-1.90
-4.48	-4.48	-4.32	-4.03	-2.11	-1.90
-4.67	-4.67	-5.04	-3.40	-3.21	-1.90
-5.17	-5.17	-4.70	-4.60	-2.36	-1.90
-4.47	-4.47	-5.56	-3.80	-1.75	-1.90

Table 20: Molecular Docking (5LOX).



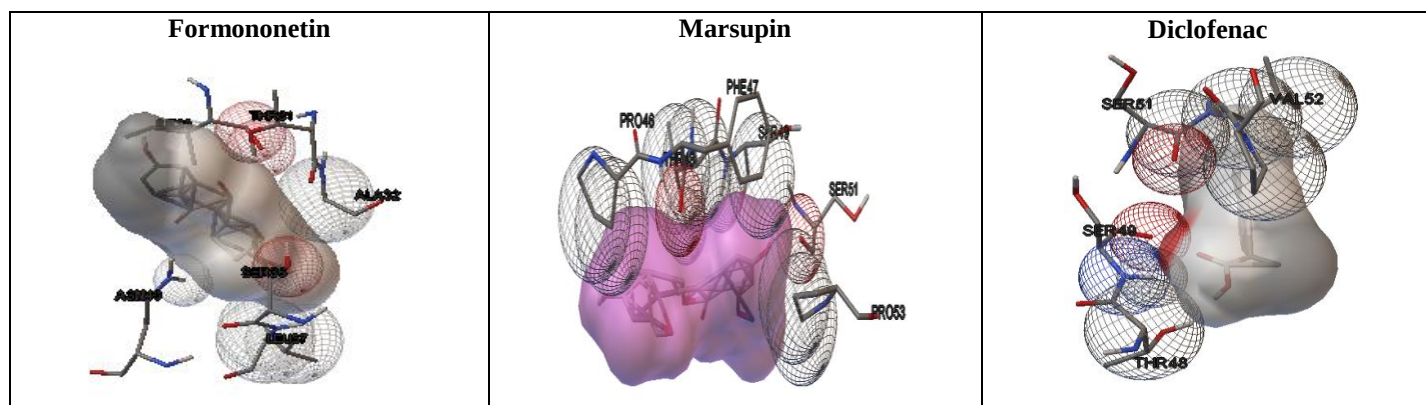
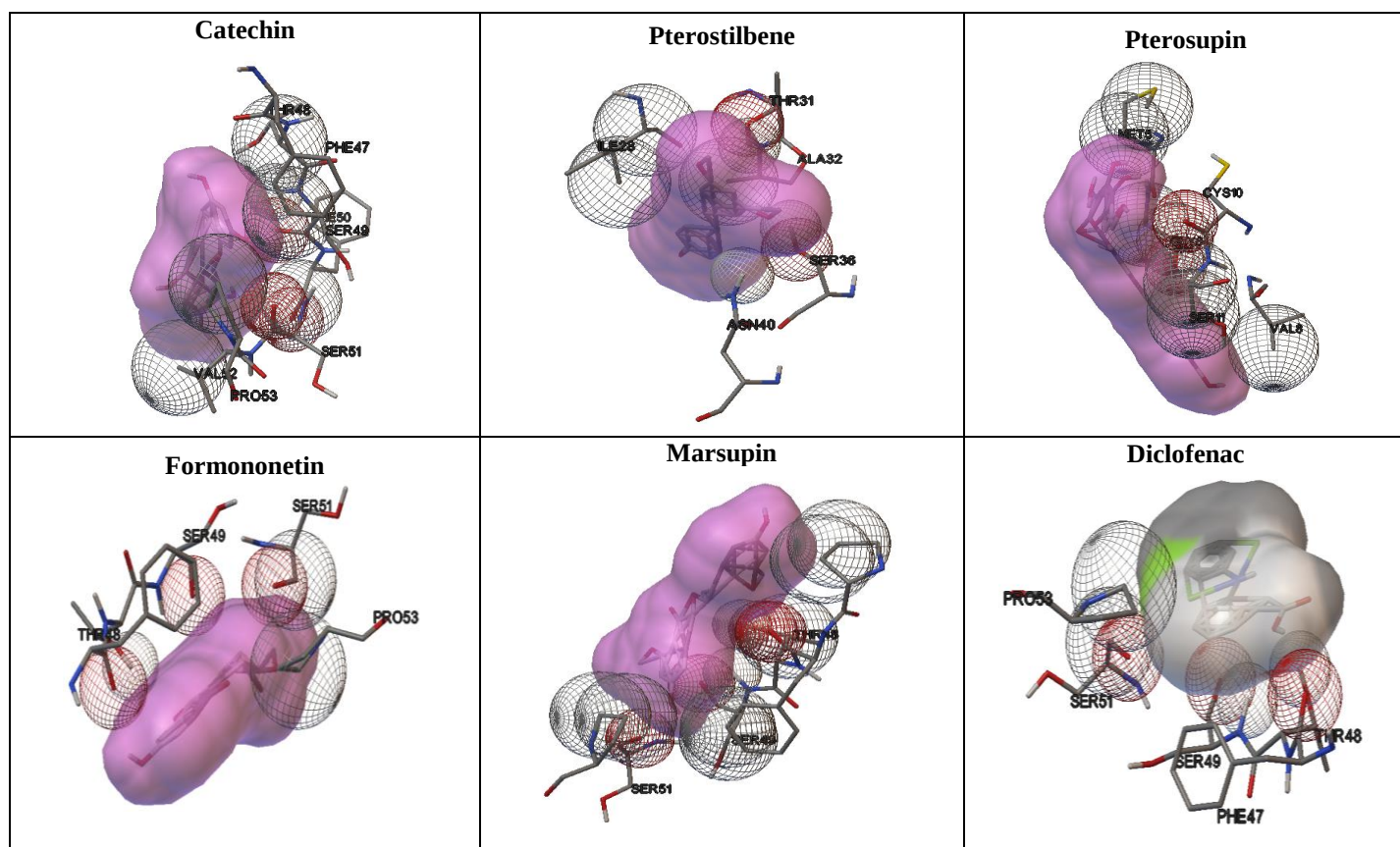


Table 21: Anti-Inflammatory Activity (5F19).

Catechin	Pterostilbene	Pterosupin	Formononetin	Marsupin	Standard (Diclofenac)
-2.61	-4.47	-4.56	-3.69	-2.80	-4.58
-4.01	-4.65	-3.01	-4.17	-2.57	-5.14
-3.47	-4.73	-2.61	-4.21	-2.63	-4.72
-2.54	-5.03	-4.28	-4.07	-2.56	-5.10
-3.63	-5.08	-2.98	-3.39	-1.35	-5.06
-3.83	-4.84	-2.70	-3.60	-2.44	-4.88
-2.78	-4.84	-3.86	-3.77	-2.14	-5.15
-3.68	-4.85	-3.54	-4.32	-2.99	-5.11
-2.75	-5.25	-3.08	-4.03	-2.58	-5.16
-4.11	-4.68	-4.02	-4.19	-3.20	-4.64

Table 22: Molecular Docking (5F19).



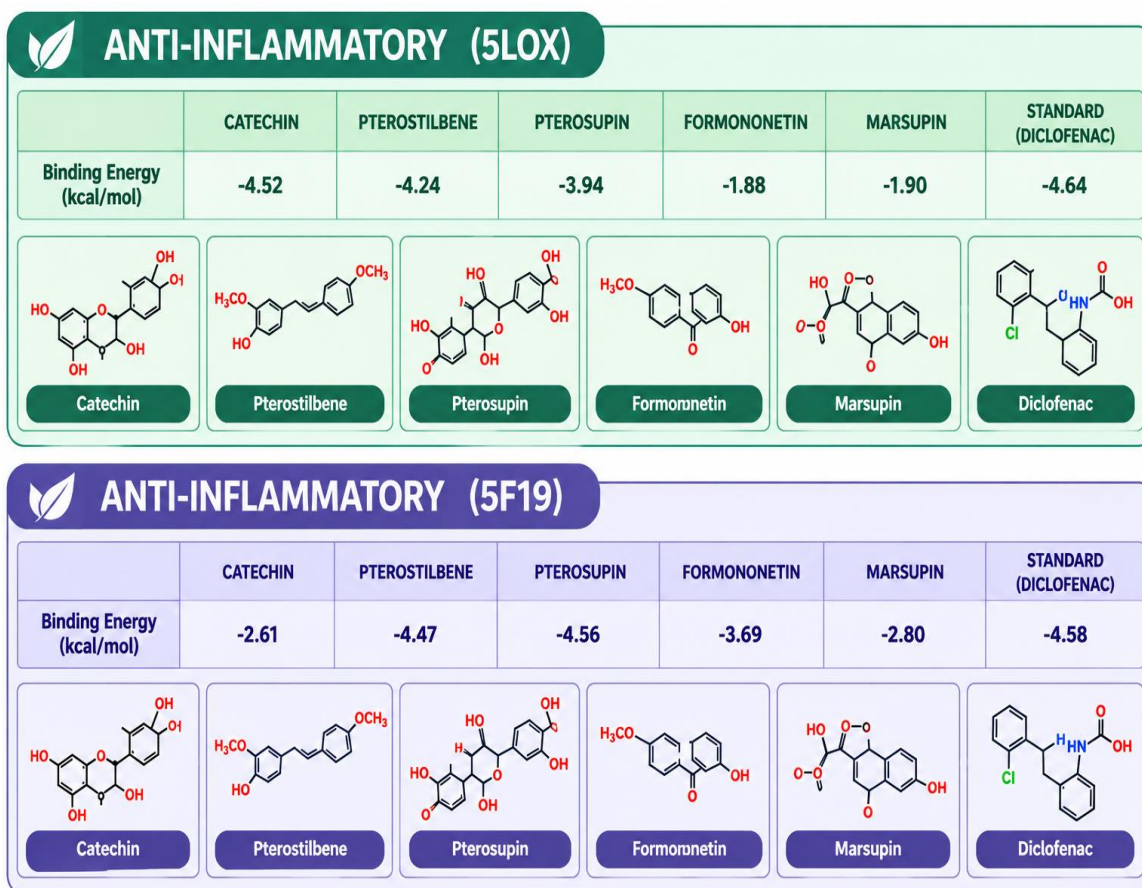


Fig. 13: Molecular Docking Results.

DISCUSSION

Green synthesis of silver nanoparticles using *Pterocarpus marsupium* stem extract was successfully achieved due to the presence of bioactive phytochemicals capable of reducing silver ions and stabilizing the formed nanoparticles. Phytochemical analysis revealed the presence of flavonoids, tannins, phenolic compounds, glycosides, alkaloids, and saponins, which are known for their antioxidant and anti-inflammatory properties. UV-Visible spectroscopic analysis showed an absorption peak at approximately 410 nm, confirming the formation of silver nanoparticles. FTIR analysis indicated the involvement of plant-derived functional groups in nanoparticle stabilization.

SEM studies demonstrated nanosized particles with relatively uniform morphology. Particle size distribution analysis confirmed the nanoscale range and acceptable polydispersity. The prepared nanoparticle-loaded gels exhibited desirable physicochemical characteristics, including suitable pH, good spreadability, acceptable viscosity, homogeneity, and no signs of irritation. Among the developed formulations, F3 demonstrated superior gel properties and stability.

In-vitro dissolution studies revealed a sustained release profile of the nanoparticles and gel formulations, indicating prolonged availability of the active constituents. The anti-inflammatory study showed that nanoparticle-loaded gels produced greater inhibition of protein denaturation than the crude nanoparticle formulation, suggesting enhanced therapeutic effectiveness due to improved drug release and skin retention. Formulation F3 exhibited the highest percentage inhibition, indicating its potential as the optimized formulation.

Molecular docking studies demonstrated favorable binding interactions between the major phytoconstituents and inflammatory target proteins, supporting the observed biological activity. These results suggest a synergistic contribution of phytochemicals and silver nanoparticles toward anti-inflammatory effects.

4. CONCLUSION

The present investigation successfully demonstrated the green synthesis of silver nanoparticles from *Pterocarpus marsupium* Roxb stem extract and their successful incorporation into a topical gel system. Characterization studies confirmed nanoparticle formation and stability, while phytochemical screening revealed the presence of important bioactive constituents responsible for therapeutic activity. The formulated nanoparticle-loaded gels exhibited desirable physicochemical properties, sustained drug release behavior, and excellent skin compatibility. Among all formulations, F3 showed superior performance with maximum anti-inflammatory activity and favorable release characteristics. Molecular docking studies further supported the anti-inflammatory potential of the phytoconstituents. Therefore, *Pterocarpus marsupium* silver nanoparticle-loaded topical gel can be considered a promising herbal nanoformulation for the management of inflammatory conditions and warrants further in-vivo and clinical investigations.

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