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Formulation And Physicochemical Evaluation of a Novel Topical Herbal Gel Containing Cucurbita Maxima and Camellia Sinensis for the Management of Alopecia

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ABSTRACT: Hair is an epidermal derivative originating from the skin ectoderm that serves essential protective and psychosocial roles alongside associated structures like sebaceous glands, sweat glands and nails. Androgenetic alopecia (AGA) represents the preeminent etiology of hair loss globally, impacting up to 70% of the male population as they progress beyond 50 years of age. Traditional medicine frequently leverages botanical extracts as safer alternatives to address premature hair loss and baldness. This investigation describes the design & development and in-vitro characterization of a topical polyherbal gel incorporating bioactive extracts of Cucurbita maxima (pumpkin seeds) and Camellia sinensis (green tea leaves). Following the solvent extraction of pumpkin seeds and green tea leaves, the primary concentrates were systematically incorporated into a carbomer-based matrix via trituration. The resultant formulations were evaluated for diverse physical and rheological parameters, including pH, dynamic viscosity, spread ability, extrudability, washability and dermatological safety via skin irritation metrics. Structural compatibility and potential interactions between the bioactive components and excipients were investigated using Attenuated Total Reflectance-Fourier Transform Infrared Spectroscopy (ATR-FTIR). Furthermore, in-vitro diffusion profiles were mapped using a Franz cell apparatus to isolate the optimized batch.

1. INTRODUCTION

As an anatomical accessory derived from the ectoderm during early embryogenesis, human hair plays a pivotal role in physical protection, thermo-regulation and non-verbal social communication. Distinct patterns of hair length, colour and style heavily influence perceived personality profiles. Consequently, aberrations such as alopecia cause substantial psychological distress. The pathophysiology of androgenetic alopecia (AGA) the most prevalent form of hair loss in aging populations is primarily mediated by genetic predispositions, systemic hormonal imbalances, nutritional deficits, elevated metabolic stress and certain pharmacological therapies [1-3].

At a cellular level, AGA is driven by the hyper-reactivity of hair follicles to dihydrotestosterone (DHT). This interaction induces progressive follicular miniaturization, triggering a shortened anagen (active growth) phase and a prolonged telogen (resting) phase. Current synthetic interventions, such as minoxidil, are frequently limited by adverse clinical profiles, including persistent migraines, pruritus, localized erythema and unwanted hypertrichosis [4-7]. To overcome these limitations, cosmetic science is

increasingly focusing on topical nutraceuticals food-derived bioactive agents that provide distinct therapeutic benefits with diminished toxicological profiles. By transitioning these naturally derived ingredients into structured topical matrices. This study introduces an innovative, stable polyherbal hair gel designed to utilize the synergistic properties of *Cucurbita maxima* and *Camellia sinensis* for hair follicular rejuvenation [8,9].

2. MATERIALS AND METHODS

2.1 Botanical Collection and Processing

Fresh seeds of *Cucurbita maxima* and mature leaves of *Camellia sinensis* were obtained from commercial suppliers in the Salem district of Tamil Nadu, India. The raw pumpkin seeds were mechanically pulverized into a homogeneous powder using an industrial milling unit and stored in hermetically sealed vessels. The green tea leaves were thoroughly shade-dried, ground to a coarse consistency using a mechanical mill, and classified through a standard No. 40 mesh sieve before being stored under moisture-free conditions [10,11].

2.2 Extraction Protocol

- **Cucurbita maxima Seed Extraction:** A 5.0 g aliquot of the prepared seed powder was loaded into a Soxhlet extraction apparatus and subjected to continuous hot percolation using absolute ethanol as the extraction solvent at a controlled temperature range of 60–80°C [12].
- **Camellia sinensis Leaf Extraction:** A 100 g portion of defatted green tea leaf powder was extracted inside a Soxhlet framework using 200 mL of solvent-grade ethanol. The extraction proceeded at a temperature range of 60–70°C until the raw matrix was completely exhausted of phytochemical compounds [13,14].

3. PREFORMULATION CHARACTERIZATION

Pre formulation profiling was performed to establish baseline physicochemical profiles, melting criteria and potential drug-excipient interactions capable of influencing downstream pharmacokinetics or product stability [15].

3.1 Organoleptic Evaluation

The crude polyherbal concentrates were evaluated for foundational organoleptic qualities, including colour uniformity, olfactory characteristics, physical appearance and taste profiles [16].

3.2 Spectrophotometric Target Discovery (λ_{max})

Ultraviolet-Visible (UV-Vis) spectrophotometric analysis was performed using a Shimadzu spectrophotometer. Stock solutions were prepared by dissolving 10 mg of each isolated plant extract into a phosphate buffer platform adjusted to a physiological pH of 6.8. The solution was scanned through an analytical window of 200–800 nm to map the specific absorption maxima (λ max) [17,18].

3.3 Drug-Excipient Compatibility Mapping (ATR-FTIR)

To evaluate structural stability and rule out potential chemical incompatibility between the active botanical fractions and the core polymers, infrared spectra were collected using an Attenuated Total Reflectance (ATR) FTIR spectrophotometer. Samples were placed directly onto the crystal surface of the instrument and scanning was executed over a spectral range of 4000–400 cm^{-1} against a clean background profile [19, 20].

3.4 Gravimetric Yield Quantification

The final extractive yield efficiency for both botanical processes was calculated using the following gravimetric expression: [21]

Evaluation of Herbal Extract Determination of Percentage yield

The percentage yield was calculated by using this formula

$$\% \text{ Yield} = \frac{\text{Weight of the dry extract}}{} \times 100$$

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Weight of the dry Plant

4. PRELIMINARY PHYTOCHEMICAL SCREENING

Standard diagnostic chemical tests were performed on the raw ethanolic fractions to determine the presence of secondary metabolites, including alkaloids, flavonoids, glycosides, tannins, saponins, steroidal compounds and protein complexes.

- **Alkaloids (Mayer's Assay):** Filtrates were treated with a few drops of Mayer's reagent along the tube wall; development of a creamy white precipitate confirmed the presence of alkaloidal structures [22].
- **Flavonoids (Shinoda's Reduction Test):** To a 5 mL sample of extract, dilute hydrochloric acid and a magnesium chloride ribbon were added. The system was heated gently, where a transition to a deep reddish-pink or muddy brown hue indicated the presence of flavonoids.
- **Carbohydrates (Benedict's Assay):** An equal volume of Benedict's reagent was introduced to 0.5 mL of plant filtrate and boiled in a water bath for 2 minutes. A characteristic brick-red precipitate indicated reducing sugars.
- **Glycosides (Bontrager's Assay):** Extracts were hydrolysed with dilute HCl in a boiling water bath, extracted with chloroform and treated with dilute ammonia. The presence of a vibrant pink organic layer indicated anthraquinone glycosides [23].
- **Cardiac Glycosides (Keller-Kiliani Test):** A 5 mL portion of extract was treated with 2 mL of glacial acetic acid containing a drop of ferric chloride solution. Concentrated sulfuric acid (1 mL) was gently layered down the tube wall. The appearance of a brown interface ring alongside a pale green coloration in the upper phase confirmed the presence of deoxy-sugars characteristic of cardenolides [24].
- **Polyphenols (Ferric Ferricyanide Assay):** Plant filtrates were heated for 30 minutes, treated sequentially with 1% ferric chloride and 1% potassium ferricyanide and monitored for a green-blue complex indicating polyphenolic matrices [25].
- **Tannins (Ferric Chloride Test):** Treating a 2 mL sample of extract with a 5% ferric chloride solution resulted in a deep violet coloration, indicating the presence of condensed or hydrolyzable tannins.
- **Phenols (Lead Acetate Assay):** The addition of a 10% lead acetate solution to an aqueous extract solution yielded a heavy dark green mass, indicating phenolic content [26].
- **Phytosterols (Liebermann-Burchard Assay):** Filtrates were dissolved in acetic anhydride and treated with concentrated sulfuric acid down the tube sides. A progressive colour shift from violet to blue indicated phytosterol components [27].
- **Saponins (Foam Test):** A 0.05 mL sample of filtrate was diluted with 5 mL of distilled water and shaken vigorously. The formation of a dense, stable honeycomb foam that persisted upon mild warming confirmed the presence of saponins [28].
- **Proteins (Ninhydrin & Biuret Tests):** For the Ninhydrin test, samples were heated with reagent drops to monitor for a purple-blue complex. For the Biuret test, samples were treated with 5% sodium hydroxide and copper sulphate solutions to monitor for a diagnostic blue-to-violet shift [22].
- **Terpenoids (Salkowski Characterization):** A 5 mL sample of extract was combined with 2 mL of chloroform, followed by the careful addition of concentrated sulfuric acid to form a baseline layer. A deep reddish-brown interface indicated underlying terpenoids [29].
- **Steroids:** Samples were treated sequentially with chloroform, acetic anhydride and concentrated sulfuric acid. The formation of a deep pink or red chromophore indicated steroidal rings [29].

5. DESIGN AND FABRICATION OF THE POLYHERBAL MATRIX

The topical polyherbal gel batches were fabricated using a Carbopol 934 polymer framework. The structural gel base was composed of Carbopol 934, polyethylene glycol (PEG) and rose oil. Specifically, 2 g of Carbopol 934 along with exact concentrations of the botanical extracts were systematically dispersed within 80 g of ultrapure distilled water. This

mixture was agitated continuously on a magnetic stirrer at 800 rpm for 1 hour to ensure complete polymer hydration. Glycerine was subsequently added dropwise under constant agitation until a clear, smooth, and aesthetically uniform gel network was successfully formed. The complete formulation matrix parameters are described in Tables 1 and 2 [30].

6. FORMULATION PERFORMANCE EVALUATION

6.1 Macro-Organoleptic and Visual Inspection

The formulated polyherbal matrices were visually examined for core aesthetic factors, including colour consistency, transparency index, scent profile, overall smoothness and freedom from particulate contaminants or air pockets.

6.2 Potentiometric pH Evaluation

The apparent pH values of the formulated hair gels were checked using a calibrated digital pH meter at an ambient temperature of 25 ± 2°C.

6.3 Rheological Viscosity Profiling

Dynamic viscosity assessments were performed using a Brookfield viscometer configured with spindle No. 6 operating at an analytical rotational speed of 100 rpm. Readings were collected after a 2-minute equilibrium period. All measurements were recorded in triplicate to determine mean rheological scores [31].

6.4 Phase Homogeneity Assessment

The prepared gel systems were verified for structural consistency via macroscopic screening after settling into final storage tubes. The formulations were checked for phase separation, gritty textures or polymer agglomerations [32].

6.5 Washability Index

A predefined mass of the gel formulation was applied to healthy human skin surfaces to observe the ease, speed and completeness of clean-up using standard tap water under normal manual washing conditions.

6.6 Extrudability Analysis

The polyherbal hair gels were filled into collapsible aluminium delivery tubes. Manual pressure was applied to the tube base to judge the ease of extrusion and classify the physical behaviour of the gel ribbon.

6.7 Spreadability Dynamics

Spreadability was evaluated using a customized testing apparatus featuring a secure wooden block and two parallel glass slides. A standardized 20 g weight was loaded onto the assembly pan and the exact time required for the upper movable slide to completely separate from the fixed baseline slide was recorded. The effective spreadability index (S) was calculated using the following relation: [33]

S=M.L/T

Where:

- S = Spread ability performance factor (g· cm/sec)
- M = Total mass loaded onto the pan platform (g)
- L = Total linear length of the glass slide channel (cm)
- T = Time duration required to achieve total slide clearance (sec)

6.8 Dermatological Irritancy Profiling

Dermatological safety trials were performed on five healthy human volunteers after obtaining informed verbal consent. A 1g sample of the optimized hair gel formulation was applied across a designated 2-square-inch area on the dorsal aspect of the hand. The test sites were monitored over a predefined observation window to check for signs of focal erythema, localized edema, macroscopic lesions, cutaneous irritation or inflammatory responses.

6.9 In-Vitro Diffusion Kinetics (Franz Cell Apparatus)

In-vitro molecular diffusion studies were performed using a classical Franz diffusion cell system. Pre-cut cellulose membranes were fully conditioned via immersion in distilled water for 1 hour at room temperature before being mounted between the donor and receptor compartments. The active diffusion cross-sectional area was defined at 0.75 cm^2, with an underlying receptor chamber volume of 4.5mL.

The receptor medium consisted of an absolute ethanol phase to maintain sink conditions by increasing the solubility of the lipophilic botanical constituents. The receptor phase was continuously agitated at 50 rpm using a magnetic stir bar and maintained at a physiological skin surface temperature of 35 ± 0.5°C to achieve a membrane interface temperature of 32°C.

An aliquot of each gel candidate (20 mg/cm^2) was applied to the donor chamber, and the experiment was run over an 8-hour testing period. At regular 1-hour intervals, samples of the receptor fluid were collected and immediately replaced with equal volumes of fresh, pre-warmed receptor medium. Aliquots were diluted and analysed spectrophotometrically at the distinct absorption peaks of Camellia sinensis λ max at 287 nm, Cucurbita maxima λ max at 308 nm. [34]

6.10 Accelerated Stability Protocols (ICH Standards)

The optimized polyherbal hair gel formulation was placed into stability chambers to evaluate its shelf-life characteristics. Short-term storage evaluation was performed under controlled room temperatures (25–30°C) and refrigerated profiles (4°C) over a multi-week observation cycle. Physical attributes, including visual clarity, colour changes and odour stability, were monitored regularly. Advanced stability testing for the final optimized selection (Batch F3) was extended to a 1-month period under standard ICH guidelines to confirm its physicochemical integrity [35].

7. RESULTS AND DISCUSSION

7.1 Extraction and Mass Yield Outcomes

Soxhlet continuous hot percolation yielded dark, nutrient-dense ethanolic concentrates for both botanical sources. The total mass yield tracking registered an extractive values profile of 11.3 g for *Cucurbita maxima* seed fractions and 8.5 g for *Camellia sinensis* leaf structures, as detailed in Table 3.

7.2 Phytochemical Fingerprinting

Comprehensive phytochemical analysis of the crude extracts revealed a diverse distribution of secondary metabolites. The ethanolic seed fraction of *Cucurbita maxima* was rich in alkaloids, flavonoids, carbohydrates, polyphenols, tannins, phenols, saponins, proteins and terpenoids. Concurrently, the *Camellia sinensis* extract confirmed the presence of alkaloids, flavonoids, cardiac glycosides, tannins, phenols, phytosterols, saponins, terpenoids and steroidal components, as detailed in Table 4.

7.3 Spectrophotometric Optimization (λ max)

UV-Vis spectral scans confirmed distinct, sharp absorption maximum profiles, pinpointing λ max = 287 nm for *Camellia sinensis* and λ max = 308 nm for *Cucurbita maxima* (Figures 1 and 2). Standard multi-point calibration curves established strong linearity within an analytical concentration range of 1–10 µg/mL, obeying the Beer-Lambert law. The straight-line regression profiles showed an equation of $Y = 0.021533 \cdot X - 0.00892$ for green tea markers and $Y = 0.022 \cdot X - 0.011$ for pumpkin seed components (Tables 5 and 6; Figures 7 and 8).

7.4 Structural Interaction and Compatibility Profile (FTIR)

The compiled ATR-FTIR spectra for the isolated plant extracts, the blank carbomer matrix components and the final polyherbal gel formulation are presented in Figures 3 through 6. A comparative overlay of these functional group absorption profiles showed that the characteristic peaks of the active extracts and excipients were preserved without significant shifting or the appearance of new anomalous peak networks. This confirms the structural compatibility and chemical inertness of the gel matrix components.

7.5 Physicochemical and Rheological Characteristics

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The performance metrics across all 12 experimental design batches (F1 to F12) are presented in Table 7. The formulations displayed consistent visual textures, spanning from slightly white to yellowish-white gels with excellent smoothness and zero grit or macro-agglomerations. The structural pH values ranged between 5.85 and 7.62. This performance fits within the target carbomer cross-linking threshold (pH 6.0–6.8) which is ideal for achieving optimal viscosity while matching the natural acid mantle of human skin. Dynamic viscosity profiles ranged widely between 4,250 and 17,540 cps. Spreadability data varied between 6.4 and 18.3 g·cm/sec, showing a strong dependence on the polymer-to-extract blending ratios (Figures 9 and 10). Initial screening identified four batches F2, F3, F6 and F11 that satisfied the targeted parameters for professional topical applications, demonstrating premium extrudability and clean washability without leaving sticky residues.

7.6 Human Skin Safety Assessment

Dermatological evaluations confirmed excellent safety for the majority of the gel matrices. Batches F1 through F8, F10 and F11 produced zero signs of redness, edema, inflammation, or cutaneous discomfort. Minor localized irritation was noted only in higher active concentration batches F9 and F12, confirming that the optimized selection remains non-irritating and completely safe for human skin use (Table 8).

7.7 In-Vitro Active Elution Profiles

Comparative diffusion data for the selected core candidates (F2, F3, F6 and F11) are detailed in Tables 9 and 10 and Figures 11 and 12. After 8 hours of continuous sampling, batch F3 demonstrated superior performance, achieving a cumulative release of 89.09 ± 2.47% for *Camellia sinensis* active components and 88.73 ± 1.43% for *Cucurbita maxima* compounds. This performance was significantly higher than the other three candidates, leading to the selection of Batch F3 as the final optimized formulation.

7.8 ICH Stability Performance

The optimized polyherbal batch (F3) demonstrated excellent structural stability during accelerated stability testing. Evaluation after 1 month of storage at controlled room temperatures (25–30°C) showed no significant changes in physical appearance, sensory feel or dynamic viscosity (shifting minimally from 4,250 to 4,380cps). The formulation maintained a stable pH profile (6.56 to 6.75) and sustained high drug diffusion kinetics (88.67 ± 1.54% for green tea and 87.97 ± 1.24% for pumpkin seed extracts), confirming its commercial viability and robust shelf life (Table 11).

Table 1: Base Composition of the Polyherbal Gel Matrix

Component Name	Standard Content Mass (g)	Functional Role
Carbopol 934	1	Primary Gelling Agent
Polyethylene Glycol (PEG)	5	Humectant / Co-Solvent
Methyl Paraben	1	Antimicrobial Preservative
Triethanolamine	*q. s*	Neutralizing Agent / pH Modifier
Glycerine	5	Emollient / Plasticizer
Rose Oil	1	Fragrance Agent
Distilled Water	100	Primary Vehicle / Solvent System

Table 2: Composition Profiles for Batches F1 to F12

Component Matrix	F1 [0.25:1]	F2 [0.5:1]	F3 [1:1]	F4 [1.5:1]	F5 [0.25:2]	F6 [0.5:2]	F7 [1:2]	F8 [1.5:2]	F9 [0.25:3]	F10 [0.5:3]	F11 [1:3]	F12 [1.5:3]
Pumpkin Seed Extract (g)	1	1	1	1	2	2	2	2	3	3	3	3
Green Tea Extract (g)	1	1	1	1	2	2	2	2	3	3	3	3
Carbopol 934 (g)	0.25	0.5	1.0	1.5	0.25	0.5	1.0	1.5	0.25	0.5	1.0	1.5
Polyethylene Glycol (g)	5	5	5	5	5	5	5	5	5	5	5	5
Glycerine (g)	5	5	5	5	5	5	5	5	5	5	5	5
Methyl Paraben (g)	1	1	1	1	1	1	1	1	1	1	1	1
Triethanolamine (g)	1	1	1	1	1	1	1	1	1	1	1	1
Rose Oil (g)	1	1	1	1	1	1	1	1	1	1	1	1
Distilled Water (g)	100	100	100	100	100	100	100	100	100	100	100	100

Table 3: Mass Extraction Yield Performance

Botanical ID	Plant Part Used	Methodology Selected	Extractive Mass Recovered (g)
Cucurbita maxima	Seed	Continuous Hot Soxhlet Percolation	11.3
Camellia sinensis	Leaf	Continuous Hot Soxhlet Percolation	8.5

Table 4: Preliminary Phytochemical Screen of Derived Extracts

Sl. No.	Chemical Diagnostic Target Assay	*Cucurbita maxima* Seed Extract	*Camellia sinensis* Leaf Extract
1	Alkaloid Presence Screening	+	+
2	Flavonoid Presence Screening	+	+
3	Carbohydrate Assay	+	-

4	Glycoside Screening	-	-
5	Cardiac Glycoside Assay	-	+
6	Polyphenolic Phenotypic Test	+	-
7	Tannin Assay	+	+
8	Phenolic Detection Screen	+	+
9	Phytosterol Analytical Test	-	+
10	Saponin Evaluation Index	+	+
11	Protein Structural Screening	+	-
12	Terpenoid Assay Profile	+	+
13	Steroidal Identification Test	-	+
Note: (+) signifies structural.	**'+' presence**	**'-' absence**	

Fig No 01: λ max of *Camellia sinensis*

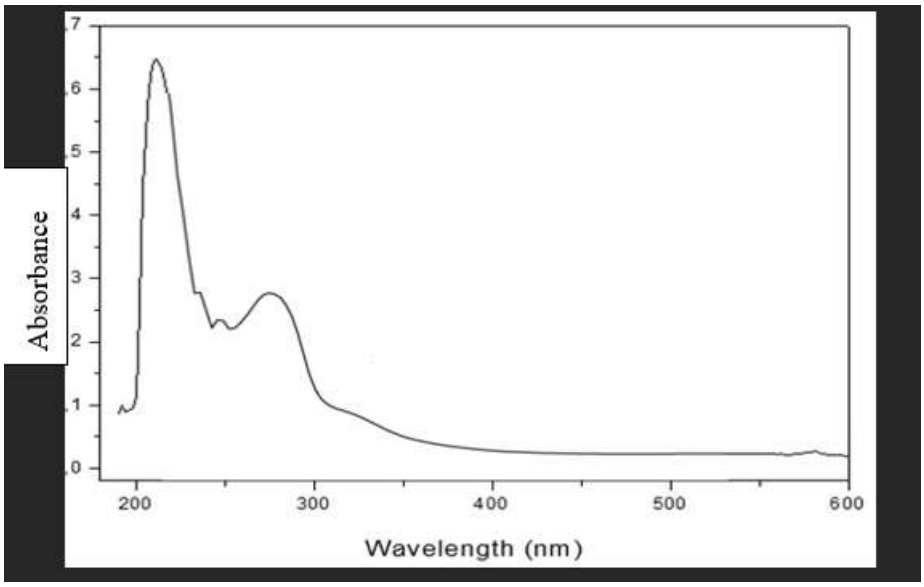

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Fig No 02: λ max of *Cucurbita maxima*

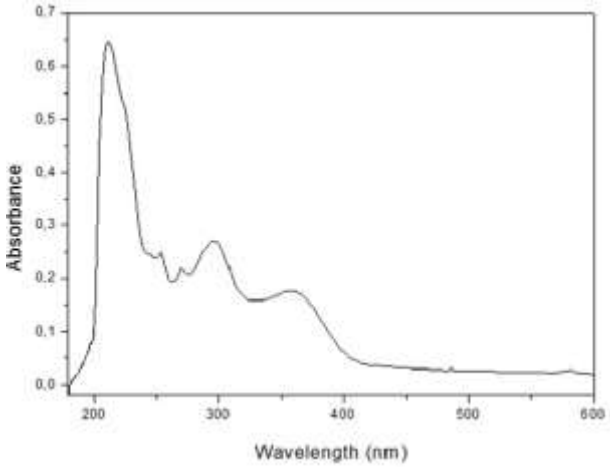

Fig No 03: ATR-FTIR of Extract of *Camellia sinensis*

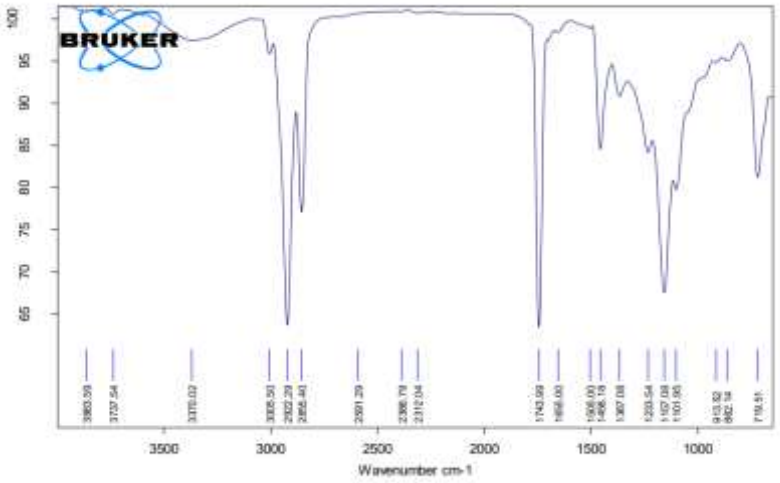

Fig no: 04 ATR-FTIR of Extract of *Cucurbita maxima*

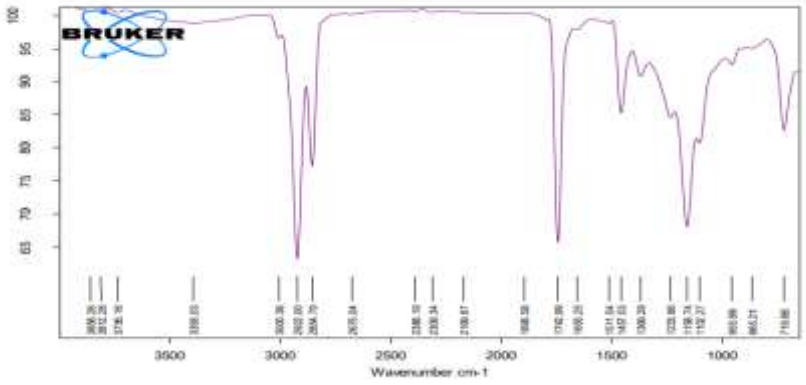

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Fig no: 05 ATR-FTIR OF CARBOPOL + PEG+ GLYCERINE + METHYL PARABEN + TRIETHANOLAMINE+ ROSE WATER + DISTILLED WATER.

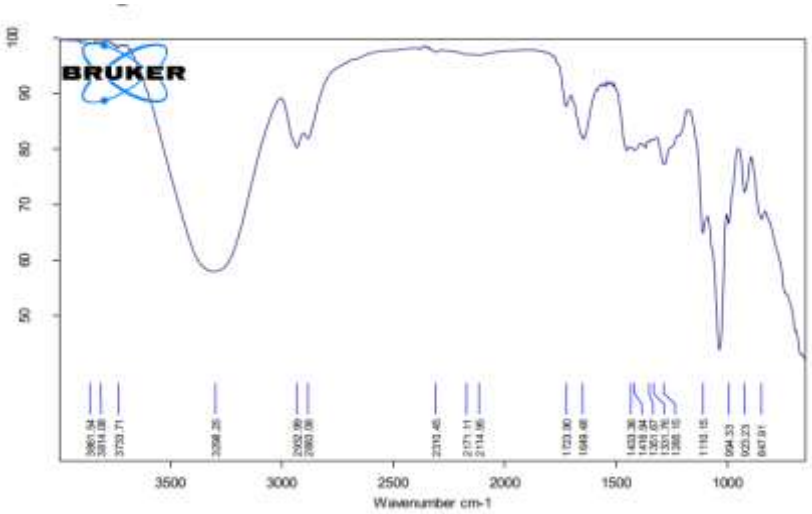

Fig no: 06 ATR-FTIR OF COMPARISON OF Extracted *Cucurbita maxima*+ Extracted *Camellia sinensis* + EXCIPIENTS +HAIR GEL

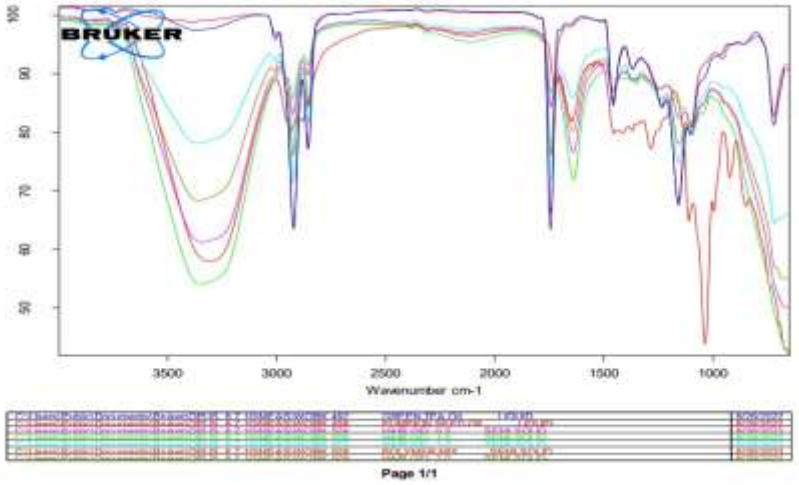

Table No 05: Absorbance of standard curve *Camellia sinensis*

S. No	Concentration (µg /ml)	Absorbance λ max 287 nm
1	1	0.0134
2	2	0.0298
3	3	0.053
4	4	0.0776
5	5	0.1056
6	6	0.1221

7	7	0.1398
8	8	0.1678
9	9	0.1845
10	10	0.2015
	Equation of straight line	Y= 0.021533 *X +(-0.00892)
	Slope	0.022
	Intercept	-0.009

Figure No 7: Calibration of standard curve *Camellia sinensis*

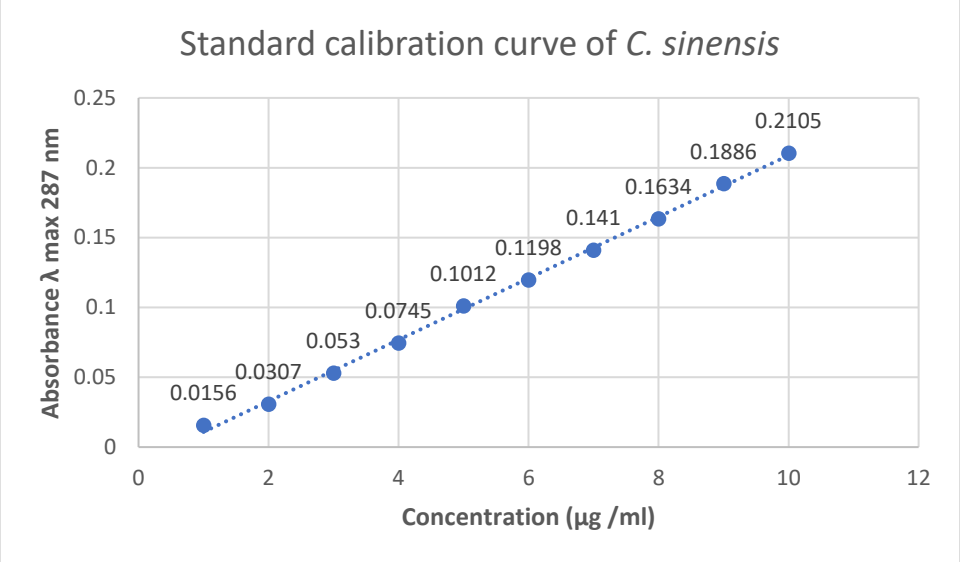

Table No 06: Absorbance of standard curve *Cucurbita maxima*

S. No	Concentration (µg /ml)	Absorbance λ max 287 nm
1	1	0.0156
2	2	0.0307
3	3	0.053
4	4	0.0745
5	5	0.1012
6	6	0.1198
7	7	0.141
8	8	0.1634
9	9	0.1886
10	10	0.2105

Equation of straight line	Y= 0.022 *X +(-0.011)
Slope	0.022
Intercept	-0.011

Figure No 8: Calibration of standard curve *Cucurbita maxima*

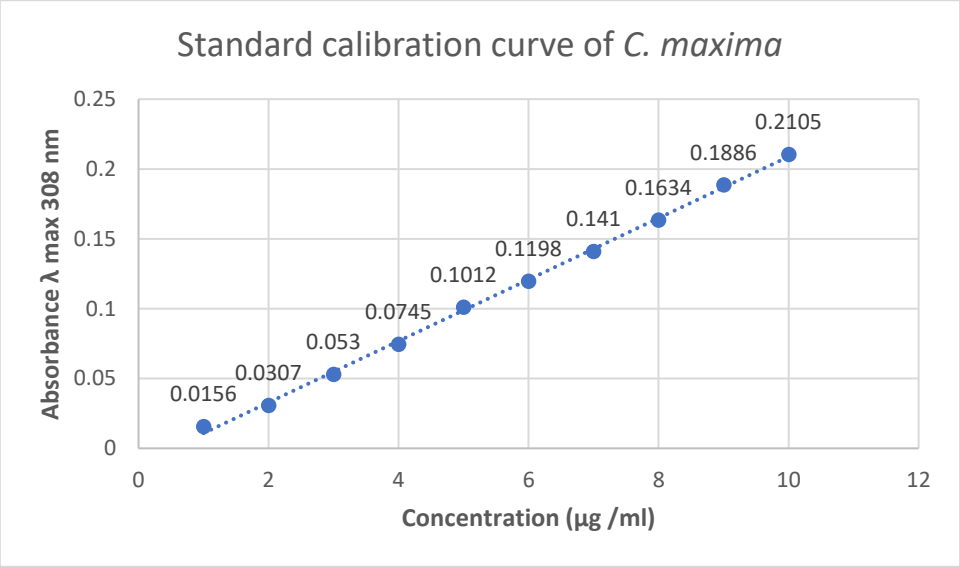

Table 7: Physicochemical Profiling of Formulations F1 to F12

Code	Physical Appearance Matrix	Measured pH	Spreadability (g·cm/s)	Dynamic Viscosity (cps)	Extrudability Index	Structural Homogeneity	Washability
F1	Off-white, low viscosity gel	6.05	12.3	6,500	++	Smooth	Complete
F2	Light yellowish-white, viscous gel	6.75	10.2	12,250	+++	Smooth	Complete
F3	Light yellowish-white, viscous gel	6.56	18.3	4,250	++++	Smooth	Complete
F4	Light yellowish-	6.32	6.4	7,540	++	Smooth	Complete

	white, viscous gel						
F5	Off-white, low viscosity gel	6.75	11.2	7,600	++	Smooth	Complete
F6	Off-white, low viscosity gel	6.25	9.8	13,450	+++	Smooth	Complete
F7	Light yellowish-white, viscous gel	6.27	13.4	5,550	++	Smooth	Complete
F8	Light yellowish-white, viscous gel	5.98	7.5	6,500	++	Smooth	Complete
F9	Light yellowish-white, low viscosity gel	7.30	10.6	8,500	++	Smooth	Complete
F10	Light yellowish-white, viscous gel	5.85	12.5	8,250	++	Smooth	Complete
F11	Light yellowish-white, viscous gel	6.78	13.4	12,540	+++	Smooth	Complete
F12	Light yellowish-white, heavy gel	7.62	11.3	17,540	++	Slightly firm	Complete

Evaluation Key: (++++) Excellent; (+++) Good; (++) Fair; (+) Poor

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Fig No 9: Determination of Spreadability

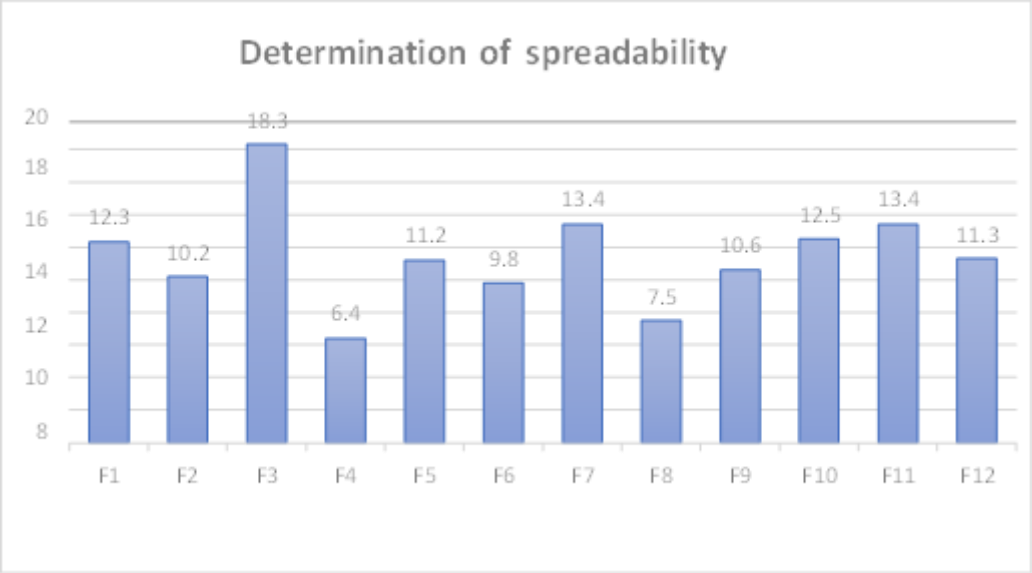

Fig No 10: Determination of pH

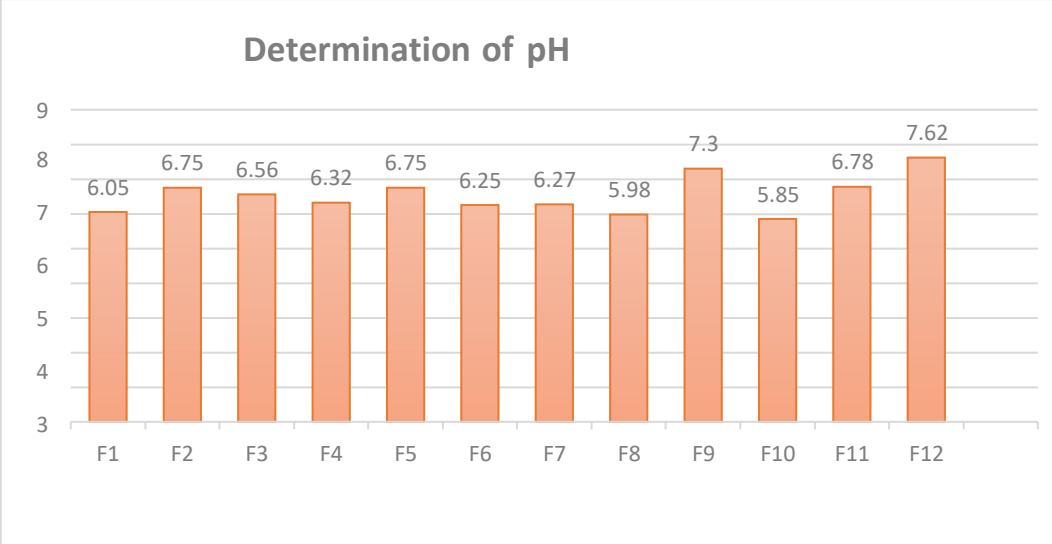

Table No 08: Irritancy test

Formulation	Irritation
F1	Nil
F2	Nil
F3	Nil
F4	Nil
F5	Nil

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F6	Nil
F7	Nil
F8	Nil
F9	Slightly Irritant
F10	Nil
F11	Nil
F12	Slightly Irritant

Table No 09: *In vitro* drug (*Camelia sinensis*) release

Time (hours)	Gel 1 F2	Gel 2 F3	Gel 3 F6	Gel 4 F11
0	0	0	0	0
1	12.98	17.76	14.76	13.67
2	21.49	22.64	19.43	18.54
3	24.12	36.98	28.86	21.89
4	30.98	51.99	40.87	24.21
5	39.94	59.87	49.86	30.454
6	44.98	67.93	56.09	35.32
7	50.86	80.71	69.98	42.81
8	68.98	89.09	74.98	48.74

Fig No 11: *In vitro* drug (*Camelia sinensis*) release

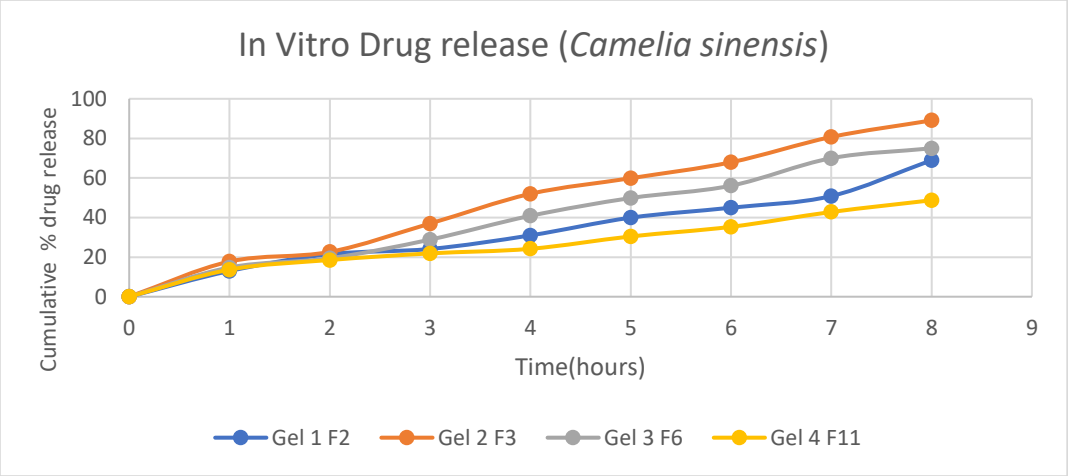

Table No 10: *In vitro* drug (*Cucurbita maxima*) release

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Time (hours)	Gel 1 F2	Gel 2 F3	Gel 3 F6	Gel 4 F11
0	0	0	0	0
1	12.61	16.99	15.89	17
2	19.87	28.96	21.69	25.97
3	25.54	37.9	29.67	33.2
4	31.09	49.03	33.6	47.13
5	42.05	60.89	36.98	58.23
6	54.13	69.9	49.5	63.98
7	61.54	79.47	60.11	79.53
8	69.29	88.73	67.62	82.43

Fig No 12: *In vitro* drug (*Cucurbita maxima*) release

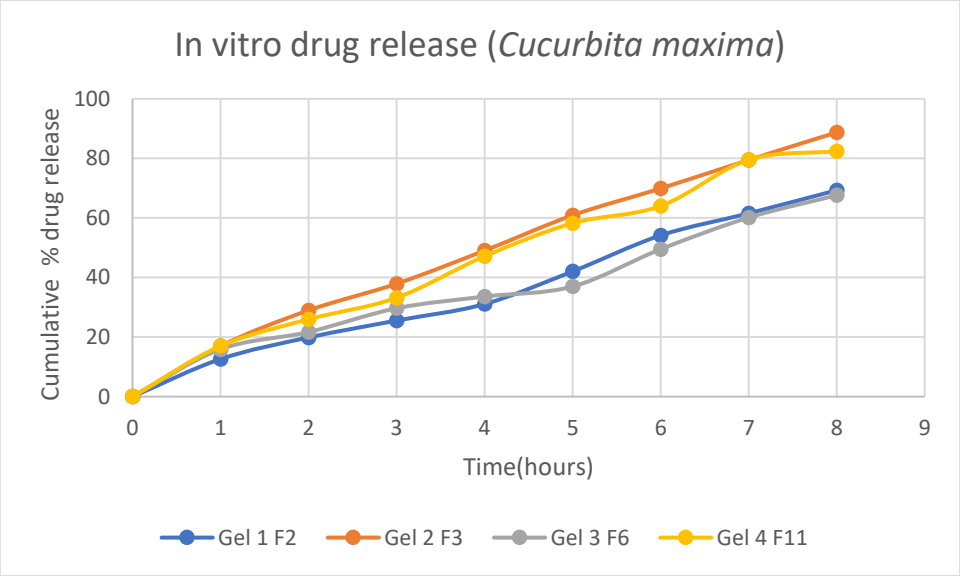

Table 11: ICH Stability Profile for the Optimized Matrix (Batch F3)

Evaluated Parameter	Baseline Values (Day 0)	Post-ICH Aging Values (Month 1 at 25–30°C)
Physical Appearance	Pale Yellowish-White Gel	Pale Yellowish-White Gel
Feel on Skin Application	Uniformly Smooth	Uniformly Smooth
Potentiometric pH	6.56	6.75
Dynamic Viscosity (cps)	4,250	4,380

In-Vitro Release (*C. sinensis*)	89.09 ± 2.47%	88.67 ± 1.54%
In-Vitro Release (*C. maxima*)	88.43 ± 1.46%	87.97 ± 1.24%

8. CONCLUSION

This study successfully developed a stable, non-irritating, and high-performance polyherbal topical gel by combining *Cucurbita maxima* seed oil fractions and *Camellia sinensis* green tea extracts within a Carbopol 934 polymer network. These botanical ingredients work synergistically to arrest excessive hair fall and stimulate follicular activity. The optimized candidate, Formulation F3, demonstrated ideal viscosity, superior spreadability, excellent washability, and high in-vitro drug release profiles. Furthermore, stability testing confirmed that the formulation maintains its physicochemical integrity under standard storage conditions. Future research will focus on evaluating the long-term stability profile of this formulation and conducting in-vivo animal model studies to confirm its clinical efficacy in managing various forms of alopecia.

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AUTHOR CONTRIBUTIONS

Dr. V. Muruganantham: Conceptualization, study design, project administration, supervision, manuscript drafting, and critical revision of the manuscript. Methodology, extraction procedures, formulation development of the topical herbal gel, and analytical measurements. Physicochemical evaluation (pH, viscosity, spreadability, extrudability, stability studies), statistical analysis, and data curation.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ETHICS STATEMENT

Option A (For purely in vitro / physicochemical studies without animal testing): This study involved only *in vitro* formulation development and physicochemical evaluations. No human participants or animal models were used; therefore, ethical approval from an Institutional Animal Ethics Committee (IAEC) or Institutional Ethics Committee (IEC) was not required.

DATA AVAILABILITY STATEMENT

The datasets generated and analyzed during the current study are available from the corresponding author [Dr. V. Muruganantham] upon reasonable request.

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