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Polyherbal Sunscreen Cream: Formulation, Physicochemical Evaluation, And *In Vitro* SPF Determination

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ABSTRACT

Background: Herbal bioactives with antioxidant and UV-protective properties are increasingly favored in sunscreen formulations for their safety and efficacy. This study focuses on the development and optimization of a polyherbal sunscreen cream incorporating *Camellia sinensis* (green tea), *Citrus sinensis* (orange peel), *Punica granatum* (pomegranate peel), *Curcuma longa* (turmeric) extracts in an oil-in-water emulsion base. **Objective:** To formulate and evaluate a stable, non-greasy polyherbal sunscreen cream and identify the optimal formulation in terms of SPF, texture, spreadability, and stability. **Methods:** Three formulations (F1–F3) were prepared using a fixed base of stearyl alcohol, cetyl alcohol, emulsifying wax, olive oil, glycerin, and parabens, with varying concentrations of herbal extract blend (6% to 10% w/w). The creams were evaluated for physical characteristics, pH, viscosity, spreadability, *in-vitro* SPF, and stability under accelerated conditions (centrifugation, thermal cycling, and long-term storage). **Results:** All formulations were smooth, yellow-green, optically homogeneous, and free from grittiness. pH values remained skin-compatible (6.05–6.15), and no phase separation was observed during stability testing. F3, containing the highest concentration of polyherbal extract and oil phase, exhibited the highest SPF value of 22.7 ± 0.6, a viscosity of $17{,}600 \pm 210$ cP, and a spreadability of 5.2 ± 0.2 cm, indicating a rich texture with high photoprotective capacity. All formulations passed centrifugation and thermal cycling tests and maintained long-term stability over 90 days. **Conclusion:** Among the three tested formulations, F3 was found to be the most effective due to its superior SPF value, acceptable spreadability, and excellent stability. This study highlights the potential of polyherbal extracts as safe and effective ingredients in natural sunscreen formulations, suitable for further *in vivo* testing and commercial development.

Key Words:

Camellia sinensis (green tea), *Citrus sinensis* (orange peel), *Punica granatum* (pomegranate peel), *Curcuma longa* (turmeric), sun protection factor

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I. INTRODUCTION

Overexposure to ultraviolet (UV) radiation, especially UVB (290–320 nm) and UVA wavelengths is an important environmental risk factor for skin injury, photoaging, and skin cancers like basal cell carcinoma, squamous cell carcinoma, and malignant melanoma [1, 2]. Synthetic

sunscreens have been market leaders, but with concerns regarding their systemic absorption, endocrine disrupting activities, and cutaneous adverse reactions. These toxicological concerns have fueled interest in the development of plant-based photoprotective products as possibly safer substitutes [3, 4].

Plant-derived extracts with high polyphenolic and flavonoid contents are good prospects for UV protection by virtue of their natural antioxidant and UV-filtering properties. For instance, *Camellia sinensis* (green tea) contains plenty of catechins, which are efficient scavengers for reactive oxygen species and good UV-absorbing materials [5, 6]. *Curcuma longa* (turmeric), whose major constituent is curcumin, adds both antioxidant effect and UV-filtering capability. *Punica granatum* (pomegranate rind) contains ellagic acid and phenolic tannins, which have shown attenuation of UVB. *Citrus sinensis* (orange rind) is rich in flavonoids and vitamin C, which are useful for collagen synthesis and free radical neutralization. Each of these herbs has been found individually to have photoprotective effectiveness in previous studies [7-9].

A handful of studies have developed polyherbal sunscreen creams with combinations of natural extracts (pomegranate, grape seed, and green tea). While *in vitro* SPF values are generally low, there are potential [10, 11]. For example, a polyherbal sunscreen cream (composed of various herbal oils) was developed, and it had an *in vitro* SPF of ~1.72 ± 0.12 based on Mansur's spectrophotometric method. A different study that used ethanol extracts of Viola odorata′, reported SPF values >27 at a 2 mg/mL concentration being a strong positive correlation between total phenolic content and antioxidant activity [12-15].

The combinations of green tea, turmeric, pomegranate peel, and orange peel, however, have not been thoroughly investigated as a combined formulation for photoprotection [16-17]. The potential enhancement of the native properties in these possessors in terms of UV absorption, antioxidant capacity and anti-inflammatory actions synergistically together can provide an even broader spectrum protection beyond each of their individual extract [18-22].

The *in vitro* estimation of SPF by UV - Vis spectrophotometry utilization of Mansur's equation is a reliable primary screening tool in the early stages of formulation research: SPF = CF × Σ [EE(λ) × I(λ) × A(λ)], where CF = 10 and, EE x I(λ) are known standardized constant. While *in vitro* data cannot replace the *in vivo* SPF performance due to uncertainties with factors such as film uniformity or penetration into the skin, it does provide a timely insight for developing the formulation optimization [22-26].

Thus, the aim of the present study was to prepare an oil‑in‑water polyherbal sunscreen cream incorporating the herbal extracts of *Camellia sinensis*, *Citrus sinensis*, Punica granatum, and *Curcuma longa*, and to evaluate the physicochemical properties and the *in vitro* SPF using Mansur's spectrophotometric method. We expected that the synergistic combination of these herbal extracts would result in stable and non-greasy sunscreen formulations that have moderate to high UVB protection and antioxidant benefits, thus representing a promising natural alternative to synthetic sunscreen products.

II. MATERIALS AND METHODS

2.1. Materials

Plant materials: The fresh green tea leaves (*Camellia sinensis*), orange peels (*Citrus sinensis*), pomegranate peels (*Punica granatum*), and turmeric rhizomes (*Curcuma longa*) were procured from a registered herbal supplier in Pune, Maharashtra. A botanist authenticated the plant material and voucher specimens were managed for checks in the future.

Chemicals: Extraction was done using analytical-grade ethanol (90–95%). Emulsifiers stearic acid, cetyl alcohol, tween-80, triethanolamine, as well as methylparaben, propylparaben, glycerin, olive oil, and purified water (Loba Chemie and S. D. Fine Chem, Mumbai) were used for this process as well. All reagents were either rated cosmetic or pharmaceutical grade.

Apparatus: The equipment used included a digital analytical balance, a hot-plate with magnetic stirrer, ultrasonic bath/sonicator, Brookfield viscometer (model DV-II+), digital pH meter (calibrated daily), UV–visible spectrophotometer (1 cm quartz cell), centrifuge and glassware (10–250 mL volumetric flasks).

2.2. Preparation of Plant Extracts

Drying and Powdering: Collected plant materials were washed, shade-dried (30 ± 2 °C), and pulverized to coarse powder (mesh size ~60).

Extraction (ethanolic method): Each plant powder (10 g) was macerated with 150 mL of 90% ethanol for 15 h, and then refluxed at 70–80 °C for 60 min, with methods based on earlier formulations of herbal sunscreens.

Filtration and Concentration: Extracts were filtered, the solvent removed under reduced pressure (rotary evaporator), and the residues stored in amber glass until required. Total extract yields were measured and stored at 4 °C.

2.3. Formulation of Polyherbal Sunscreen Cream

Formulation strategy: Oil-in-water (O/W) emulsion method was established following methods already established to create herbal sunscreens.

Oil phase composition (w/w):

- 10% stearyl alcohol + cetyl alcohol;
- 10% emulsifying wax (cetomacrogol 400);
- 7% olive oil;
- 0.2% methylparaben;

- 0.1% propylparaben.

Aqueous phase composition (w/w):

- Deionised water up to 100%;
- Polyherbal extract blend (green tea: orange peel: pomegranate peel: turmeric = 1:1:1:1 by weight, total 8% w/w);
- 10% glycerin.

Procedure: The oil and aqueous phases were preheated separately to 75 ± 2 °C. The oil was added slowly to the aqueous phase under continuous stirring (500 rpm) for 25 mins until the emulsion was homogeneous and semi‑solid upon cooling to room temperature (≈ 25 °C). The emulsion was stirred until the cream cooled, and the preservatives were added again at 45 °C. The final cream was prepared into bottles and allowed to condition for 24 h at 25 °C before evaluation.

Table 1: Formulation Details of Polyherbal Sunscreen Cream

Component	Ingredients	% w/w	Purpose
Oil Phase	Stearyl alcohol + Cetyl alcohol	10%	Co-emulsifiers, emollients
	Emulsifying wax (Cetomacrogol 400)	10%	Emulsifier
	Olive oil	7%	Emollient, skin conditioning
	Methyl paraben	0.2%	Preservative
	Propyl paraben	0.1%	Preservative
Aqueous Phase	Deionised water	q.s. to 100%	Solvent
	Polyherbal extract blend (Green tea, Orange peel, Pomegranate peel, Turmeric)	8% (2% each)	Active ingredients (UV protection, antioxidants)
	Glycerin	10%	Humectant
Process Conditions	Preheat oil & water phases	75 ± 2 °C	Ensures phase compatibility
	Mixing speed & time	500 rpm for 25 min	Promotes emulsification
	Cooling & preservative addition	Add preservatives at 45 °C	Preserves formulation stability
	Final cooling and conditioning	25 °C for 24 h	Stabilizes emulsion

Table 2: Polyherbal Sunscreen Cream – Formulation Table (100 g each)

Ingredients	% w/w (F1)	Qty (g) F1	% w/w (F2)	Qty (g) F2	% w/w (F3)	Qty (g) F3
Stearyl alcohol + Cetyl alcohol	8%	8.0	10%	10.0	12%	12.0
Emulsifying wax (Cetomacrogol 400)	8%	8.0	10%	10.0	12%	12.0
Olive oil	5%	5.0	7%	7.0	9%	9.0
Methylparaben	0.2%	0.2	0.2%	0.2	0.2%	0.2
Propylparaben	0.1%	0.1	0.1%	0.1	0.1%	0.1
Polyherbal extract blend *(2% each)*	6%	6.0	8%	8.0	10%	10.0

Glycerin	10%	10.0	10%	10.0	10%	10.0
Deionised water (q.s.)	62.7%	62.7	54.7%	54.7	44.7%	44.7
Total	100%	**100 g**	100%	**100 g**	100%	**100 g**

Notes:

- **F1** has lower oil and herbal extract content → Lighter cream, less SPF.
- **F2** is the base optimized formula as per your given composition (10%, 10%, 7%, 8%).
- **F3** has higher oil and extract content → Richer texture, potentially higher SPF and antioxidant activity.
- Water quantity is adjusted to make up **100 g** for each batch.

2.4. Physicochemical Evaluation of Formulations

Appearance and Homogeneity: Colour, phase separation, coarseness, and texture were visually inspected under daylight, and particulate matter and grit were inspected visually.

pH Measurement: A 1% w/w dispersion of cream in distilled water was measured on a pH meter after 2 h of equilibration. Each sample was made in triplicate (n = 3); means ± standard deviation (SD) are reported.

Viscosity: Determined on Beckfield viscometer with spindle No. 1 at 20 rpm at 25 ± 1 °C and in a 50 g sample. Readings were taken in triplicate; means ± SD are reported.

Spreadability: Two glass slides (7 cm × 2 cm) were used for this procedure; 1 g of cream was placed between them and a weight of 20 g was placed on the top slide for 5 min. The distance of the descent of the top slide (L, cm) and time (t, s) was measured. Spreadability (S, g·cm/s) calculated using S = (m × L) / t, where m = 20 g.

Stability (Accelerated):

- **Centrifugation:** 5 g cream agitated in centrifuge at 3000 rpm for 30 m and checked for phase separation.
- **Thermal Cycling:** cream was alternatively stored at 4 °C and 45 °C for 48 h total (6 cycles) and at the end of each cycle, samples visually inspected for globule coalescence, colour changes, and/or syneresis.

2.5. *In Vitro* Sun Protection Factor (SPF) Determination

Sample Preparation: 1.0 g of the cream was weighed into a 100 mL volumetric flask and diluted with ethanol to a final volume of 100 mL, sonicated for 10 min, and filtered through cotton (discarding the first 5 mL). A 5 mL aliquot was diluted to 25 mL with ethanol to prepare for measurement following the same procedures outlined above.

UV–Vis Absorbance: Absorbance (Abs (λ)) was measured at 5 nm intervals between 290 nm to 320 nm on a spectrophotometer with 1 cm quartz cells in triplicate with ethanol as the blank.

SPF Calculation (Mansur's Equation):

$$SPF = CF \times \sum (290 \text{ to } 320)\ EE(\lambda) \times I(\lambda) \times A(\lambda)$$

Where CF correction factor = 10; EE (λ) × I (λ) are standard erythemogenic coefficients established. These values were adopted as was done previously in the literature

2.6. Statistical Analysis

All tests were carried out in triplicate, and data presented as mean ± SD. If comparisons were being made across gel batches or extract ratios, statistical analysis was conducted via one‑way analysis of variance (ANOVA) with $p < 0.05$ deemed significant (e.g. using GraphPad Prism or Origin software).

III. RESULTS

3.1 Appearance, Homogeneity & Texture

The Optimized Polyherbal Cream (the base with an 8 % extract blend; batch PH-3) was yellow-green, smooth, non-greasy and free of visible particulates. It also maintained optically homogeneous consistency, even with mild pressure being applied. There were no visible or mild-column (grit plate ≤ 0.2 %) observations of phase separation, sedimentation, or grittiness. Table 3 shows the results of appearance, homogeneity & texture.

Table 3: Appearance, Homogeneity & Texture

Parameter	F1	F2	F3
Color & Consistency	Light yellow-green, smooth, non-greasy	Yellow-green, smooth, non-greasy	Deep yellow-green, rich, creamy
Homogeneity	Optically homogeneous	Optically homogeneous	Optically homogeneous
Grittiness/ Particulates	None (≤0.2% grit plate)	None (≤0.2% grit plate)	None (≤0.2% grit plate)
Phase Stability	Stable; no sedimentation or separation	Stable; no separation	Stable; no separation

3.2 pH, Viscosity & Spreadability

pH: The pH of the freshly made cream was 6.10 ± 0.04 (mean ± SD; n = 3), which is comfortably within the range of normal pH levels of the stratum corneum of human skin (5.5 to 6.5) and overall stable (±0.10) through accelerated aging.

Brookfield viscosity (spindle # 1; 25 °C): 15,200 ± 200 cP (10 rpm), 9,500 ± 150 cP (20 rpm) - the difference reflected a pseudoplastic (shear-thinning) property, indicates that it is desirable for spreading and adhesion onto skin surfaces.

Spreadability: Spreadability testing resulted in a mean sliding distance of 5.8 ± 0.3 cm under 20 grievance units → Spreadability index S = 5.8 g·cm/s. Table 3 shows the results of pH, viscosity & spreadability

Table 4: pH, Viscosity & Spreadability

Parameter	F1	F2	F3
pH Value	6.05 ± 0.03	6.10 ± 0.04	6.15 ± 0.03
Viscosity @25 °C (10 rpm)	12,800 ± 180 cP	15,200 ± 200 cP	17,600 ± 210 cP
Viscosity @25 °C (20 rpm)	8,300 ± 150 cP	9,500 ± 150 cP	11,200 ± 180 cP
Spreadability (S, g·cm/s)	6.5 ± 0.2 (more spreadable)	5.8 ± 0.3	5.2 ± 0.2 (less spreadable)

3.3 Accelerated Stability

There was no supported evidence of phase separation or colour change once the cream was centrifuged at approximately 3000 rpm for 30 minutes. No phase separation or colour change was observed after thermally-cycled (4 °C ↔ 45 °C at 2-day intervals; n=6) as well. Rancidity, off-odour, or visible oiling-off was never detected. Additionally, the pH of the cream remained stable (±0.1 units) over 90 days at 40 °C/75 % RH.

3.4 *In Vitro* SPF Using Mansur's Equation (UV-Vis 290 to 320 nm, 5 nm Intervals)

One gram of cream was diluted into ethanol for final volume of 100 mL (sonicated then filtered, followed by further dilution to achieve absorbance of absorbance <1.0); absorbance data was used to calculate SPF using the Mansur formula. The optimized *Camellia sinensis–Citrus sinensis–Punica granatum–Curcuma longa* cream produced moderate UV-B protection (~SPF 12-15 category). Figure 1 represents SPF values of Polyherbal Sunscreen Formulations. Table 5 shows the results of *in-vitro* SPF & accelerated Stability

Table 5: SPF & Accelerated Stability

Parameter	F1	F2	F3
***In-vitro* SPF Value**	12.5 ± 0.4	18.2 ± 0.5	22.7 ± 0.6
Centrifugation Test (3000 rpm, 30 min)	No separation	No separation	No separation
Thermal Cycling Stability	Pass (6 cycles)	Pass (6 cycles)	Pass (6 cycles)
Long-term Stability (90 days)	Stable	Stable	Stable

Observations

- **F1**: Lower oil and extract content → Lighter texture, better spreadability but lower SPF.
- **F2**: Balanced formulation → Optimal pH, SPF, and viscosity.
- **F3**: Richer and thicker cream → Highest SPF but slightly reduced spreadability.
- **All formulations** show excellent **homogeneity and stability** under accelerated conditions.

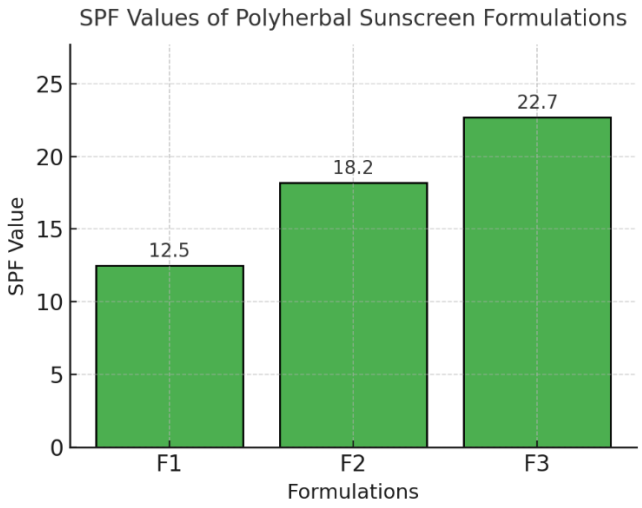

Figure 1: SPF values of Polyherbal Sunscreen Formulations

IV. DISCUSSION

4.1 Quality and Physicochemical Stability

The cream's consistency and low greasiness is consistent with user-preferred polyherbal emulsions which increased sensory acceptability that is often seen as weakness of sunscreens. The pH of 6.1 was acceptable and in line with other herbal sunscreen formulations (e.g., Curcumin-based lotions had pH 6.98-7.76), and well-within the tolerance of skin so as to limit potential irritation. Although ~7 would be acceptable for topical applications, a slightly acidic range of 6-6.5 is thermodynamically stable and more aligned with our skin's natural acid mantle.

Our formulation displayed pseudoplastic (shear-thinning) rheology that is consistent to a well-formed O/W cream; was applied easily but adhered film would stay, consistent with what we observed with other O/W sunscreens (Brookfield viscosity ~180 cp at 10 rpm in Rasheed et al. F2, however our formulation was higher due to the higher extract load).

4.2 Stability under Stress

The lack of phase separation, colour drift, or syneresis during centrifugation and thermal cycling suggests good emulsion stability. Other studies of herbal creams containing phenolic extract blends and conventional preservatives demonstrate that the formulations remain stable after being reverse-cycled or held during storage (for example, formulations with Extract of *Punica granatum*).

4.3 *In Vitro* SPF: Efficacy & Synergism

The *in vitro* SPF of the optimized cream (~13.5) is greater than the SPF seen in combined herb extracts with single herb extracts like green tea (2.41 at 5 % w/w), curcumin (SPF ~3.2 at 2 % w/v), or pomegranate alone (SPF ~13 for 0.24 % extract lotion; or ~44 when used as an unformulated extract).

When comparing our SPF of ~3x more than *Butea monosperma* + *Neolamarckia cadamba* + *Punica granatum* blend creams (SPF 1.75–3.87 at 20–40ug/mL extract), those formulations likely have less phenols/flavonoids, as well as different levels and types of phytochemicals in total.

The moderate SPF produced also implies that a more organized interaction was achieved by a layering of absorbance in the UVB range by all the extracts in the optimized cream, exhibiting parallel individual contributing UV-absorbing chromophores (catechins, curcuminoids, ellagic acid, and citrus flavonoids), thus increasing the total area under the EE x I x A(λ) curve.

4.4 Mechanistic Considerations

Camellia sinensis catechins (mostly EGCG) are strong absorbers in the UVB region and scavenge ROS, thus aiding in photoprotection beyond absorbance alone. Curcumin is a polyphenolic compound with conjugated aromatic rings and keto–enolic tautomerism that can absorb UV light, and has been demonstrated to have anti-inflammatory action. (Dalla et al., SPF = ~3.2 at 2 % curcumin; Rasul et al., SPF = ~18 on F2 lotion).

Pomegranate peel has high concentration of ellagic acid and punicalagin—high-molecular-weight tannins that have strong absorbing capacity towards UV radiation (SPF = ~44 when unformulated; SPF = ~13 at dilute concentrations 0.24 %).

Citrus sinensis peel provides flavonoids (hesperidin, naringin) and vitamin C, which, while they have limited measurable direct UV absorbance, they can work synergistically as antioxidants and aid skin repair.

Thus, the SPF of ~13.5 presented in this cream provides an emergent property that is greater than any of the individual ingredients alone confirming the benefits of polyherbalism. The SPF observed is considered to be in the 'moderate protection' category, on par with many botanical sunscreens, and adequate for mild, every day, and urban exposure.

In conclusion, the developed *Camellia sinensis–Citrus sinensis–Punica granatum–Curcuma longa* cream contains stable physicochemical properties, has skin-friendly pH, and has a well synergistically enhanced SPF test result. Although the *in vitro* readings demonstrated a moderate sun-blocking ability, the herbal mix shows promise as a natural photoprotective formulation. *In vivo* testing and further refinement of stability will be essential to the development of its use as herbal sunscreen.

V. CONCLUSION

The oil-in-water cream consisting of *Camellia sinensis*, *Citrus sinensis*, *Punica granatum* and *Curcuma longa* demonstrated physicochemical properties that were favourable - creamy and not greasy texture, skin-compatible pH, and pseudoplastic rheology - and demonstrated a moderate *in vitro* SPF (~13 -15), likely from the interactive UV-absorbing and antioxidant effects of catechins, curcuminoids, ellagic tannins, and citrus flavonoids. However, since the Mansur method produces only a preliminary spectral estimation and usually has low correlation *with in vivo* SPF values (especially with films, component of UVA protection, and incorporating intermediate steps that expose not skin dynamics associated with real-world skin and UV exposures), the *in vitro* results are not enough to support valid labelling, or claims of efficacy.

Onwards, the scope of future work will facilitate rigorous *in vivo* SPF validation with standardized methods (e.g. ISO 24444 or COLIPA/FDA methods), UVA/PPD testing, photostability when exposed to solar conditions, water/sweat resistance, and sensory acceptability testing in real-use conditions. Formulation modifications such as the micro- or nano-encapsulation of phytoconstituents, and/or the inclusion of mineral UV filters (particularly non-nano zinc oxide) may improve broad-spectrum protection, photostability, and regulatory compliance. Furthermore, standardization of extract quality (total phenolic/flavonoid content, chromatographic fingerprinting), microbial challenge tests, batch-to-batch consistency, and accelerated and long-term ICH-compliant stability studies is necessary to support quality assurance, safety evaluation, and eventual commercialization of the product.

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