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Formulation, Physicochemical Standardization, and Photoprotective Evaluation of a Polyherbal Sunscreen Cream Containing Aloe barbadensis, Daucus carota, and Pterocarpus santalinus

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Abstract:

Background: Chronic exposure to solar ultraviolet (UV) radiation triggers complex biological damage, including severe erythema, accelerated photoaging, hyperpigmentation, and elevated risk profiles for cutaneous malignancies. While synthetic organic UV filters offer robust photoprotection, their routine dermatological use is frequently limited by high rates of photocontact allergic sensitization, localized irritation, and systemic bioaccumulation concerns. This study describes the development, comprehensive physicochemical standardization, and photoprotective screening of an oil-in-water (o/w) polyherbal sunscreen cream incorporating active fractions of Aloe vera, Carrot seed oil (Daucus carota), and Red Sandalwood (Pterocarpus santalinus).

Methods: The o/w emulsion cream was synthesized using a blended emulsifier system consisting of stearic acid, cetyl alcohol, and triethanolamine, serving as the carrier matrix for the phytochemically active ingredients. Standard organoleptic inspection, homogeneity, potentiometric skin-pH compatibility, spreadability kinetics, and centrifugal phase stability profiles were monitored. The in vitro Sun Protection Factor (SPF) was systematically determined via spectrophotometric analysis scanning the 290–320 nm UV-B spectrum.

Results & Conclusion: The optimized polyherbal cream presented as a smooth, homogeneous, light pinkish-cream matrix possessing a highly refreshing, pleasant aromatic odor and zero phase separation. The potentiometric pH ranged between 6.2 and 6.6, matching standard human epidermal envelopes. Rheological spreadability was uniform under low mechanical shear force, and the formulation exhibited no signs of grittiness. Spectrophotometric evaluation confirmed a robust, built-in in vitro SPF rating, validating the synergistic UV-absorbing performance of the natural carotenoid and polyphenolic constituents. The findings establish that this polyherbal preparation serves as an effective, highly biocompatible, and non-toxic alternative to conventional synthetic topical sunscreens.

Introduction

The human skin is the body's largest and primary protective organ, covering its entire external surface and serving as a first-order physical and biological barrier against environmental elements [1]. Its crucial homeostatic functions include body temperature regulation, prevention of transepidermal water loss, and protection against physical trauma, toxic chemical entries, and pathogenic microorganisms [1, 2]. However, chronic exposure to solar radiation, specifically the high-energy ultraviolet (UV) spectrum, regularly breaches these protective barriers, inducing severe localized cellular damage [3].

Solar UV radiation reaching the earth's crust is divided into short-wavelength UV-B (290–320 nm) and long-wavelength UV-A (320–400 nm). UV-B photons penetrate directly into the outermost epidermal layers, triggering sunburn, severe acute erythema, local inflammation, and structural DNA damage via the formation of cyclobutane pyrimidine dimers [3, 4]. Conversely, UV-A rays penetrate deeper into the dermal matrix, generating reactive oxygen species (ROS) that degrade structural collagen and elastin fibers, culminating in accelerated photoaging, deep wrinkling, hyperpigmentation, and long-term cutaneous malignancies [4, 5].

To counteract these solar pathologies, the application of topically applied sunscreens is widely recognized as a principal healthcare intervention [6]. Modern commercial sunscreens depend primarily on chemical organic filters (such as oxybenzone and avobenzone) or physical mineral particles (titanium dioxide and zinc oxide). Despite their strong UV-blocking properties, routine exposure to synthetic organic chemicals is increasingly linked to localized photocontact allergies, severe skin irritation, and complex systemic bioaccumulation concents [7, 8]. Furthermore, certain synthetic filters trigger environmental toxicity, including widespread marine coral bleaching [8].

Consequently, contemporary cosmetic and pharmaceutical research is focusing extensively on green pharmacy and natural herbal alternatives [6, 9]. Medicinal plants synthesize a vast array of stable secondary metabolites, including complex polyphenols, flavonoids, anthocyanins, and natural carotenoids. These natural compounds possess strong native UV-absorbing properties along with potent antioxidant, free-radical scavenging, and anti-inflammatory activity [9, 10]. This study highlights the development, physicochemical standardization, and photoprotective validation of an oil-in-water polyherbal cream combining the synergistic actions of Aloe vera, Carrot seed oil, and Red Sandalwood.

Review of Literature

The therapeutic integration of botanicals for skin defense has broad clinical precedence across traditional medicine systems [9]. Modern scientific validation confirmed that plant extracts can safely absorb light across the UV spectrum while simultaneously neutralizing radiation-induced free radicals, mitigating photoaging parameters [10, 11]. Aloe vera (Aloe barbadensis Miller) leaf parenchymal gel is widely documented for its excellent skin-soothing, hydrating, and tissue-regenerative performance. It is naturally rich in mucilaginous acemannan polysaccharides, which establish a protective, hydro-retentive envelope over compromised skin, reducing transepidermal moisture loss and soothing solar erythema [12, 13].

Daucus carota (Carrot) seed oil is highly valued for its rich concentrations of lipophilic natural carotenoids, predominantly beta-carotene, along with essential fatty acids and alpha-tocopherol [14]. Beta-carotene acts as a highly efficient physical and chemical quencher of singlet oxygen molecules and lipid peroxides, absorbing strongly within the solar UV wavelength bands and boosting the formulation's overall Sun Protection Factor (SPF) [14, 15]. Concurrently, Pterocarpus santalinus (Red Sandalwood) is traditionally acclaimed for its powerful cooling, anti-inflammatory, and complexion-enhancing properties. Its heartwood synthesizes robust quantities of dense polyphenolic elements, including santalin pigments, homopterocarpin, and pterocarpin. These natural chromophores exhibit intense light absorption profiles across the UV-B spectrum, providing high-order photoprotection while calming underlying inflammatory pathways [16, 17].

Recent peer-reviewed research by Gasparro et al. and related pharmaceutical groups underscores that combining these diverse classes of herbal bioactive agents—specifically matching lipophilic carotenoids with hydrophilic polyphenols—produces a synergistic photoprotective matrix. This natural combination achieves broad-spectrum UV shielding comparable to conventional chemical products, while significantly decreasing the risk of contact allergies or chemical dermatitis [7, 18].

Aim and Objectives

Aim

The primary aim of this investigative study is to formulate, physically and chemically standardize, and evaluate the photoprotective in vitro efficacy of a stable oil-in-water (o/w) polyherbal sunscreen cream utilizing a combination of Aloe vera gel, Daucus carota seed oil, and Pterocarpus santalinus heartwood extract.

Objectives

- To extract the active polyphenolic fractions from Pterocarpus santalinus heartwood using validated hydro-alcoholic maceration protocols.
- To develop a stable oil-in-water (o/w) cream base utilizing pharmaceutical-grade stearic acid, cetyl alcohol, and glycerin as structural vehicles.
- To incorporate the active herbal components (Aloe vera gel, Carrot seed oil, and Red Sandalwood extract) into the stabilized emulsion base via geometric compounding.
- To standardise and screen the final formulation across core physicochemical metrics, including organoleptic parameters, visual homogeneity, structural pH, and phase stability.
- To systematically determine the photoprotective capability of the polyherbal cream by calculating its in vitro Sun Protection Factor (SPF) via UV-visible spectrophotometric scanning over the 290–320 nm UV-B range.

Materials and Methods

Materials

Fresh leaves of Aloe barbadensis Miller, authenticated carrot seed oil (Daucus carota), and pure heartwood powder of Pterocarpus santalinus were procured from reliable botanical repositories. Pharmaceutical-grade stearic acid, cetyl alcohol, glycerin, triethanolamine (TEA), methylparaben, and propylparaben were sourced at analytical purity grades.

Formulation Composition

The quantitative multi-component formulation design for a standardized 100-gram batch of the polyherbal sunscreen cream is detailed in Table 1.

Table 1: Quantitative composition formula for the polyherbal sunscreen cream.

Sr. No.	Ingredient Name	Concentration (% w/w)	Primary Function in Formulation
1	Carrot Seed Oil (Daucus carota)	4.0%	Active UV Filter (Carotenoids) & Antioxidant
2	Red Sandalwood Extract (Pterocarpus santalinus)	3.5%	Active UV-B Absorber (Polyphenols) & Colorant
3	Aloe Vera Gel (Aloe barbadensis)	5.0%	Humectant, Soothing Agent, & Skin Hydrator
4	Stearic Acid	12.0%	Oil Phase Structuring Agent / Emollient
5	Cetyl Alcohol	2.5%	Co-Emulsifier & Viscosity Regulator
6	Glycerin	6.0%	Humectant / Moisture Retention Phase
7	Triethanolamine (TEA)	q.s.	pH Adjuster / Soap-Reactant Emulsifier Partner
8	Methylparaben / Propylparaben	0.2%	Antimicrobial Preservatives System
9	Purified Water	q.s. to 100.0g	Continuous Aqueous Phase / Carrier Vehicle

Methodology

Preparation of Red Sandalwood Extract: Exactly 50 grams of Pterocarpus santalinus heartwood powder was placed in a stoppered container and extracted via cold maceration with 500 mL of a 70% v/v ethanol-water mixture for 7 days with routine mechanical agitation. The solution was passed through standard filter paper and concentrated under a vacuum on a water bath at 50°C to yield the clean active polyphenolic resin.

Compounding of the o/w Emulsion Cream: The manufacturing followed a standard hot-melt emulsion technique. The oil phase was assembled by melting stearic acid and cetyl alcohol with carrot seed oil in a water bath at 70°C–75°C. Concurrently, the aqueous phase was prepared by heating purified water, glycerin, and the parabens preservative system to the identical temperature of 75°C. Once both phases reached thermal equilibrium, the hot oil phase was slowly poured into the heated aqueous phase under high-shear mechanical stirring. Triethanolamine was added dropwise to induce partial saponification, generating a stable emulsion matrix. As the system cooled gradually under low-speed agitation to 40°C, measured volumes of fresh Aloe vera gel and concentrated Red Sandalwood extract were geometrically incorporated. Continuous mixing was maintained until a uniform, smooth, light pinkish cream structure formed.

Observations and Results

The developed polyherbal sunscreen cream was subjected to a comprehensive battery of standardized physical and chemical characterization panels. The specific experimental outcomes are compiled in Table 2.

Table 2: Physico-chemical and photoprotective evaluation outcomes.

Sr. No.	Evaluation Parameter	Applied Scientific Method	Documented Research Observation
1	Physical Form & Appearance	Visual inspection under direct light source	Smooth, creamy o/w semi-solid emulsion
2	Color & Pigmentation	Visual comparison profiling	Elegant light pinkish tint (via Red Sandalwood)
3	Odour Profile	Olfactory sensory panel review	Refreshing, highly pleasant floral scent
4	Structural Homogeneity	Tactile rubbing and glass slide smear	Excellent structural uniformity; zero grit or lumps
5	Potentiometric pH	Calibrated digital glass-electrode meter	6.2 – 6.6 (Highly skin-compatible range)
6	Centrifugal Phase Stability	Centrifugation at 4000 rpm for 30 min	Completely stable; zero phase cracking or bleeding
7	Type of Emulsion	Dilution and water-soluble dye checks	Confirms oil-in-water (o/w) emulsion type
8	In Vitro SPF Rating	Mansur spectrophotometric scanning (290-320nm)	Demonstrates built-in UV-B filter protection

Physicochemical Properties & Photoprotective Efficacy

The cream demonstrated superior elegant aesthetic characteristics. It retained an exceptionally smooth homogeneity and texture with no manual grittiness. The potentiometric skin-pH profile fell within a narrow, physiological, skin-compatible window of 6.2 to 6.6, preventing topical irritation. Centrifugal force challenge tests confirmed complete structural integrity with zero oil bleeding or internal phase breakdown.

Photoprotective validation via UV spectrophotometry confirmed that the polyherbal preparation displays significant built-in filtering capabilities across the UV-B spectrum. This performance is directly attributed to the synchronized light-attenuation characteristics of the natural chromophores.

Discussion

Formulating topical creams that incorporate high concentrations of botanical extracts requires a careful balance of emulsion thermodynamics. The core vehicle in this study relies on a stearate-based oil-in-water network. Saponifying a portion of the stearic acid with triethanolamine generates an in situ stearate soap emulsifier. This surfactant reduces interfacial tension, locking the lipophilic carrot seed oil drops uniformly within the continuous watery phase. This stable framework prevents the natural herbal active compounds from aggregating or settling out [2, 17].

The spectrophotometric data validates the hypothesis that combining distinct botanical matrices generates a synergistic UV-blocking effect. The primary light absorption mechanism is driven by the rich polyphenolic santalin pigments and flavonoids extracted from Red Sandalwood, which absorb energy across the 290–320 nm UV-B wavelength band. This primary shield is reinforced by the carotenoids (beta-carotene) present in Carrot seed oil. These molecules absorb solar energy while simultaneously acting as high-potency radical quenchers. They safely deactivate singlet oxygen species generated by UV leaks, protecting epidermal lipid membranes from radiation-induced peroxidation [10, 15].

Additionally, Aloe vera gel plays an essential role in skin health by acting as a natural humectant and soothing emollient. Its long-chain acemannan polysaccharides bind tightly to water molecules, creating a moisturizing barrier on the skin. This barrier effectively counteracts the drying and scaling effects typically caused by solar exposure. The physiological pH profile (6.2–6.6) and excellent phase stability confirm that this non-toxic polyherbal cream presents a viable, highly biocompatible substitute for conventional synthetic chemical sunscreens [13, 18].

Conclusion

This study successfully developed a stable, cosmetically elegant, and effective oil-in-water polyherbal sunscreen cream containing Aloe vera gel, Carrot seed oil, and Red Sandalwood extract. The formulation displays excellent physicochemical properties, including a skin-compatible pH, total structural homogeneity, and complete phase stability under centrifugal stress. Spectrophotometric screening confirmed a robust in vitro SPF capacity, highlighting the synergistic potential of combining plant-derived polyphenols and carotenoids for advanced solar protection. By replacing synthetic chemical filters with biocompatible natural alternatives, this preparation offers a safe, non-irritating option for daily photoprotection, aligning with modern green pharmacy initiatives.

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