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FORMULATION AND CHARACTERIZATION OF ANTIMICROBIAL TOPICAL GELS INCORPORATING JAMUN SEED MEDIATED ZINC OXIDE AND SILVER NANOPARTICLES

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ABSTRACT

This study aimed to formulate and evaluate topical gels loaded with zinc oxide and silver nanoparticles synthesized using *Syzygium cumini* (Jamun) seed extract through an aqueous decoction method. Preformulation studies, including solubility analysis and ultraviolet spectrophotometric calibration, confirmed the suitability of the seed powder for formulation development. Zinc oxide nanoparticles were synthesized by reacting zinc sulphate with the extract under alkaline conditions, while silver nanoparticles were produced by incubating silver nitrate with the extract in dark conditions. Silver nanoparticles demonstrated a drug content of 84.87% and an entrapment efficiency of 86.76%, and % drug release of 80.45%, while zinc oxide nanoparticles showed 86.45%, 89.67%, and 86.45% respectively. Scanning electron microscopy confirmed the uniform distribution of nano-sized particles, and Fourier-transform infrared spectroscopy indicated no significant chemical interactions between the components. The optimized nanoparticles were incorporated into a gel base consisting of hydroxypropyl methylcellulose and Carbopol. The final gel formulations exhibited a clarity test (light brown colour formulation), pH range of 6.8 to 7.0, excellent spreadability. In-vitro release studies showed that the biogenic silver nanoparticle gel achieved 96.38% drug release over eight hours, following diffusion-controlled kinetics, providing superior antimicrobial potential and sustained release, suggesting its effectiveness as a stable topical drug delivery system.

Keywords: *Jamun seed extract, Green synthesis, Zinc oxide nano particles, Silver nanoparticles, Topical drug delivery.*

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INTRODUCTION

Skin and soft tissue infections (SSTIs) represent a common and persistent public health problem worldwide, affecting individuals of all age groups and significantly contributing to morbidity and healthcare expenditure. These infections are frequently caused by bacterial pathogens and often require prolonged treatment, particularly in regions where access to adequate medical facilities is limited. In recent years, the increasing incidence of antimicrobial resistance has further complicated the management of these infections, reducing the effectiveness of many conventional therapeutic agents [1]. In addition, traditional topical formulations commonly used for the treatment of skin infections often show limitations such as inadequate penetration through the skin barrier, short residence time at the site of application, instability of active ingredients, and irregular drug release, which can ultimately compromise therapeutic outcomes. Consequently, the development of improved drug delivery systems with enhanced antimicrobial effectiveness has become an important focus in pharmaceutical research [2]. Nanotechnology has emerged as a promising field in modern pharmaceutical sciences, offering innovative approaches for improving drug delivery and therapeutic performance. Nanoparticles possess unique physicochemical properties, including a high surface area-to-volume ratio and small particle size, which enhance their interaction with microbial cells and biological membranes. Among various nanomaterials studied for biomedical applications, zinc oxide nanoparticles (ZnO NPs) have gained considerable attention due to their broad-spectrum antimicrobial activity, biocompatibility, and additional pharmacological benefits such as anti-inflammatory and wound-healing properties [3]. These characteristics make ZnO nanoparticles particularly suitable for topical antimicrobial formulations. However, many conventional methods used for synthesizing nanoparticles involve hazardous chemicals, complex procedures, and high energy consumption, which may

pose environmental and biological risks [4-5]. To address these concerns, green synthesis methods utilizing plant extracts have been increasingly investigated as eco-friendly and sustainable alternatives for nanoparticle production. Plant-mediated synthesis offers several advantages, including reduced toxicity, cost-effectiveness, and improved biocompatibility. Plant extracts contain a wide variety of phytochemicals such as phenolic compounds, flavonoids, tannins, and alkaloids that can function both as reducing agents and stabilizing agents during nanoparticle formation. Among various medicinal plants, *Syzygium cumini* (L.) Skeels, commonly known as Jamun, has attracted significant scientific interest due to its rich phytochemical profile and diverse therapeutic properties. Studies have reported that different parts of this plant, particularly the seeds, contain biologically active compounds that exhibit antioxidant, antimicrobial, anti-inflammatory, and antidiabetic activities. These phytochemical constituents make *Syzygium cumini* a suitable candidate for the green synthesis of metal nanoparticles with potential biomedical applications. Despite the promising antimicrobial potential of plant-mediated nanoparticles, their direct application to the skin may present certain challenges such as aggregation of particles, limited retention time, and uneven distribution on the skin surface [6]. To overcome these limitations, the incorporation of nanoparticles into suitable topical delivery systems has been widely explored. Gel-based formulations are particularly advantageous for topical administration due to their non-greasy nature, ease of application, good spreadability, and ability to maintain prolonged contact with the skin [7]. Polymers such as Carbopol are commonly employed in gel formulations because they provide desirable rheological and bioadhesive properties that contribute to the stability and effectiveness of semisolid preparations [8,9]. Moreover, topical gels can facilitate controlled drug release and enhance patient compliance compared with conventional dosage forms [10].

Therefore, the development of nanoparticle-loaded gel formulations using plant-mediated synthesis represents a promising approach for improving topical antimicrobial therapy. In this context, the present study focuses on the green synthesis of zinc oxide nanoparticles using *Syzygium cumini* seed extract and their incorporation into a topical gel formulation. This strategy combines the antimicrobial potential of ZnO nanoparticles with the therapeutic properties of plant-derived phytochemicals and the advantages of gel-based drug delivery systems, thereby offering a sustainable and potentially effective approach for the management of skin infections [7,11].

MATERIALS

The materials used in the present study included Jamun (*Syzygium cumini*) seeds, zinc sulphate heptahydrate ($ZnSO_4 \cdot 7H_2O$), silver nitrate ($AgNO_3$), zinc chloride ($ZnCl_2$), Carbopol 934 (E15), hydroxypropyl methylcellulose (HPMC), ethanol, sodium hydroxide (NaOH), and deionized water. All reagents were of analytical grade and used as received without further purification.

METHODOLOGY

Preparation of *Syzygium cumini* Seed Extract

Mature seeds of *Syzygium cumini* were collected and washed thoroughly with distilled water to remove adhering impurities. The cleaned seeds were shade-dried at room temperature to preserve heat-sensitive phytochemical constituents. After complete drying, the seeds were ground into a fine powder using a mechanical grinder to increase the surface area for efficient extraction.

Approximately 2 g of the powdered material was accurately weighed using an analytical balance and transferred into a clean 50 mL beaker. About 10 mL of deionised water was added as the extraction solvent, and the mixture was subjected to hot maceration on a magnetic stirrer equipped with a hot plate at 65 °C for 2 h under continuous stirring. Controlled heating facilitates the extraction of water-soluble phytoconstituents such as phenolic compounds, flavonoids, tannins, alkaloids, and glycosides while minimizing degradation of thermolabile compounds [1–3].

During the extraction process, the solution gradually developed a yellow coloration, indicating the diffusion of phytochemicals into the aqueous medium. After completion of the extraction period, the mixture was allowed to cool to room temperature and then filtered through Whatman filter paper to remove insoluble residues. The resulting clear filtrate was collected as the aqueous seed extract and stored in sterile containers at 4 °C for further experimental use.

Methodology 1

Green Synthesis of Zinc Oxide Nanoparticles from *Syzygium cumini* Seeds

Zinc oxide nanoparticles were synthesized using a plant-mediated green synthesis approach in which *Syzygium cumini* seed extract served as a natural reducing and stabilizing agent. A 0.1 M zinc sulfate solution was prepared by dissolving 2.8754 g of $ZnSO_4$ in 100 mL of distilled water with continuous stirring until a clear and homogeneous solution was obtained.

Subsequently, 10 mL of the prepared seed extract was added dropwise to the zinc sulfate solution under constant stirring. The interaction between zinc ions and phytochemical constituents present in the extract was indicated by the development of a pale yellowcolor in the reaction mixture. The pH of the solution was gradually adjusted to 10 through the slow addition of 0.1 M sodium hydroxide solution, which resulted in the formation of a white precipitate of zinc hydroxide. Upon aging and subsequent drying, the precipitate was converted into zinc oxide nanoparticles [4,5].

The precipitate was collected by filtration and washed several times with distilled water to remove unreacted impurities. The obtained material was then dried in a hot air oven at 75 °C for approximately 180 min to yield zinc oxide nanoparticles as a fine white powder. The dried nanoparticles were stored in airtight containers for further characterization and formulation studies.

Methodology 2

Green Synthesis of Silver Nanoparticles from *Syzygium cumini* Seeds

For the preparation of silver nanoparticles, 5 g of powdered *Syzygium cumini* seeds was boiled in 100 mL of deionised water for approximately 5 min. The mixture was allowed to

cool and then filtered to obtain a clear plant extract. The filtrate was further centrifuged at 5000 rpm for 15 min at 4 °C, and the resulting supernatant was used as the reducing medium for nanoparticle synthesis [6].

For the synthesis process, 10 mL of the plant extract was mixed with 90 mL of a 1 mM aqueous silver nitrate solution. The reaction mixture was incubated under dark conditions at room temperature for 24 h. A visible color change from pale yellow to brown confirmed the formation of silver nanoparticles due to the reduction of Ag^+ ions by phytochemicals present in the extract. The synthesized nanoparticles were collected by centrifugation, washed with distilled water to remove residual impurities, and lyophilized to obtain a dry nanoparticle powder for further analysis and antimicrobial evaluation [6,7].

Methodology 3

Preparation of Herbal Gel Containing *Syzygium cumini* Extract

The herbal gel formulation was prepared using hydroxypropyl methylcellulose (HPMC) and Carbopol as gelling agents in a 1:1 ratio to achieve suitable viscosity and gel strength. The polymers were dispersed in distilled water and allowed to hydrate for approximately 24 h to ensure complete swelling and uniform dispersion [8,9].

The hydrated polymer mixture was then mechanically stirred at 1000 rpm to obtain a smooth and homogeneous gel base free from lumps. Triethanolamine (TEA) was added dropwise to the formulation to adjust the pH to approximately 7.0, resulting in proper gel formation due to neutralization of the Carbopol polymer [9,10].

After gel formation, the prepared *Syzygium cumini* seed extract was incorporated into the gel base with continuous stirring for about 30 min to obtain a uniform formulation suitable for topical application. For nanoparticle-loaded formulations, approximately 3 g of jamun extract containing either zinc oxide nanoparticles or silver nanoparticles was incorporated into 25 g of the prepared gel base to obtain ZnO nanoparticle gel and Ag nanoparticle gel formulations, respectively [10,11].

Evaluation of Herbal Gel Formulation

Determination of pH

The pH of the prepared *Syzygium cumini* (jamun) seed extract, synthesized nanoparticles, and gel formulations was measured using a calibrated digital pH meter. For the analysis, about 1 g of the sample was dispersed in 10 mL of distilled water and allowed to equilibrate for approximately 30 minutes. After equilibration, the pH electrode was immersed into the sample solution and the reading was recorded at room temperature. Maintaining a suitable pH is essential for topical formulations because it should be close to the natural pH of the skin to prevent irritation and to maintain formulation stability during storage and application [8,10].

Spreadability Test

The spreadability of the prepared gel was assessed using the slip-and-drag technique. Around 1 g of the gel formulation was placed between two clean glass slides. A specific weight was then applied on the upper slide to allow the gel to spread uniformly. The time required for the upper slide to move a predetermined distance under the applied weight was measured. Adequate spreadability indicates that the formulation can be easily applied and evenly distributed on the skin surface, which improves patient compliance and therapeutic effectiveness [9,10].

Drug Content Determination

The amount of drug present in the gel containing silver and zinc oxide nanoparticles was determined spectrophotometrically. Approximately 1 g of the gel formulation was dissolved in 100 mL of phosphate buffer solution (pH 7.4). The mixture was continuously stirred to ensure complete release of the drug from the gel base and then filtered using Whatman filter paper to remove insoluble materials. The absorbance of the filtered solution was measured using a UV–Visible spectrophotometer at a suitable wavelength. The drug concentration in the sample was calculated with the help of a previously established calibration curve [6,7].

Drug Entrapment Efficiency

The entrapment efficiency of the nanoparticle-loaded formulation was evaluated using a centrifugation technique. A known quantity of the nanoparticle dispersion was centrifuged at 10,000 rpm for 30 minutes to separate the free drug from the drug entrapped within the nanoparticles. The supernatant obtained after centrifugation, which contained the unentrapped drug, was analyzed using spectrophotometric methods. The percentage of drug entrapped within the nanoparticle system was calculated using the following equation:

Entrapment Efficiency (%) = (Total drug − Free drug) / Total drug × 100

This parameter represents the proportion of drug effectively incorporated into the nanoparticle carrier system and provides insight into the efficiency of the formulation process [5,7].

In Vitro Drug Release Study

The release behavior of the drug from the gel formulation was evaluated through an in vitro drug release study using the dialysis membrane method. A measured amount of the drug-loaded gel was placed inside a dialysis membrane, which was then immersed in 100 mL of phosphate buffer solution (pH 7.4). The release medium was maintained at 37 ± 0.5°C and continuously stirred to simulate physiological conditions. At specific time intervals, 5 mL samples were withdrawn from the release medium and replaced with an equal volume of fresh buffer to maintain constant volume and sink conditions. The collected samples were analyzed using a UV–Visible spectrophotometer at the appropriate wavelength to determine the amount of drug released. The cumulative percentage drug release was calculated and plotted against time to study the release profile of the formulation[9,10].

RESULTS AND DISSCUSSIONS

The following section details the preformulation, characterization, and evaluation of Jamun (*Syzygium cumini*) seed-based nanoparticle gel formulations.

1. Preformulation Studies of Jamun Seed Powder

1.1 Organoleptic Properties: Organoleptic properties of Jamun seed powder were observed and results were given below

Table 01: Organoleptic properties of Jamun seed powder

Organoleptic properties	Result
Colour	Light brown
Crystallinity	A fine powder
Taste	Mildly Bitter and Astringent
Odour	A strong, Characteristic herbal Odor

1.2. Solubility Profile The solubility of the powder was tested in various solvents to determine the most effective medium for extraction.

Table 02: Solubility of Jamun seed powder

Name of Solvent	Solubility and Inference
Distilled water	Forms a suspension; lower solubility index (~4-8%)
Phosphate buffer (pH 6.8)	Similar to water, soluble due to neutral Ph
Phosphate buffer (pH 7.4)	Soluble; slightly basic pH aids dissolution of some acidic compounds
HCl (0.1N)	Very slightly soluble; acidic conditions can protonate some compounds reducing solubility
NaOH (0.05N)	Soluble; basic conditions significantly aid the dissolution of phenolic and acidic compounds

1.3 Melting Point The melting point of the pure Jamun seed powder was found to be between **260°C and 270°C**, consistent with established literature.Melting point of pure **Jamun seed powder** was found to be ± 1.15 ^{0}C this is corresponded with the reported melting point.

Table 3: Melting point of the pure Jamun seed powder

S. No	Melting point (^{0}C)	Mean± SD (n=3)
1	258	259± 1.15^{0}C
2	259	
3	260	

1.4. Calibration curve of Jamun seed powder:

Data for calibration curve of Jamun seed powder in pH 6.8 phosphate buffer is given in below table. The calibration curve is obtained with regression equation and correlation coefficient which is

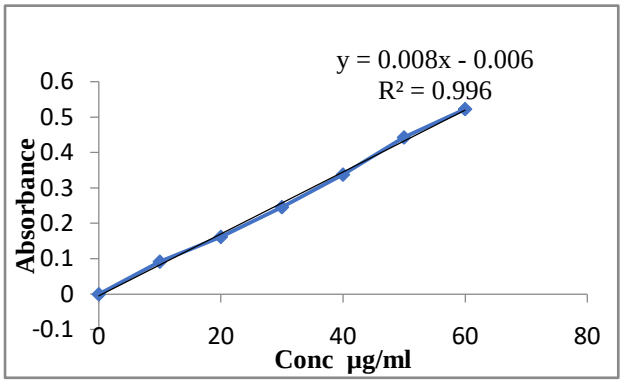


Figure 01: Calibration curve of Jamun seed powder

Table 04: Calibration curve of jamun seed powder in pH 6.8 phosphate buffer.

S.NO	Conc (µg/ml)	Absorbance (Mean ± SD) (n=3)
0	0	0.00
1	10	0.093 ± 0.032
2	20	0.128 ± 0.042
3	30	0.246 ± 0.028
4	40	0.328 ± 0.053
5	50	0.440 ± 0.011
6	60	0.523 ± 0.320

2. Characterization and evaluation studies of formulations:

2.1. Characterization and evaluation studies of Jamun seed ZnO Nanoparticles and Jamun seed Ag Nanoparticles:

A). % Drug content: % Drug content ofJamun seed ZnO and Jamun seed Ag Nanoparticles (A1-A4 & B1-B4) was calculated and results reported in Table.

Table 05: %Drug content of A. Jamun seed ZnO Nanoparticles(A1-A4)

B. Jamun seed Ag Nanoparticles formulations (B1-B4).

Formulation code		% Drug content	
J ZnO	J Ag	J ZnO	J Ag
A1	B1	21.13	38.98
A2	B2	48.98	47.01
A3	B3	86.45	66.17
A4	B4	73.17	84.87

B). % Drug entrapment efficiency: % Drug entrapment efficiency of**Jamun seed ZnO Nanoparticles and Jamun seed Ag Nanoparticles:** formulations (A1-A4 & B1-B4) was calculated and results reported in Table:

Table 06: % Drug entrapment efficiency of A. Jamun seed ZnO Nanoparticles(A1-A4)

B. Jamun seed Ag Nanoparticles formulations (B1-B4)

C). *In-vitro* drug release: % Drug release of **Jamun seed ZnO Nanoparticles and Jamun seed Ag Nanoparticles formulations** was calculated and results reported in Table:

Formulation code		% Drug entrapment efficiency	
J ZnO	J Ag	J ZnO	J Ag
A1	B1	43.04	20.02
A2	B2	74.0	59.06
A3	B3	89.67	62.56
A4	B4	70.06	86.76

Table 07*: In-vitro* drug release of A. Jamun seed ZnO Nanoparticles(A1-A4)
B. Jamun seed Ag Nanoparticles formulations (B1-B4).

Time (Hrs)	Cumulative % Drug release							
	A1	A2	A3	A4	B1	B2	B3	B4
0	0	0	0	0	0	0	0	0
1	5.82 ± 0.02	6.53 ±0.01	9.44 ±0.01	6.25 ±0.02	5.49 ±0.03	7.53 ±0.01	6.82 ± 0.02	8.42±0.01
2	11.58 ± 0.01	12.20 ± 0.03	20.12 ± 0.3	11.55 ± 0.01	13.68 ± 0.3	14.20 ± 0.03	11.58 ± 0.01	19.12 ± 0.3
3	18.22 ±0.03	16.52 ±0.01	45.42±0.02	15.82 ±0.01	17.22±0.01	19.52 ±0.01	17.25 ±0.03	25.42±0.02
4	22.64 ±0.02	19.33 ±0.01	52.98±0.1	22.20 ±0.02	22.82 ±0.03	24.33 ±0.01	22.94 ±0.02	42.98±0.01
5	30.92 ±0.02	26.48 ±0.01	55.92±0.3	28.23 ±0.03	24.58 ±0.01	29.84 ±0.01	30.29 ±0.02	55.92±0.3
6	34.83 ±0.01	27.45 ±0.03	67.32±0.01	30.01 ±0.02	25.23 ±0.02	34.15 ±0.03	38.88 ±0.01	67.32±0.01
7	42.22 ±0.02	32.98 ±0.01	73.98±0.02	33.39 ±0.01	26.92 ±0.3	42.68 ±0.01	48.22 ±0.02	75.98±0.02
8	46.18 ±0.03	35.88 ±0.02	86.45±0.01	37.82 ±0.12	28.98 ±0.02	55.88 ±0.02	50.18 ±0.03	80.45±0.01

Note: From the above results i.e. characterization and evaluation studies of **Jamun seed ZnO Nanoparticles and Jamun seed Ag Nanoparticles**; A3 and B4 formulations were selected for the further studies because they produce better results compared to other formulations.

2.2. Evaluation studies for different gel formulations

Appearance, pH, spreadability and cumulative % drug release of jamun loaded gel formulations were evaluated and reported in Table:

Table 08: Evaluation of Gel formulations

S.NO	Gel Formulation	Appearance	pH mean SD± n= 3	Spreadability mean SD± n= 3 (cm/5 min)	Cumulative % Drug release (for 1hr)
1	HPMC 3%	Homogeneous and transparent	6.8±0,2	4.07±0.12	68.12
2	HPMC 3.5%	Homogeneous and transparent	7.0±0.1	4.55±0.02	59.11
3	HPMC 4%	Homogeneous and transparent	7.2±0.2	4.8±0.09	45.10
4	Carbopol 0.6%	Homogeneous and transparent	6.7±0.2	3.54±0.29	33.20
5	Carbopol 0.8%	Homogeneous and transparent	7.1±0.2	4.12±0.18	54.82
6	Carbopol 1%	Homogeneous and transparent	6.8±0.1	4.84±0.22	73.93
7	H:C 1:1	Homogeneous and transparent	6.9±0.1	3.03±0.15	92.30
8	H:C 2:1	Homogeneous and transparent	7.2±0.2	4.5±0.04	62.14
9	H:C 1:2	Homogeneous and transparent	7.1±0.1	4.33±0.25	64.28

Note: From the above results i.e. Evaluation studies of different gel formulations; H: C (HPMC: Carbopol) 1:1 formulation is selected for the further studies because it produces better results compared to other gel formulations.

2.3. Characterization and evaluation studies of Jamun seed ZnO Nanoparticles loaded Gel formulation and Jamun seed Ag Nanoparticles loaded Gel formulations:

A. Clarity test: The formulations were visually checked for clarity and it is appeared like Light brown Semisolid Formulation.

B. pH analysis:pH of formulation is determined by using digital pH meter by immersing the electrode in gel formulation and pH is measured results shown in table .

C. Spreadability: Spreadability was expressed in terms of time in seconds. Take two slides to slip off from the gel, placed in between the slides, under certain weight. Lesser the time taken for separation of the two slides, better the spreadability.

Table 09: Appearance, pH and spreadability of optimised Jamun seed ZnO-Ag Nanoparticles loaded gel formulations.

S.NO	Formulation code	Appearance	pH mean SD± n= 3	Spreadability mean SD± n= 3(cm/5 min)
1	A3	Light brown Semisolid Formulation	7.0±0.1	3.45±0.02
2	B4	Light brown Semisolid Formulation	6.8±0.2	4.57±0.12

D. % Drug content:

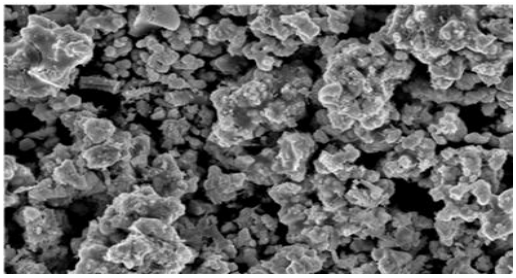
Table 10: % Drug content of Jamun seed ZnO Nanoparticles loaded Gel formulation and Jamun seed Ag Nanoparticles loaded Gel formulations

Formulation code	% Drug content
A3	56.50
B4	85.52

E. % Drug entrapment efficiency: % Drug entrapment efficiency of **Jamun seed ZnO Nanoparticlesloaded Gel formulation and Jamun seed Ag Nanoparticles loaded Gel**formulations were calculated and results of % drug entrapment efficiency were found to be in the range of 48.00 % - 94.40 %. The results revealed that maximum amount of drug entrapped into the formulation B4.

Table 11: % Drug entrapment efficiency of Jamun seed ZnO Nanoparticles loaded Gel formulation and Jamun seed Ag Nanoparticles loaded Gel formulation.

F. SEM: (**Scanning Electron Microscopy**): It appeared like nano size particles.



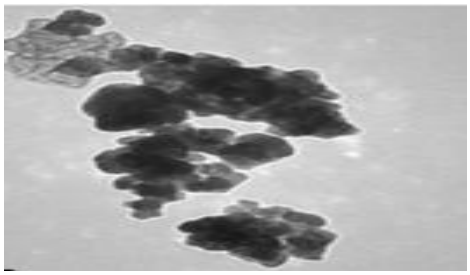
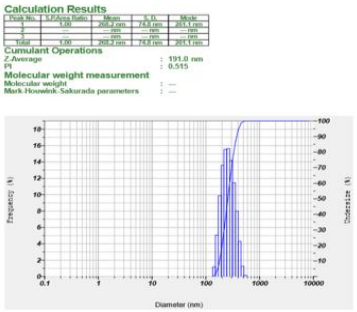
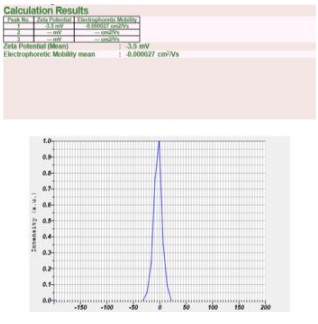


Figure 02: Jamun seed ZnO Nano Particles

Figure 03: Jamun seed Ag Nano Particles

G. Particle size analysis of Jamun seed ZnO Nanoparticles loaded Gel formulation and Jamun seed Ag Nanoparticles loaded Gel formulations





Figures 04 & 05: Particle size analysis, zeta potential and Poly dispersability index of optimised formulations.

Table 12: Particle size analysis, zeta potential and Poly dispersability index of optimised formulations

Particle size analysis, zeta potential and Poly dispersability index			
Formulation	**Z- Average size (d.nm)**	**Poly dispersability index**	**Z-Potential (mV)**
A3	122.0	0.726	-6.2
B4	191.0	0.515	-3.5

H). FT-IR studies of Jamun seed powder:FT-IR spectroscopic study of the **Jamun seed powder** was shown in the below table 15 and figure. In FT-IR spectrum of Jamun seed powder characteristic peaks are coincides with the reported peak values.

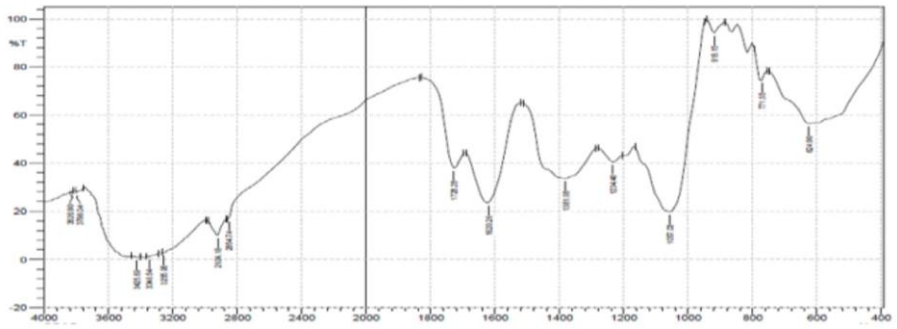


Figure 06: FT-IR spectrum of Jamun seed powder

Table 13: FT-IR characteristic peaks of Jamun seed powder

Functional Group	Wave number (cm^{-1}) obtained
O-H stretching (alcohols, phenols, water)	~3400
C-H stretching (methyl/methylene groups)	~2900
C=O stretching (carbonyl, ester, aldehyde)	~1730
C=C stretching (aromatic ring) / **N-H bending** (amine)	~1630
C-H bending	~1465 and ~1355
C-O stretching (ether, phenolic structures)	~1230
C-O-C stretching (pyranose ring in cellulose)	~1157 and ~1024
C-H bending /⍰-glycosidic linkages	~920 and ~860
C-Cl stretching (organohalides)	~770

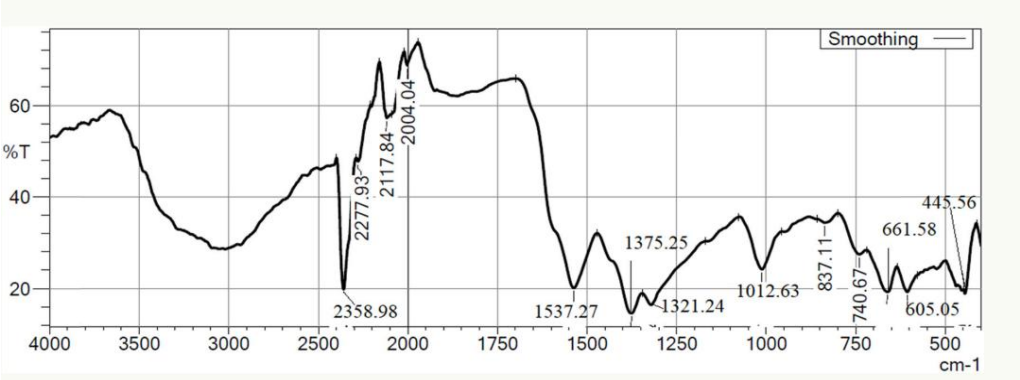


Figure 07: FT-IR spectrum of ZnO Jamun seed Nano particles

Table 14: FT-IR characteristic peaks of ZnO Jamun seed Nano particles

Functional groups	Wave numbers (cm^{-1}) obtained
O-H stretching (alcohols, phenols)	~3400
C-H stretching (alkanes)	~2900
C=O stretching (carbonyl, ester)	~1730
C=C stretching (aromatic ring) or **N-H bending** (amine)	~1630
C-H bending	~1465 and ~1355
C-O stretching (ether, phenol, alcohol)	~1230
C-O-C stretching (glycosidic linkages)	~1157 and ~1024
C-H bending or **C-Cl stretching** (organohalides)	~770

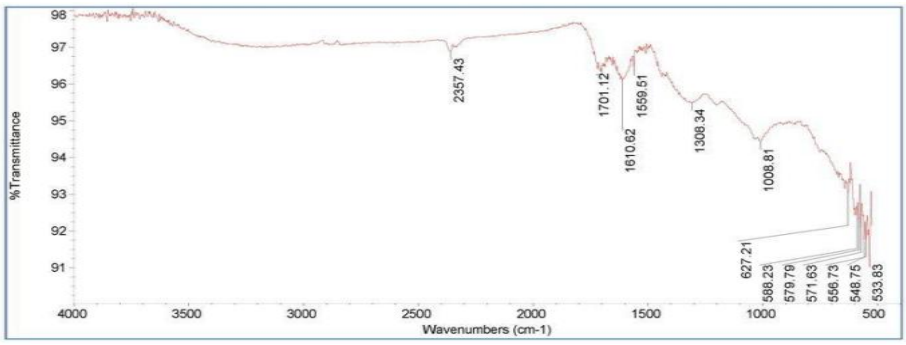


Figure 08: FT-IR spectrum of Ag Jamun seed Nano particles

Table15: FT-IR characteristic peaks of Ag Jamun seed Nano particles

Functional groups	Wave numbers (cm^{-1}) obtained
O-H stretching	~3400 (broad peak)
C-H stretching	~2900 (broad, jagged peaks)
C=O stretching	**1701.12**
C=C stretching (aromatic)	**1610.62**, **1559.51**
C-H bending	**1465**, **1355**
C-O stretching	**1230**, **1008.81**
C-Cl stretching	**627.21**
O=C=O stretching	**2357.43** (likely atmospheric CO\u2082)

I). % Drug release::% Drug release of **Jamun seed ZnO Nanoparticles loaded Gel formulation and Jamun seed Ag Nanoparticles loaded Gel formulations** was calculated and given below

Table 16: % Drug release of Jamun seed ZnO Nanoparticles B. Jamun seed Ag Nanoparticles formulations

Time	Cumulative % drug release	
	A3	B4
0 min	0	0
5 min	8.44± 0.01	10.02± 0.02
10 min	13.82± 0.01	21.53± 0.1
15 min	15.62± 0.02	28.22± 0.03
20 min	18.33± 0.02	31.09± 0.04
25 min	21.09± 0.3	35.82± 0.01
30 min	23.35± 0.04	39.99± 0.02
35 min	25.66± 0.01	44.38± 0.02
40 min	29.76± 0.02	49.0± 0.01
45 min	33.99± 0.01	53.55± 0.02
50 min	36.43± 0.03	58.69± 0.3
55 min	38.02± 0.03	60.88± 0.05
1hr	40.58± 0.01	64.95± 0.02
1 ½ hr	42.44± 0.01	68.02± 0.04
2 hr	43.52± 0.02	70.54± 0.02
2 ½ hr	44.38± 0.03	71.05± 0.02
3 hr	46.66± 0.05	73.83± 0.3
4 hr	47.55± 0.02	74.55± 0.02
5 hr	49.23± 0.02	76.93± 0.03
6 hr	58.58± 0.02	81.09± 0.01
7 hr	64.44± 0.01	88.48± 0.02
8 hr	75.62± 0.01	96.38± 0.02

J). Drug release kinetics: *In-vitro*drug release data obtained was fit to different kinetic models like Zero-order, First order, Higuchi, Hixson-Crowell, Korsmeyer-Peppas plots and results were shown in the table.

Regression coefficient (R2) was considered to be main parameter for interpreting the drug release kinetics.

Zero order and first order kinetics:

Data obtained from *in vitro* drug release studies, are plotted as cumulative % drug release versus time (Zero order) and log cumulative % drug remaining versus time (First order).

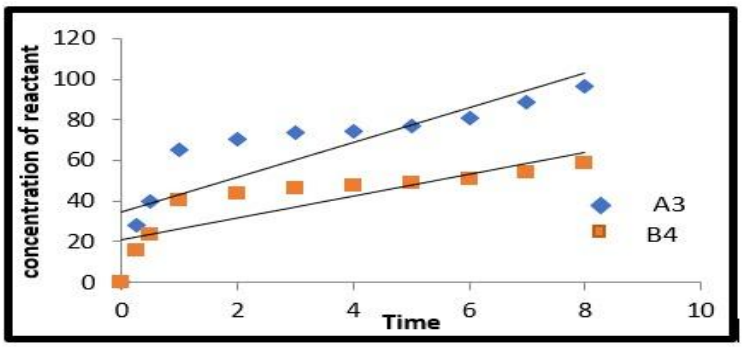


Figure 09: Zero order kinetics of A3&B4 Jamun seed ZnO & Ag nano particles

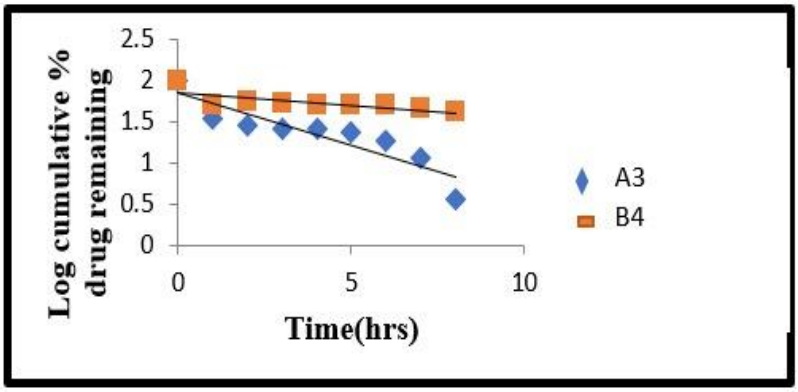


Figure 10: First order kinetics of A3&B4 Jamun seed ZnO Nanoparticles & Jamun seed Ag Nanoparticles.

Higuchi and Korsmeyer-Peppas kinetic models: Data obtained from *in vitro* drug release studies, are plotted as cumulative % drug release versus square root of time (Higuchi plot) and log cumulative % drug release versus log time (Korsmeyer- peppas plot).

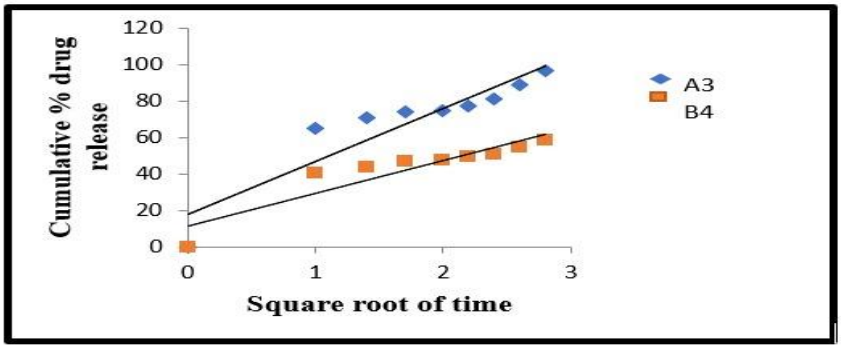


Figure 11: Higuchi kinetic model of A3 and B4 Jamun seed ZnO Nanoparticles & Jamun seed Ag Nanoparticles

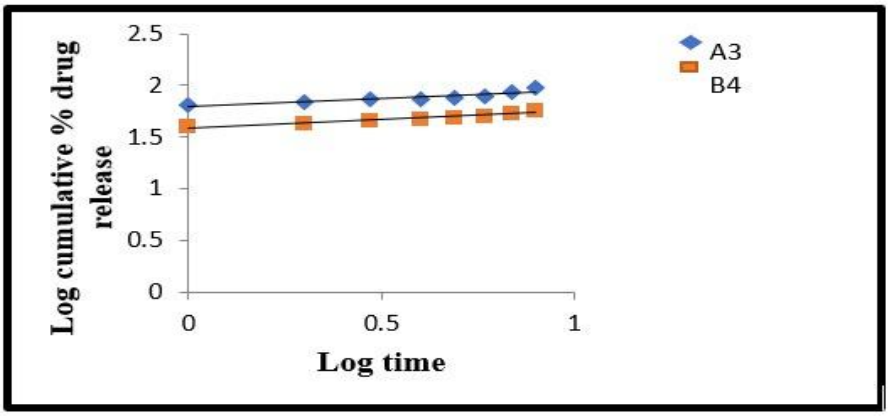


Fig 12: Korsmeyer-Peppas kinetic model of A3 and B4 Jamun seed ZnO Nanoparticles & Jamun seed Ag Nanoparticles

Hixson Crowell kinetic model: Data obtained from *in vitro* drug release studies, are plotted as cube root of % drug release versus time.

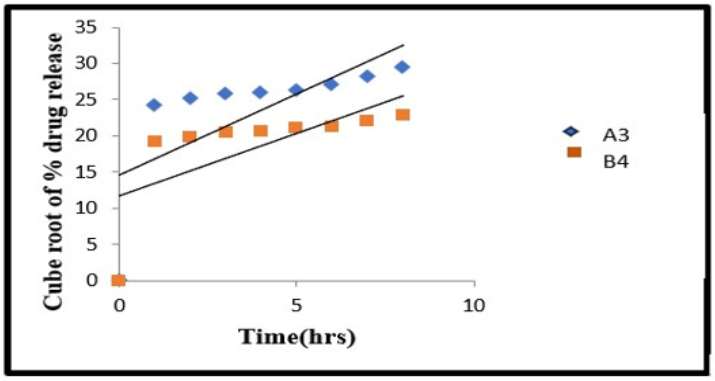


Fig 13: Hixson Crowell kinetic model of A3 and B4 Jamun seed ZnO Nanoparticles & Jamun seed Ag Nanoparticles.

Table 17 : Drug release kinetics regression values for A3&B4 Jamun seed ZnO Nanoparticles & Jamun seed Ag Nanoparticles.

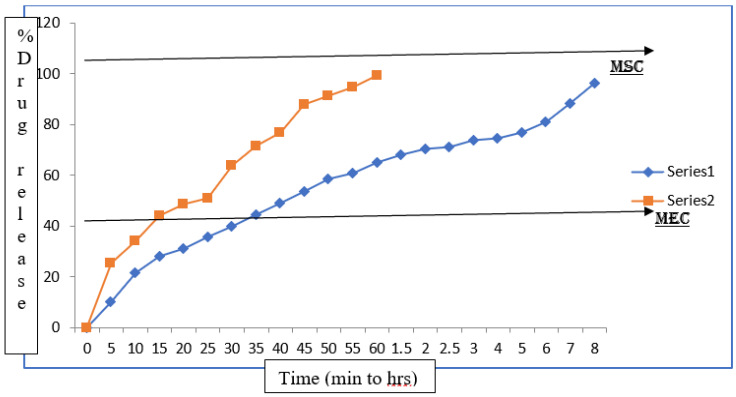
Formulation code	Zero order R^2	First order R^2	Higuchi model R^2	Hixson Crowell model R^2	KorsMeyer-Peppas model R^2	n value for Korsmeyer-Peppas model
A3	0.981	0.932	0.938	0.820	0.758	0.80
B4	0.979	0.893	0.924	0.853	0.652	0.84

NOTE: The R^2 values for the formulations mentioned in above table and highest regression coefficient obtained for the zero-order kinetics. This indicates that the drug release from the all the formulations followed the diffusion-controlled release mechanism.

I). % Drug release of marketed formulation (Anti-microbial silver gel):

Table 18: % Drug release of marketed formulation (Anti-microbial silver gel)

S.NO	Time (min)	Cumulative % drug release
1	0	13.35±0.01
2	5	25.26±0.23
3	10	34.29±0.06
4	15	43.99±0.3
5	20	48.84±0.54
6	25	50.99±0.1
7	30	63.82±0.4
8	35	71.64±0.01
9	40	76.93±0.05
10	45	87.81±0.02
11	50	91.22±0.4
12	55	95.01±0.01
13	60	99.38±0.5



Series1- Jamun seed Ag Nanoparticles Gel formulation, Series-2 Marketed formulation (Anti-microbial silver gel).

Fig 14: %Drug release comparison B/W optimised formulation B4 and marketed formulation (Anti-microbial silver gel).

SUMMARY AND CONCLUSION

Green Synthesis of Nanoparticles from *Syzygium Cumini*

This study focused on the eco-friendly "green synthesis" of Zinc Oxide (ZnO) and Silver (Ag) nanoparticles using Jamun (*Syzygium cumini*) seed extract. These nanoparticles were successfully incorporated into a stable topical gel formulation for potential pharmaceutical and dermatological applications.

Methodology & Synthesis

- **Extract Preparation:** 2g of dried Jamun seed powder was macerated in 10 mL of deionised water at 65°C for 2 hours.

The resulting yellow filtrate served as a natural reducing and stabilizing agent, replacing hazardous chemicals.

- **Zinc Oxide Nanoparticles (ZnONPs):** Synthesized by reacting Zinc Sulphate with the extract. The pH was adjusted using Sodium Hydroxide to form a white precipitate, which was then washed, dried, and pulverized.
- **Silver Nanoparticles (AgNPs):** Produced by treating Silver Nitrate solution with the extract under dark conditions to prevent photo-reduction. The process was finalized through purification and lyophilization.
- **Gel Formulation:** A topical gel base was prepared using a 1:1 ratio of HPMC and Carbopol, neutralized with Triethanolamine. The synthesized nanoparticles (either ZnO or Ag) were uniformly blended into this base.

Key Findings

- **Green Synthesis Success:** The use of *Syzygium cumini* extract proved to be an efficient, cost-effective, and non-toxic method for nanoparticle production.
- **Physicochemical Properties:** The final nanoparticle-loaded gels exhibited excellent consistency, skin-compatible pH, and uniform drug distribution.
- **Stability:** The formulation maintained its integrity, demonstrating the effectiveness of the plant-based capping agents in preventing nanoparticle aggregation.

CONCLUSION

The research successfully demonstrates that Jamun seed extract is a viable bio-reductant for metallic nanoparticle synthesis. By integrating these particles into a stable HPMC/Carbopol gel, the study provides a foundation for developing potent, herbal-based antimicrobial and anti-inflammatory topical treatments. This approach aligns with modern "green chemistry" standards, offering a sustainable alternative to traditional chemical synthesis.

AUTHOR CONTRIBUTION

All authors are contributed equally

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Nil

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INFORM CONSENT ETHICAL STATEMENT

Not Applicable

CONFLICT OF INTEREST

Mot Declared

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