Indian Journal of Traditional Knowledge
Vol 25(4), April 2026, pp 309-325
DOI: 10.56042/ijtk.v25i4.22916

A scoping review of methodologies opted for photoprotection of herbal formulation for the herbal sunscreen formulation

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Received 20 August 2025; revision on 09 January 2026; accepted 09 April 2026

In the current scenario, fragmented and inconsistent photoprotective evaluation methodologies for herbal drugs and formulations must be evaluated and standardised through a scoping review. In order to identify gaps, improve scientific rigour, and support the development of potent herbal photoprotective agents, this review methodically examines the current landscape of experimental approaches and analytical techniques used to evaluate herbal and Ayurvedic sunscreen formulations. Peer-reviewed studies published since 2000 were included, and a review was carried out in accordance with PRISMA-ScR guidelines, and databases like PubMed, Science Direct, AYUSH Research Portal, and Google Scholar were searched. Studies that used analytical standardisation techniques like UV-Vis spectrophotometry, FTIR, or HPLC and examined herbal or plant-based formulations for photoprotective efficacy using *in-vitro*, *ex-vivo*, *in-vivo*, or clinical models were included. Of the 1445 Studies, 36 studies-28 *in vitro*, 7 *in vivo*, and 1 clinical trial met the eligibility criteria of the review. The findings show that phytochemicals such as flavonoids, polyphenols, and carotenoids are widely used and a variety of dosage forms, such as creams, gels, nanoemulsions, and liposomes, were formulated. These formulations showed cellular protection, antioxidant capacity, and quantifiable SPF values. Nonetheless, there is a wide variation in formulation strategies, assessment criteria, and standardisation methods. In order to promote the development and clinical translation of sunscreens derived from plants, the review highlights the urgent need for standardised protocols and regulatory alignment. This work provides a consolidated foundation for future research and innovation in natural or Herbal photoprotection.

Keywords: Ayurveda, Ayurvedic photoprotection, Herbal sunscreen, Plant-based sunscreen, Scoping review, SPF evaluation

IPC Code: Int Cl.[26]: A61K 36/00

Photoaging, hyperpigmentation, immunosuppression, and skin cancer are consequences of ultraviolet (UV) radiation, especially UVB (280-320 nm) and UVA (320-400 nm). The growing prevalence of UV-mediated disorders across the globe emphasizes the need for safe and effective sun protection solutions. In 2022, Jesus *et al*. Even though sunscreens with synthetic UV filters such as benzophenones, cinnamates, and salicylates provide broad-spectrum protection, doubts have been raised regarding their long-term safety and effects on the ecosystem due to concerns about their dermal absorption into the body, which can further lead to potential endocrine disruption, stability under sunlight, and overall environmental impact[1].

So, investigating plant-derived UV protection solutions has become more favourable in response to these problems. Bioactive substances such as flavonoids, polyphenols, terpenoids, carotenoids, and alkaloids present in herbal and Ayurvedic drugs naturally absorb UV rays, have antioxidant activity, reduce inflammation, and protect against DNA Damage[2]. The Photoprotective mechanisms of extracts from plants like *Aloe vera*, *Camellia sinensis* (green tea), *Curcuma longa* (turmeric), and *Glycyrrhiza glabra* (liquorice) have been thoroughly studied and have resulted in highly effective outcomes in a variety of experiments[3,4].

Also, the development of newer herbal sunscreen delivery systems in these articles, such as nanoemulsions, liposomes, nanogels, and lipid-based nanoparticles, which are advancements in pharmaceutical nanotechnology These novel approaches enhance the penetration of the active ingredients into the skin, also increase the duration of retention of the active phytoconstituents, and

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further enhance stability, all of which contribute to overcoming many of the drawbacks of conventional medicaments.

Despite a number of studies on herbal sunscreen, a comprehensive synthesis of its scope is limited, and methodologies are failing. Variability in formulation, phytochemical constituents, and different testing models hampers standardization, comparison, and regulatory approval. Photoprotective efficacy can be evaluated through multiple techniques, including *in-vitro* spectrophotometric SPF estimation and cellular assays, *ex-vivo* skin models, and *in-vivo* clinical testing. Advanced, sophisticated analytical techniques like HPLC, FTIR, UV-visible spectrophotometry, and GC-MS were being widely used for phytochemical identification, ensuring formulation quality and consistency. Assessment and the advancements of the herbal photoprotective agents and their acceptance widely depend upon addressing the diversity of methodologies.

The motivation behind this study is the rising market demand for natural and eco-friendly skincare products, combined with a scientific and regulatory focus on herbal actives for sun-protection[5]. A scoping synthesis of the literature is essential. A scoping review is more suited for investigating new fields with a variety of data than systematic reviews, which focus on certain clinical outcomes. Thus, allowing for a massive examination of the research concerning herbal sunscreen, also identifying shortcomings, guiding future innovations, gives direction and clinical applications. This scoping review intends to systematically identify, outline, summarize, and compile the current status of research on herbal botanicals with a focus on phytochemicals and plant species used for UV protection, as well as formulation strategies that incorporate both conventional and modern drug delivery techniques like nanotechnology. A variety of experimental methodologies (*in vitro*, *ex vivo*, and *in vivo*) were employed in order to assess the photoprotection. In addition, pharmaceutical and analytical approaches for the characterization, standardization, and quality control of herbal photoprotective agents were also used. Through analyzing the current trends in the global market, and with all the current findings of the review, along with aligning it to the regulatory affairs, and investigating technologies, product development, and clinical validation of the same in the field of natural photoprotective agents.

Methodology

Study design

The PRISMA-ScR 2.0 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) Guidelines were adhered to carry out the scoping review (Scoping, n.d.-b). describing the data on plant-based sunscreen formulations, including phytochemical constituents, formulation procedures, evaluation techniques, and analytical techniques, was the aim of this review[6,7].

Eligibility criteria

Inclusion criteria

This review included full-text, English-language, peer-reviewed studies published from 2000 onwards that investigated the photoprotective potential of herbal ingredients or polyherbal formulations. Eligible studies evaluated topical dosage forms (lotions, gels, creams) and advanced delivery systems (liposomes, nanoemulsions).to ensure methodological rigor and comparability, only studies reporting physicochemical characterization and photoprotective assessment using validated analytical techniques (e.g., FTIR, UV–Vis spectrophotometry, HPLC) were included. Evidence from formulation-focused studies and biological efficacy evaluations (*in vitro, in vivo*, and limited clinical studies) was critically appraised, while reports lacking analytical standardization or defined photoprotection outcomes were excluded.

Exclusion criteria

Review articles and articles that have used organic UV filters as part of Photoprotection are excluded, articles that have solely toxicity studies were also excluded.

Information sources and search strategy

A systematic literature search was conducted across PubMed, Science Direct, AYUSH Research Portal, DHARA, and Google Scholar to ensure comprehensive coverage of biomedical, Ayurvedic, and phytopharmacological literature. The search strategy combined controlled vocabulary (MeSH terms, where applicable) with predefined free-text keywords related to Ayurvedic and herbal sunscreens, UV protection, SPF assessment, and photoprotection. Core search terms included: “Ayurvedic sunscreen” OR “herbal sunscreen”; ((Ayurvedic OR herbal) AND sunscreen); “UV protection”; “phytochemicals”; “SPF evaluation”; and “Ayurvedic photoprotection”. Reference lists of

eligible articles were manually screened to capture additional relevant studies not indexed in the selected databases. The search was restricted to peer-reviewed publications from 2000 onwards.

Study selection and data extraction

Study selection followed a two-stage screening process. Titles and abstracts of all retrieved records were independently screened by two reviewers to identify potentially eligible studies, followed by full-text assessment against predefined inclusion criteria. Discrepancies were resolved by consensus, with adjudication by a third reviewer when required. Final inclusion was based on methodological quality and direct relevance to the review objectives. Data extraction was performed using a structured Data Extraction Sheet (DES) to ensure consistency and minimize extraction bias. Core study characteristics (author, year, title, and study design) were recorded for all included articles. Domain-specific DES templates were used for clinical, *in vitro*, and *in vivo* studies. Clinical data were extracted using the PICOT framework, while experimental studies captured intervention/activity and key outcomes (Table 1-3). Data extraction was independently performed by two reviewers and verified by a third reviewer for accuracy.

Table 1 — Data extracted from *in vivo* studies

S. No.	Product/activity	Results	Author/References
1.	• SLN- Aloe Vera (using GMS and Tween 80) • Photoprotective potential	Key findings include: Particle Size & Stability: 96–213 nm, zeta potential: −8.5 and 19.1 mV. Entrapment Efficiency: 75.7% to 86.1%. Microscopy Analyses (AFM, SEM, and digital microscopy): characterized as nanosized, smooth, spherical, and well-dispersed Thermal & Structural Analysis: (DSC and PXRD): reduced crystallinity in SLNs. *In vivo* SPF: Found to be 14.81±1.01. *In vivo* Skin Irritation Index: Recorded at 0.06.	Lavita Roshni Rodrigues *et al.*[8] 2020
2.	• PGG (Pentagalloyl glucose) • Cytoxicity • Antioxidant	Pentagalloyl glucose (PGG) synthesis: yielding 300 mg from 10 g of tannic acid (3% yield). Product identification through: HPLC and FAB-MS. Human dermal fibroblasts cytotoxicity: exhibited minimal cytotoxicity with up to 50 μM PGG, and UVB doses up to 200 mJ/cm² did not significantly affect cell viability. PGG demonstrated significant reductions: UVB-induced reactive oxygen species (ROS), superoxide generation, with concentration-dependent scavenging of superoxide radicals, and moderate effects against peroxynitrite in cell-free systems. In vivo studies using SKH: HR-1 hairless mice: PGG (L/A) ↓UVB-induced skin damage, characterized by ↓epidermal thickening and inflammation. reduced NF-κB activation (Histopathology).	Byung-Hak Kim[9] *et al*., (2015) 2015
3.	• Silymarin-loaded solid lipid nanoparticles (SLNs) • Particle size, Zeta potential, Microscopic, SPF	Particle size & Zeta potential: SLNs particle sizes: 26.87 to 129.5 nm, PDI values: 0.160 and 0.692, and zeta potentials: -0.745 to +3.53 mV, Microscopy studies: Digital imaging, SEM, and AFM: smooth, spherical, and stable morphology with even dispersion. Entrapment efficiency: Entrapment efficiency: 83.96% to 92.36%, ↑with the concentration of Tween 80, with F6 -highest efficiency. *In vitro* & *Ex vivo* release: F6, highest in vitro (91.92%) and ex vivo (86.5%) drug release over 8 hours, following Higuchi model kinetics. Skin irritation study: The primary irritation index: Low (0.08), confirming safety. SPF studies: *In vitro* SPF values: 12.24 to 13.80, with F6 highest value; *in vivo*, F6 provided effective UV protection (SPF 14.01) and delayed erythema.	Gladyston Netto *et al.*[10] 2018

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Table 1 — Data extracted from *in vivo* studies (Contd.)

S. No.	Product/activity	Results	Author/References
4.	• Emulsion • Antioxidant, Cytotoxic	Phytochemical omposition: GC-MS identified 54 compounds in I. carnea leaf extract, primarily 1,2,4-butanetriol (62.95%), along with other compounds such as n-hexadecanoic acid and phytol (antioxidant and wound-healing properties). Antioxidant activity: strong antioxidant effects in Assays (83.02% DPPH inhibition at 1000 µg/mL). Cytotoxicity: Exhibited selective cytotoxicity (melanoma cells) (IC_{50} = 48.95 µg/mL), safe for Vero cells. Herbal Cream Formulation: Creams (extract concentrations) (50, 100, 200 mg) found to be stable for 90 days. Permeation: FIHC-200 (highest release of active compounds). UVB Protection: reduced UVB-induced skin damage in rats. Skin Elasticity: FIHC-200 improved skin elasticity.	Madasamy Sundar *et al.*[11] 2021
5.	• Extract	Polyphenol & flavonoid content: *"Green" honeybush extract* had significantly higher TPC (179.62 mg/g) and flavonoids than *fermented honeybush* (69.92 mg/g), with flavonols/flavones most abundant. Hesperidin &mangiferin content: Higher in *"green" honeybush* (40.74 mg/g and 62.72 mg/g) than *fermented* (24.26 mg/g and 2.56 mg/g). Mangiferin was dominant in green, while hesperidin dominated fermented. UV–VIS absorption: *"Green" honeybush* showed absorption peaks aligning with hesperidin and mangiferin; fermented extract showed a peak corresponding only to hesperidin. Antioxidant capacity: *"Green" honeybush* had higher antioxidant capacity across FRAP, TEAC, and ORAC assays than fermented, with mangiferin outperforming hesperidin. Sunburn protection: Topical *"green" and fermented honeybush* extracts reduced UVB-induced erythema, peeling, and edema. Pure compounds had minimal effect. Edema & hyperplasia: Both extracts significantly inhibited UVB-induced edema and epidermal hyperplasia. Hesperidin had moderate effects; mangiferin was ineffective against hyperplasia. Antioxidant enzyme activity*: ex vivo* Extracts restored catalase and SOD activity post-UVB exposure; fermented honey bush was most effective. Mangiferin increased SOD only; hesperidin moderately protective. Lipid peroxidation: Both extracts reduced MDA levels, indicating lipid peroxidation inhibition. Hesperidin and mangiferin offered moderate protection. Inflammation (COX-2 expression): Extracts significantly suppressed UVB-induced COX-2 expression. Hesperidin offered moderate protection; mangiferin showed a negligible effect.	Antoinette Petrova *et al.*[12] 2011

Data items and synthesis strategy

Data charting process

A standardized data-charting framework was applied to extract key variables from eligible studies, including plant source(s), formulation type, reported SPF and UVA/UVB protection, experimental methodology, and analytical techniques used for standardization.

Data synthesis

Extracted data were synthesized descriptively and tabulated to map methodological approaches, outcome measures, and evidence gaps in the photoprotective evaluation of herbal and Ayurvedic formulations.

Table 2 — Data extracted from *in vitro* studies

S. No.	Cell line	Parameter Assessed	Results	References
1.	Human skin fibroblast (HSF) cell	MTT, p-Nrf protein expression, Cell viability post UVA and UVB Irradiation, SPF determination. Antioxidant Parameters (SOD, ROS, Glutathione peroxidase, Lipid peroxidation)	Toxicity > 300 µg/mL. LBP (Lipid-Bound Protein) facilitates the translocation of Nrf2, aiding in protection against ultraviolet light. LBP enhances levels of SOD (superoxide dismutase) and GSH-px (glutathione peroxidase). Reactive oxygen species (ROS) levels rise after irradiation and are not reversed by LBP. LBP slightly reduces the level of lipid peroxidation (LPO).	Bihua Liang *et.al.*[13] 2018
2.	N/A	SPF evaluation, Radical scavenging activity through DPPH, ABTS	SPF of two plant species: Leucas zeylanica (39.8 ± 0.35) and Lasia spinosa (8.9 ± 0.57). High radical scavenging activity of H. furcatus, L. zeylanica, M. cerviana, O. zeylanica, and O. Mungos when compared to ascorbic acid and Trolox standards for DPPH and ABTS assays, respectively.	Mayuri Tharanga Napagoda *et.al.*[14] 2016
3.	N/A	Total phenol, Total flavonoid, Total alkaloid, Total tannins DPPH, ABTS, Anti-collagenase, Anti-elastase, Tyrosinase Inhibitory, Xanthine oxidase inhibitory, anti-inflammatory, SPF Activity	Antioxidant capacities: TPC: 44.34 ± 0.7 mg GAE/g Flavonoids: 24 ± 0.5 mg QE/g (DPPH IC50): 42.66 ± 1.8 µg/mL (Ascorbic acid :38.24 ± 2.5 µg/mL) (ABTS IC50): 13.32 ± 1.1 µg/mL (Trolox :7.42 ± 0.8 µg/mL) Enzyme inhibitory activities: Anti-collagenase: IC50 of 32.52 ± 1.6 µg/mL (standard EDTA: 35.45 ± 1.7 µg/mL) Elastase: IC50 of 32.24 ± 1.7 µg/mL (standard oleanolic acid: 30.56 ± 1.8 µg/mL) Tyrosinase: IC50 of 175.812 ± 2.1 µg/mL (standard Kojic acid: 52.24 ± 2.5 µg/mL) Xanthine oxidase: IC50 of 22.88 ± 1.9 µg/mL (standard Allopurinol) UV blocking potential: SPF of 21.68 ± 0.06 at 250 µg/mL, with both wild and *in vitro*-derived *M. acuminata* extracts.	Biswajit Bose *et.al.*[15] 2017
4.	N/A	SPF	The SPF (Tsanspore Tape method) for wavelengths between 200-400 nm. The SPF values for ZnOn and *T. Polium* Extract were found to be 5.3.	Mehdi Ansari *et.al.*(6) 2013
5.	N/A	SPF, Antioxidant activity	The UV analysis (GZ spectrophotometer UV-754) scanning wavelengths from 200 nm to 400 nm in 10 nm increments. The absorbance measurements recorded were: 1.8 at 200-220 nm, 1.9 at 230 nm, 1.8 at 240 nm, and 1.4 at 290 nm.	Musa Runde *et.al.*[16] 2023
6.	N/A	GC–MS study, SPF evaluation	Twenty-two compounds were characterised, out of which trans-beta-Ocimene (46.18%), dihydrotagetone (31.66%), Cis-Tagetone (4.63%), Artemisia ketone (3.42%), Neo-allo-ocimene (3.74%), Limonene (2.69%), Verbenone (0.93%) are in major amounts. SPF: 14.84 ± 0.16	Mishra AK *et.al.*[17]2012
7.	Human Melanoma Colo38 Cell Line	Antioxidant activity *in vitro* by DPPH, PCL, FRAP, and ORAC assays, SPF, Anti-proliferative effects of extracts from *Moringa oleifera* on Human Melanoma Colo38 Cell Line	DPPH (IC50) values (µg/mL) are as follows: 232.6 ± 7.61, 305.8 ± 12.15, and 232.8 ± 0.60. PCL was measured in µmol TE/g with results of 506.8 ± 3.19, 367.1 ± 6.96, and 512.1 ± 10.30. FRAP values (µmol TE/g) were recorded at 496.6 ± 8.74, 418.3 ± 12.24, and 369.24 ± 27.52. ORAC results (µmol TE/g) showed values of 2942.8 ± 27.28, 2272.5 ± 14.72, and 2345.2 ± 10.64. SPF: 2.01 ± 0.02, and the UVAP: 1.44 ± 0.01. Additionally, Moringa oleifera hydroalcoholic extracts demonstrated an anti-proliferative effect, with an IC50 of 30.64 ± 2.37 µg/mL.	Anna Baldisserotto *et.al.*[18] 2018
8.	Human Dermal Fibroblast	MTT assay, Comet assay Ethidium bromide/acridine orange staining, Reactive oxygen species	EA fraction of okra: exhibited a significant protective effect against UV-B-induced cell damage, concentration-dependent (10–30 µg/mL), with results showing $p<0.001$. It ↓comet formation and ↑% head DNA to 92.3 ± 1.8%, UV-B protection, and no genotoxicity. UV-B exposure induced apoptosis in HDF cells, but pretreatment with the EA fraction dose-dependently reduced damage and restored membrane integrity, (free radical scavenging activity)	Juilee Patwardhan *et.al.*[19] 2016

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Table 2 — Data extracted from *in vitro* studies (Contd.)

S. No.	Cell line	Parameter Assessed	Results	References
9.	N/A	SPF	SPF values of various herbal oils (spectrophotometry): Olive oil (7.549), coconut oil (7.119), peppermint oil (6.668), tulsi oil (6.571), and lemongrass oil (6.282), indicating good photoprotective potential. Moderate SPF values: castor oil (5.687), lavender oil (5.624), almond oil (4.659), and orange oil (3.975). Lower SPF values: mustard (2.105), chaulmoogra (2.019), lemon (2.810), eucalyptus (2.625), sesame (1.771), and tea tree oil (1.702). Rose oil had the lowest SPF at 0.248.	Kaur, Chanchal Deep *et.al.*[20] 2010
10.	N/A	SPF	SPF: 31.84±3.24, pH 6.75±0.05, Spreadability 7.13±1.12, Viscosity 1015±1.13, % Drug Content 2.56±1.13.	Disha Dutta *et.al.*[21] 2022
11.	N/A	SPF	Week 1, Week 2, Week 3, Week 4, Week 8 SPF values are 15.92±0.34, 15.53±0.48, 15.60±0.25, 15.77±0.51, and 15.26±0.84, respectively.	Amina Ahmady *et.al.*[22] 2020
12.	N/A	UV absorptivity of natural oils and fruit/vegetable powders UV transmittance of 20 µm-thick formulations, Formulation types: aqueous (F1–F3) and oil-based (O1–O5), Microscopy (light and SEM), Film appearance and spreadability on skin	Oils exhibited minimal UV-blocking capabilities, exception of vitamin E under 310 nm. Among the natural ingredients, purple carrot powder (50 wt%) provided the most significant UV-blocking effect. Transmittance: purple carrot displayed 29% (lowest), orange carrot 66%, and the beet root 71%. The oil formulation containing purple carrot, with vitamin E and aloe (O5): the most effective UV protection, 43.8% transmittance. Microscopic examination: particles had aggregated, and the dried films appeared uniform. skin appearance: purple carrot resulted in less noticeable staining compared to the other options.	S. Gause *et. al.*[23] 2016
13.	N/A	SPF, Antioxidant	The SPF values for formulations F1, F2, and F3 were 14.94 ± 0.72, 9.45 ± 0.62, and 16.91 ± 1.20, respectively. The antioxidant activity of resveratrol was measured at 38.67 ± 3.24, 52.50 ± 3.25, 64.82 ± 3.07, and 85.44 ± 3.41. The antioxidant activity of green tea extract was determined to be 37.41 ± 3.57, 53.16 ± 4.62, 61.96 ± 4.11, and 77.5 ± 5.08, respectively.	Sohini Bhattacharya *et.al.*[24] 2020
14.	N/A	TPC, TFC, SPF	Nv-HA = 61.66 ± 5.14 mg GAE/g, while Nv-HA = 90.27 ± 5.03 mg CE/g. For the concentrations of 0.5 and 1.0% (v/v), Nv-HA exhibited values of 5.43 ± 0.07 and 11.73 ± 0.04, respectively.	Raimundo Gonçalves de Oliveira-Júnior *et.al.*[25] 2017
15.	S. typhimurium TA102 and TA104 strains	TPC, DPPH, HPLC-DAD, SPF, Ames Salmonella microsome mutagenicity assay, Photomutagenicity and photoprotective tests	6.01 ± 0.00, 5.09 ± 0.01, EE 1.04 ± 0.01, 382.0 ± 14.8 for H. laevifolia; 7.75 ± 0.00, 0.52 ± 0.01, 0.28 ± 0.01, 3.48 ± 0.01 for Leucobryum species AE, HE, EE, ME extracts, respectively. 136.0 ± 7.8 h, > 1000, 382.0 ± 14.8, > 1000 for H. laevifolia; 375.0 ± 9.2, 76.0 ± 8.5, > 1000, > 1000 for Leucobryum species AE, HE, EE, ME extracts, respectively. Identification of phenolic compounds. SPF values: 6.48 ± 0.46, 13.82 ± 1.02, 13.93 ± 1.02, and 17.57 ± 0.28, 9.28 ± 0.76, 12.00 ± 0.67 for AE, HE, EE of *Holomitriopsis laevifolia* and *Leucobryum* sp., respectively. No mutagenic activity: in frame shift mutations (TA98 and TA97 strains), substitution mutations (indicated strain), or transition/transversion mutations (indicated strains) was detected in either of the moss species. Both *H. laevifolia* and *Leucobryum* sp. extracts displayed no photomutagenicity in the Photo-Ames assay. Notable photoprotective effects were observed.	A.S. Fernandes *et.al.*[26] 2018
16.	L929 fibroblast cells	MTT Assay, Cytoprotection Photoprotection, Antioxidants, SPF, Photohaemolytic	*L. chinensis* extract: no cytotoxic effects in L929 fibroblasts (concentrations 0.1 to 100 µg/mL). Fibroblasts against oxidative stress H_2O_2 (300 mM), and the extract maintained cell viability post-UVA/UVB exposure. Additionally, it minimized DNA damage induced by UVA/UVB (fibroblasts). The extract ↓levels of intracellular ROS (Post UV), ↑SOD activity, did not replenish depleted GSH or influence CAT levels. the extract exhibited a high SPF of 18.90 at a concentration of 1 mg/mL and demonstrated strong UVA absorption. No photohaemolytic effect or irritation was noted in RBC, HET-CAM, or agarose overlay tests.	Liliani Carolini Thiesena *et. al.*[27] 2017

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Table 2 — Data extracted from *in vitro* studies (Contd.)

S. No.	Cell line	Parameter Assessed	Results	References
17.	N/A	Phytoconstituents, antioxidants, sun protection, and skin anti-wrinkles	The DPPH inhibition Assay (IC50 23.44±2.13, 27.54±1.97, and 30.9±2.44 µg/mL for the hexane, aqueous, and methanol fractions), respectively. The fractions of A. tinctoria exhibit very weak SPF: 0.67, 0.47, and 0.24.	Nidal Amin Jaradat *et. al*.[28] 2018
18.	N/A	Phytochemical test, Infrared analysis, UV characterization, Fluorescence identification, Flavonoids content, LCMS/MS quantification, Sun protection factor (SPF) from extracts	Ethanol exhibited the highest extraction efficiency for A. paniculata (fluorescence intensity). The extracts contain flavonoids, alkaloids, tannins, triterpenoids, and polyphenols. Infrared spectra (phenolic –OH, C=O, and aromatic compounds). Ultraviolet absorption (230 nm and 362 nm): high flavonoids. Fluorescence demonstrated UV-B (absorption: 300 nm and emission: 605 nm). HPTLC analysis: flavonoid Rf value of 0.61, corresponding to quercetin. The flavonoid content: 0.022 µg/µL quercetin equivalent. LCMS/MS analysis: identified glycosylated and non-glycosylated flavonoids. Quercetin-3-glucoside quantified: 9.17 mg/mL, SPF values: 15.42 and 28.41,↑with the concentration of the extract.	Qonitah Fardiyah *et.al*.[29] 2020
19.	N/A	Extraction Yield, Phytochemical Characterization, Antibacterial Activity, Photoprotective Activity, Cytotoxic Activity, Antioxidant Activity	The methanol extract: 20.56% (Highest), n-butanol extract (18.23%) and aqueous extract (17.12%). LC-MS analysis; predominance of phenolic compounds, with anthraquinones and chromones present in the acetone (8.21 mg GAE/g) and n-butanol (6.55 mg GAE/g) extracts. Three extracts: inhibited S. aureus; zones of inhibition 24.2 mm and minimum inhibitory concentrations (MICs): 250 µg/mL. (SPF) values: with acetone (SPF 49.2), methanol (SPF 46.7), and n-butanol (SPF 44.8) extracts. acetone extract: cytotoxic effects with an LC_{50} of 85 µg/mL, aqueous and methanol extracts showed LC_{50} values (>100 µg/mL). acetone extract: potent DPPH scavenging activity,91.2% inhibition (IC_{50} of 26 µg/mL), methanol extract (IC_{50} of 52 µg/mL).	Samira Bendjedid *et.al*.[30] 2021
20.	N/A	Sun Protection Factor, Antioxidant Activity, MMP Inhibition, HPLC Profiling, Phytochemical Quantification	Ethanolic and hydroethanolic fruit extracts SPF values: (15.365 and 15.011), ; appropriate for phototypes III–IV. Both ethanolic and hydroethanolic extracts (radical scavenging activity in DPPH, ABTS, NO, and phosphomolybdate assays): significant, comparable to ascorbic acid and Trolox. The hydroethanolic fruit extracts show inhibition of MMP-1, MMP-8, and MMP-13 (up to 89.38%), nearing that of the reference inhibitor (NNGH). Emodin (main anthraquinone); new findings included: the detection of emodin-8-O- and nepodin-8-O-β-glucopyranosides in leaves and fruits, and abundance of anthraquinones (emodin, aloe-emodin, chrysophanol), which correlates with their antioxidant and anti-aging properties.	M. Uzun *et. al*.[31] 2019
21.	mouse embryonic fibroblast cells (3T3)	Phytosome Characterization, Antioxidant and Photoprotective Activity, Cytotoxicity and Phototoxicity, Optimization	EE-Viola phytosomal formulation particle size: 167.2 nm, a PDI of 0.243, and a zeta potential: –31.6 mV, indicating stability and uniform dispersion. TEM analysis: spherical morphology; entrapment efficiency: 84.7%. Enhanced antioxidant activity (IC_{50} = 47.3 µg/mL) compared to the free extract (IC_{50} = 63.9 µg/mL) In vitro SPF (18.5) greater than the free extract (10.2). The MTT assay: 85% cell viability in HaCaT and HDF cells (≤100 µg/mL), with slightly higher viability for the phytosomal formulation. An optimal D-optimal design identified the best parameters (3:1 phospholipid:extract ratio, 15 min sonication), achieving maximum entrapment and minimal particle size, with a strong predictive power (R^2 = 0.987).	Atefeh Ameri *et. al*.[32] 2024
22.	N/A	Extraction, Antioxidant Activity Metal Chelation, UV Protection Structural Analysis, Application Potential	Ramie leaf polysaccharides (RLP) extract: a polysaccharide (molecular weight-23.4 kDa). RLP showed strong antioxidant activity, as evidenced by DPPH radical scavenging, copper ion chelation, and attenuation of metal-induced oxidative stress. The polysaccharide also exhibited intrinsic UV-blocking activity, supporting its role as a natural UV filter. FTIR and NMR analyses: identified functional groups responsible for its antioxidant and metal chelation activities.	Pei Gee Yap *et.al*.[33] 2024

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Table 2 — Data extracted from *in vitro* studies (Contd.)

S. No.	Cell line	Parameter Assessed	Results	References
23.	N/A	Extraction Efficiency, Fatty Acid Composition, Tocopherol Content Silymarin Content, Antioxidant Capacity, Antibacterial Activity Antibiofilm Activity, Molecular Docking, Molecular Dynamics, Pharmacokinetics, Sun Protection	Milk thistle oil yield: 16.1%; methanolic extract yield: 7.9%. Oil composition: 66.2% linoleic acid and 23.6% oleic acid; total tocopherols: 383.4 µg/g. Methanolic extract contained 330.2 mg/g silymarin (silibinin equivalent). Antioxidant activity: CUPRAC value of 2.49 mmol TE/g; DPPH value of 0.675 mmol TE/g. Minimum inhibitory concentration (MIC) against S. aureus: 0.156 mg/mL; *E. coli*: 0.3125 mg/mL. MTE reduced P. aeruginosa biofilm formation by 33%. Silibinin showed high binding affinity to peroxiredoxin 5 but formed an unstable enzyme complex. Silibinin adheres to Lipinski's Rule of Five but has limited oral absorption due to high TPSA. Cream B (ZnO + MTE) had SPF 55.7; Cream A (ZnO only) had SPF 16.7.	Ümit Erdoğan *et.al.*[34] 2024
24.	human dermal fibroblast cells and B16-F10 melanoma cells.	R Composition, Transferosome Characteristics, Entrapment Efficiency, Antityrosinase Activity Melanin Content, Cytotoxicity Sunscreen Emulgels, Release Kinetics, Stability, Cytotoxicity of F3	R contained 0.227% phenolic compounds and 0.315% ascorbic acid, demonstrating antioxidant and anti-tyrosinase activities. Vesicle sizes ranged from 143 to 421 nm, with Tr10 being optimal for deeper skin penetration (less than 300 nm). Here's a concise, scientific, and natural rewrite with clean flow and clear results: Tr10 exhibited 44.73% encapsulation efficiency (EE) and 16.91% loading capacity (LC) for ascorbic acid, while EE and LC for phenolic compounds were 27.05% and 7.37%, respectively. It produced dose-dependent skin-whitening effects (IC_{50} = 1.40 mg/mL), significantly reduced melanin in melanoma cells, and outperformed kojic acid, while maintaining >80% cell viability at concentrations <100 µg/mL in NHF cells and <50 µg/mL in B16-F10 cells. The combined formulation F3 (Tr10 + sunscreen agents) achieved the highest SPF (23.73) and UVA-PF (21.17), demonstrated sustained ascorbic acid release and stability up to 6 h, and preserved >80% cell viability at higher test concentrations, indicating effective and biocompatible photoprotection.	Benchawan Chamsai *et. al.*[35] 2024
25.	N/A	Photoprotective efficacy, Flavonoid & Phenolic Content, Photoprotection Efficacy, Photostability, Identified UV-Active Compounds, Extract Combinations SPF	The SN ethyl acetate extract showed the highest flavonoid (103 mg/g) and polyphenol (311 mg/g) content, whereas HA and CM contained lower levels (flavonoids: 84–95 mg/g; polyphenols: 265–284 mg/g). At 10% concentration, SPF values were highest for SN (9.9), followed by HA (6.8) and CM (6.0). HA provided superior UVA protection (UVA-PF 7.0), with the highest UVA/UVB ratio (1.06) and a critical wavelength of 387 nm. SN also demonstrated greater photostability, retaining 88% of SPF after UV exposure, compared with 82% for HA and 81% for CM.The HA+CM combination achieved the highest SPF (19.5) and PF-UVA (16.6), while HA+SN and SN+CM improved SPF (up to 17.5) and UVA protection (PF-UVA 10.2–13.4).	Anna Jarzycka *et. al.*[36] 2013
26.	N/A	Extraction yield, DPPH IC50 Total phenolic content Total flavonoids, SPF before irradiation & SPF after irradiation	Phenolic content ranges from 7.6% to 22.2%; C. capituliflora leaves have the highest at 22.2%. IC50 values are 137.6 to 260.2 µg/mL, with the highest activity in C. capituliflora. GAE content peaks at 87.8 mg GAE/g in C. meyeriana, and QE content tops at 6.4 mg QE/g in C. bambusoides. Unspecified values are 34.5 to 86.2 before irradiation and 35.2 after.	Katarzyna Barbara Wróblewskaa *et.al.*[37] 2019
27.	N/A	HPLC Quantification, Flavonoids & Antioxidant Activity, SPF Values, UVA Protection, Eye Irritation (HET-CAM), Formulated SPF	Quercetin was identified in M. taxifolia extract at Rt 14.34 min, with a content of 1.12 mg/L (R^2 = 0.9987), LOD of 0.0145 mg/L, and LOQ of 0.048 mg/L, demonstrating accuracy of ≤2.09%. Total flavonoids were 168 ± 0.35 µg/mL as quercetin equivalents, with strong antioxidant activity (EC_{50} of 5.13 ± 1.08 µg/mL, R^2 = 0.853). SPF values were 15.52 at 250 µg/mL and 8.35 at 125 µg/mL. UVA-induced photobleaching reduced from 50.73% to 9.48% with the extract, showing low irritancy (irritation score of 1.93 at 250 µg/mL). An SPF of ≥6 was achieved from 2 mg/mL with 5–30% of the extract, reaching an SPF of 43.11 at 50 mg/mL, comparable to 5% benzophenone (SPF 39.84).	Sônia C.C. Costa *et. al.* [38] 2015

... Contd.

Table 2 — Data extracted from *in vitro* studies (Contd.)

S. No.	Cell line	Parameter Assessed	Results	References
28.	N/A	Total Phenolic Content, DPPH Radical Scavenging, FRAP Assay, Temperature Effect on SPF, pH Effect on SPF, Comparison with Dibenzalacetone	Orange (132.53 ± 1.45 mg GAE/100g FW) and eggplant (290.71 ± 0.64 mg GAE/100g FW) have the highest phenolic compounds. Orange has the most vitamin C (59.66 ± 0.20 µmol VC/g), while eggplant has 31.23 ± 0.45 µmol VC/g. Papaya boasts the highest Trolox equivalent (4.15 ± 0.04 µmol Trolox/g), with eggplant close behind at 4.33 ± 0.04 µmol Trolox/g. Most vegetables peak in Sun Protection Factor (SPF) at a pH of 7 and 25°C, but eggplant shows notable changes at pH 10, while beetroot and potato's SPF declines at 7°C and 45°C.	Tanya Sharma *et. al.*[39] 2020

Table 3 — Data extracted from the clinical trial

S. No.	Design and duration	Intervention and dose	Outcome measures	Results
1	RCT; 4 days	6 mg/mL ethanolic extracts of *Helichrysum odoratissimum* and *Buddlejasaligna*, applied at 2 mg/cm²	In vivo SPF, UVA PF, photostability, dermal irritancy	SPF 15.8–16.1, UVA PF ~6.5; safe, effective, non-mutagenic, low irritancy
2	Patch test & SPF study in healthy volunteers	Topical multifunctional sunscreen with *Vitis vinifera*, *Camellia sinensis*, *Ginkgo biloba*	SPF, erythema index, antioxidant enzymes, sensory analysis	SPF >15, reduced erythema, increased SOD & CAT, no irritation

Results

A total of 1,445 records were identified through database searches. After title and abstract screening, 821 records were excluded due to irrelevance, duplication, or non-original content (Fig. 1). Of the 68 articles assessed in full text, 30 were excluded (8 duplicates; 22 not meeting inclusion criteria, including use of synthetic UV filters, absence of efficacy outcomes, or non–peer-reviewed sources).

Finally, 36 studies were included in the qualitative synthesis, comprising 28 *in vitro*, 7 *in vivo*, and 1 clinical study (Fig. 1). All included studies were further analysed using a structured Data Extraction Sheet (DES) (Fig. 1).

Discussion

This review systematically evaluated the photoprotective potential of herbal drugs, their formulations, and constituent phytochemicals, integrating evidence from *in vitro*, *in vivo*, and limited clinical studies alongside reported safety profiles. In the context of growing concerns regarding cutaneous adverse effects, environmental toxicity, and endocrine-disrupting potential of synthetic UV filters, plant-based photoprotective agents are receiving increasing research attention. Synthesis of the 36 included studies revealed substantial heterogeneity in phytochemical composition, extract types, formulation bases, dosing strategies, and photoprotection assessment methodologies, underscoring both the therapeutic promise of herbal sunscreens and the lack of methodological standardization across the field.

Type of extract

A consistent trend across studies was the preferential use of ethanolic extracts, reflecting ethanol's intermediate polarity and capacity to extract diverse bioactives, including flavonoids, tannins, and phenolic acids. In a clinical study, ethanolic extracts of *Helichrysum odoratissimum* and *Buddleja saligna* were formulated at 6.0 mg/mL and applied at 2 mg/cm² in accordance with ISO 24444 guidelines-2024 (ISO 24444, n.d.), demonstrating broad-spectrum photoprotection (SPF 15.8-16.1; UVA-PF 6.5) without dermal sensitivity. Similarly, a botanical blend of ethanolic and aqueous extracts of *Vitis vinifera*, *Ginkgo biloba*, and *Camellia sinensis* incorporated into an emulsion base showed enhanced antioxidant enzyme activity and reduced UV-induced erythema in patch-test evaluations, with adherence to EU cosmetic regulatory guidelines and inclusion of sensory assessment[40,36,41].

Formulation bases: Vehicle for efficacy and safety

The formulation base critically determines the efficacy, stability, and dermal compatibility of topical photoprotective products by influencing spreadability, absorption, photostability, and sensory acceptability. Across the reviewed studies, oil-in-water (O/W) emulsions predominated due to their non-greasy profile, user acceptability, and capacity to accommodate both hydrophilic and lipophilic phytoconstituents[42]. Consistently, ethanolic extracts of *Helichrysum odoratissimum* and *Buddleja saligna* formulated in an O/W emulsion achieved SPF 15.8-16.1 with good UV protection and no dermal irritation, highlighting the role of the vehicle in

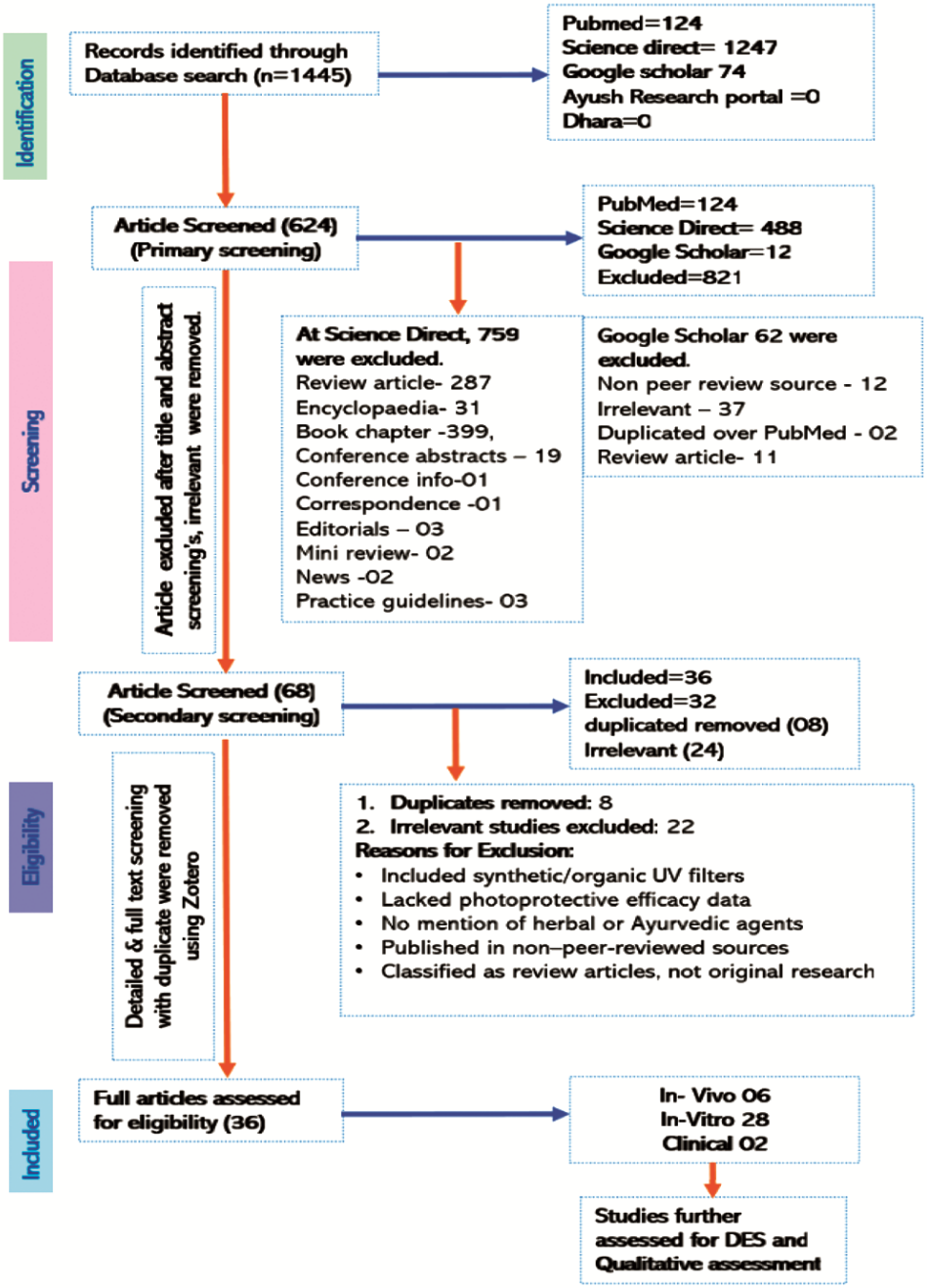

Fig. 1 — Prisma flow chart

enhancing efficacy and tolerability[41]. Similarly, an emulsion containing *Camellia sinensis*, *Ginkgo biloba*, and *Vitis vinifera* improved antioxidant enzyme activity and reduced erythema without adverse dermal reactions[40,43].

Although liposomal and gel-based carriers have been explored for enhanced penetration and retention, direct head-to-head comparisons between base types remain scarce, limiting identification of an optimal vehicle for herbal sunscreens (Table 4 & Table 5). Collectively, the evidence indicates that base composition modulates phytochemical bioavailability, stability, user compliance, and overall performance. Future studies should prioritize base standardization and comparative evaluation, particularly with respect to SPF persistence, sensory attributes, and stability under varied environmental conditions.

Methods for the estimation of sun protection

Accurate evaluation of herbal sunscreen formulations requires a combination of *in vitro*, *ex vivo*, *in vivo*, and clinical approaches (Fig. 2). The studies included in this review used different models and analytical methods, each providing complementary information on UV protection, drug availability in skin, and biological safety.

In vitro methods

In vitro evaluation of photoprotection commonly involves spectrophotometric estimation of SPF by measuring UV absorption across the UVA and UVB ranges. The Mansur method is widely used to calculate SPF from UVB absorbance values. Across the reviewed studies, crude herbal extracts and nanoformulations showed low to moderate SPF (approximately 4-8 to 12-20), with higher values generally observed in formulations enriched with polyphenols, flavonoids, and alkaloids.

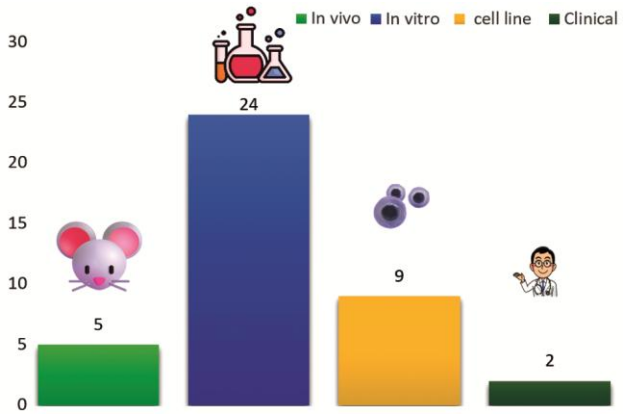

Fig. 2 — Types of studies for evaluating photoprotection

In addition, cell-based assays using human skin fibroblasts (HSF) and keratinocytes (HaCaT) were employed to assess UV-induced cytotoxicity, oxidative stress, DNA damage, and anti-inflammatory effects following UV exposure. Due to higher activity of antioxidant enzymes and decreased ROS production, Lycium barbarum polysaccharide (LBP), for instance, exhibited protective benefits against UV-induced oxidative damage in HSF cells.

Ex vivo methods

Ex vivo models that simulate in vivo skin permeability without systemic interactions involve dissected human or animal skin. Transdermal penetration, phytoconstituent retention, and photoprotective effectiveness post UV exposure have been investigated in studies employing rat or pig skin. These techniques are especially relevant for evaluating the effects of innovative formulations that offer prospective information on skin absorption and deposition, such as SLNs, lipid-based nanocarriers, and herbal emulsions[44].

In vivo animal models

The protective effects of herbal sunscreens against UVB-induced skin damage have been investigated in a variety of preclinical experiments involving albino rats, Wistar rats, and SKH-1 hairless mice. Assessment parameters included SPF value, erythema scoring, histological changes, skin elasticity, and biomarker analysis (e.g., malondialdehyde and catalase), among other variables. Various herbal formulations, such as p-coumaric acid-loaded phospholipid complexes and silymarin SLNs,

Table 4 — Common herbal agents used in sunscreen formulations

Botanical Name	Common Name	Major active constituents	Extract type	Reported SPF range	Study type
Aloe vera	Aloe	Aloin, polysaccharides	Gel, aqueous	4–8	*In vitro*, *In vivo*
Camellia sinensis	Green Tea	EGCG, catechins	Ethanol, aqueous	8–12	*In vitro*, cell lines
Curcuma longa	Turmeric	Curcumin	Hydroalcoholic	5–10	*In vitro*, *Ex vivo*
Glycyrrhiza glabra	Licorice	Glabridin, liquiritin	Ethanolic	5–12	*In vitro*, Cell-based
Ocimum sanctum	Holy Basil	Eugenol, ursolic acid	Methanolic	6–11	*In vitro*
Helianthus annuus	Sunflower	Tocopherols, flavonoids	Oil	3–6	*In vitro*

Table 5 — Herbal sunscreen formulations: Delivery Strategies and photoprotective outcomes

Formulation type	Plant/herbal extract	Delivery system	Reported SPF	Evaluation method
Cream	*Aloe vera*	Conventional emulsion	4–6	*In vitro* (UV spectrophotometry), *In vivo*
Gel	*Curcuma longa*	Aqueous gel base	5–10	*In vitro*, *Ex vivo*
Lotion/Liposomal cream	*Camellia sinensis*	Oil-in-water emulsion	8–12	*In vitro* SPF (Colipa method)
Nanogel	*Glycyrrhiza glabra*	Nanogel with carbopol	11–14	*In vitro* (UV-Vis), Cell line (HaCaT) assays
Solid Lipid Nanoparticles (SLNs)	*Curcuma longa*, *Centella asiatica*	SLNs using stearic acid	12–18	*In vitro*, Skin permeation, FTIR
Nanoemulsion	*Ocimum sanctum*, *Lycopene*	Nanoemulsion	10–16	*In vitro* SPF, DPPH antioxidant assay

substantially increased SPF and minimised UV-induced damage in the treated groups in comparison to the controls (Fig. 3).

Human clinical evaluations

Limited clinical trials on healthy volunteers have been conducted to assess erythema response (Minimal Erythema Dose, MED) post-application of herbal creams followed by sun Exposure[45]. For example, emulsion formulations containing Pistacia seed extract were topically applied and assessed for the reduction of UV-induced erythema. These studies validate the photoprotective potential of herbal sunscreen formulations on human subjects and are crucial for eventual translational and regulatory advancement for validating the drug at the tertiary level[46].

Comparative SPF values across studies

In view of a diversity of plant species, extraction strategies, formulation bases, along with evaluation approaches, an extensive spectrum of SPF values has been observed across the evaluated formulations and herbs. Solid lipid nanoparticle (SLN)-based systems notably exhibited substantial SPF augmentation; *in vivo* SPF values of 14.81±1.01 and 14.01 were achieved by SLNs loaded with silymarin and aloe vera, respectively[8]. These results are consistent with previous research suggesting that lipid-based nanoformulations are occlusion film-forming and longer-lasting release features enhance skin penetration and prolong photoprotective effect.

The dual-spectrum efficiency of the ethanol extracts of *Helichrysum odoratissimum* and *Buddleja saligna* combined to a sunscreen matrix has been shown by

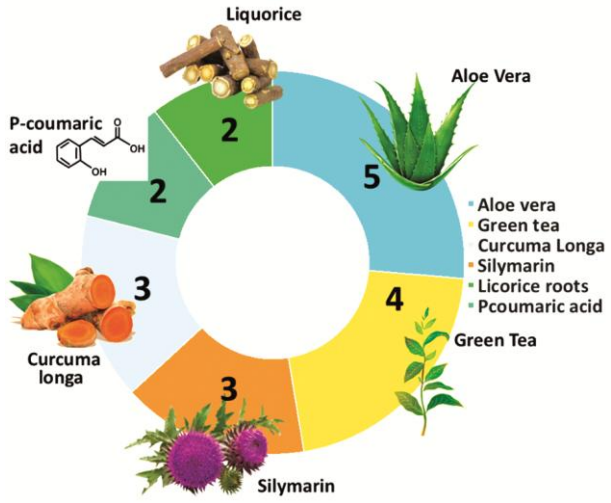

Fig. 3 — Most commonly used drugs used as photoprotective agents

slightly improved SPF values (15.8-16.1), UVA protection factors (~6.5), dermatological tolerability, and photostability. *Vitis vinifera*, *Camellia sinensis*, and *Ginkgo biloba* polyherbal sunscreens additionally demonstrated an SPF of higher than 15, complementing previous research on the synergistic antioxidant and UV-filtering characteristics of polyphenol-containing botanical mixtures[13]. *Leucas zeylanica* extracts indicated excellent UVB attenuation, achieving SPF levels of up to 39.8±0.35 by *in vitro* testing[13], among the highest determined SPF values. nevertheless, there has been no *in vivo* correlation of this significance which is encouraging, but must be interpreted carefully, considering that it was obtained from a spectrophotometric experiment. High SPF values ranging from 28.41 to 49.2 were also obtained from Andrographis paniculata extracts in Samira Bendjedid *et al.*'s research, confirming a substantial UV-filtering phytochemical content, particularly phenolic acids and flavonoids[29].

On the other hand, lower SPF values associated with certain fermented herbal extracts and natural oils, such rose oil (SPF 0.248) and A. tinctoria fractions (SPF < 1), indicate a limited photoprotective property when administered alone[47]. The study by Ümit Erdoğan *et al.*[34] highlighted the significance of combined effects with physical filters by reporting a maximum SPF of 55.7 for a topical emulsion consisting of zinc oxide (ZnO) with *Silybum marianum* extract. Overall, our results suggest that formulation construction, vehicle features, combined effects with other bioactives or physical agents, and the inherent UV-absorbing characteristics of phytoconstituents contribute to SPF effectiveness. Comparative findings from various research highlight the necessity of standardised assessment procedures and stress the significance of combining skin-permeation, antioxidant, and anti-inflammatory factors with SPF to evaluate photoprotective efficacy comprehensively.

Dose and methodological approaches

A broad range of approaches is used to evaluate herbal-based photoprotective medications, ranging from in vitro studies to *in vivo* experiments with both human and animal subjects. Each technique offers a different perspective on the biochemical significance and the effectiveness of SPF. Extract concentration as well as application thickness have significant effects on the observed efficiency.

Several studies applied the UV spectrophotometric method described by Mansur *et al*. to estimate in vitro

SPF from absorbance in the 290-320 nm range. Using this approach[10], reported that silmarin-loaded solid lipid nanoparticles (SLNs) achieved SPF values of 12.24-13.80 *in vitro*, which closely aligned with *in vivo* SPF (14.01) (Netto MPharm & Jose[10]). Similarly, Bose *et al*.[15] used UV absorbance–based estimation to evaluate ethanolic extracts of *Crotalaria verrucosa*, reporting peak SPF values of 21.68 at 250 µg/mL.

In vivo validation was supported by animal studies. Topical pentagalloyl glucose (PGG) applied to SKH:HR-1 hairless mice produced a dose-dependent reduction in UVB-induced skin inflammation, accompanied by decreased NF-κB activation and lipid peroxidation (Petrova *et al*.[12]). These in vivo findings were consistent with the reported in vitro antioxidant and ROS-scavenging activity of PGG.

Several formulation procedures were employed slightly varied dosage methods. The FIHC-200 formulation of Ipomoea carnea cream demonstrated the greatest reduction in exposure to UVB rays and regeneration of skin elasticity when tested at various extract doses ranging from 50 to 200 mg[48]. On the contrary hand, formulations based on both green and fermented Cyclopia spp. have been studied for SPF efficacy and their effects on the quantity of endogenous antioxidant enzymes, lipid peroxidation, and COX-2 expression, providing an extensive comprehension of dose-dependent effects.

Ex vivo experiments, such as permeation studies employing dialysis membranes or Franz diffusion cells, which resemble interactions with human skin, were used by certain investigators to broaden their evaluations. For example, the Silymarin SLN formulation F6 showed an ex vivo drug release of 86.5% over 8 h, which is compatible with its low irritation index and elevated *in vitro* SPF.

The internal concentration of the bioactive extract within the formulations varied greatly (e.g., 0.5% to 5% w/w or 50-300 mg/g), emphasising the lack of standardisation in botanical equivalent dose measurements even though a majority of formulations complied with the 2 mg/cm² topical application requirement. Despite being important from a scientific standpoint, the variability in dose emphasises the need for standardised procedures that encourage dosage and guarantee consistency between experiments.

Conventional and advanced dosage forms

To boost the photoprotective actions of substances originating from plants, herbal sunscreens are developed utilising traditional and innovative methods of delivery (Fig. 4). Creams, gels, and lotions with purified phytochemicals or whole plant extracts that provide UV protection and skin hydration are common formulations. Examples that are commonly used in cream- or gel-based medications include *Aloe vera*, *Curcuma longa*, and *Camellia sinensis*. *In vitro* studies demonstrated that these plants have modest SPF values, often between 4 and 12[21].

Novel formulations such as solid lipid nanoparticles (SLNs), nanogels, liposomes, and nanoemulsions have been created possible by recent developments in nanotechnology[49]. These methods of delivery promote phytochemicals' skin penetration, photostability, and retention, particularly of biological substances that are not poorly soluble in water, such p-coumaric acid[50]. or silymarin[10]. SLNs of herbal medications applied to albino rats in one *in vivo* study showed their superiority over conventional emulsions with increased SPF values and better skin penetration profiles in *ex vivo* studies. Additionally, nanogel formulations containing *Ocimum sanctum* L. or *Glycyrrhiza glabra* L. demonstrated potential in providing long-term protection and expanding the UV absorption spectrum. Additionally, these systems enable combined administration of anti-inflammatory and antioxidant drugs, optimising therapeutic results[51].

Evaluation of pharmaceutical forms

The selection of an appropriate pharmaceutical vehicle plays a crucial role in the skin permeation, cosmetic acceptability, and bioavailability of herbal photoprotective agents. The reviewed studies employed diverse evaluation approaches, including *in vitro* spectrophotometric assays, *ex vivo* diffusion studies using human or animal skin, and *in vivo* SPF determination in animal models and human participants. Common outcome measures included SPF, minimal erythema dose (MED)[52], erythema index ((PDF) SKIN ERYTHEMA ASSESSMENT TECHNIQUES, n.d.), skin irritation potential, and biochemical markers of oxidative stress.

Comprehensive pharmaceutical characterization of formulations was routinely reported to ensure safety, stability, and user acceptability. Key parameters included pH, loss on drying (LOD), spreadability, extrudability, occlusivity, acid value, fatty content, emulsion type, thermal stability, microbial load, and heavy metal content.

Notably, formulations incorporating phytochemicals such as flavonoids, polyphenols, and terpenoids showed improved skin retention and broader UV protection,

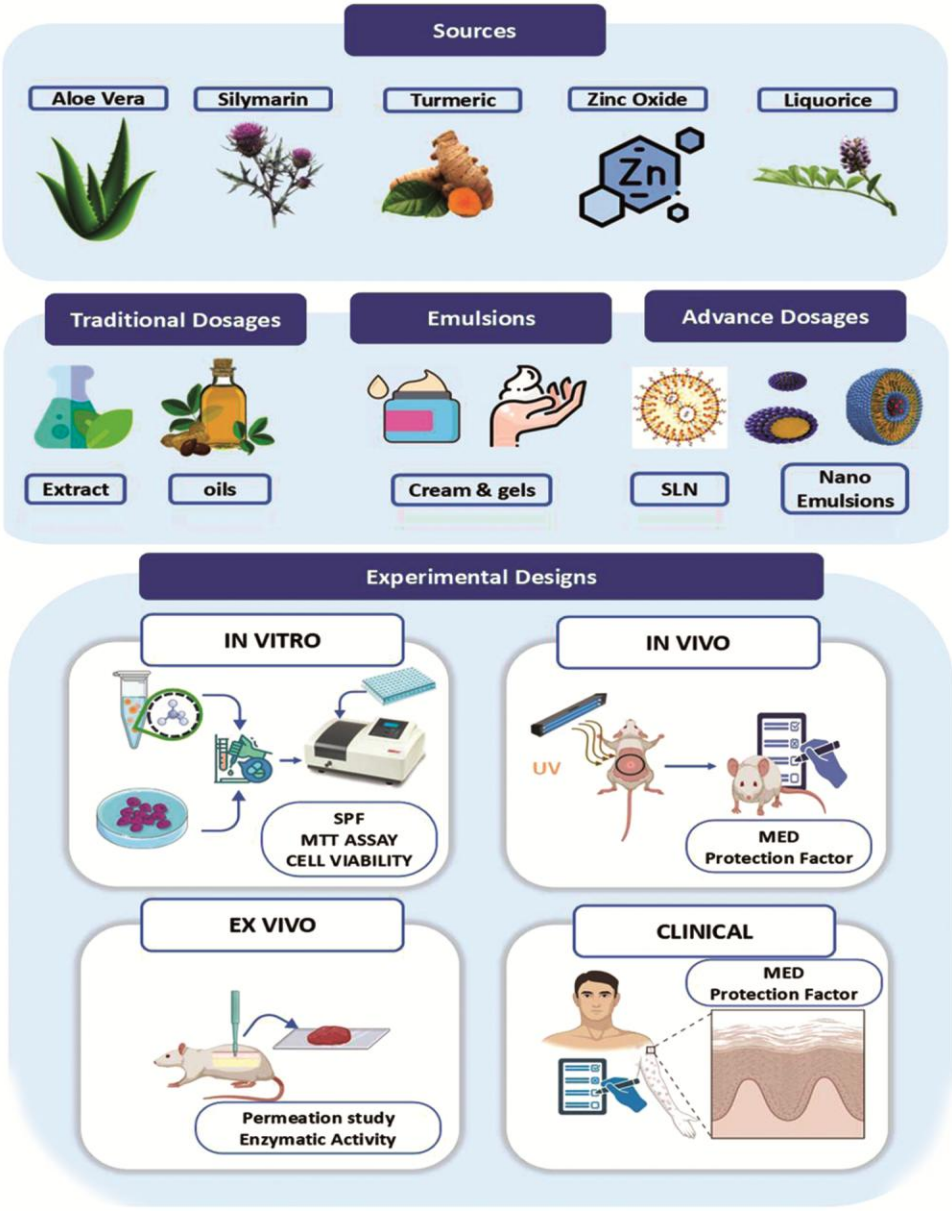

Fig. 4 — Schematic representation of commonly studied herbal, analytical strategies for photoprotective evaluation (SPF, antioxidant, spectral analysis), and explored dosage forms in UV protection research

particularly when delivered via nanocarrier systems. Stability, uniformity, and batch reproducibility were commonly verified using UV-visible spectrophotometry, high-performance liquid chromatography (HPLC), and Fourier-transform infrared spectroscopy (FTIR) (Fig. 4).

Conclusion

This scoping review synthesizes evidence from 36 studies evaluating methods used to assess the photoprotective potential of herbal and Ayurvedic formulations. Across *in vitro*, *ex vivo*, and limited *in vivo* models, plant extracts-particularly those rich in polyphenols and flavonoids-consistently showed UV-absorbing and antioxidant activity. However, substantial variability in extraction methods, formulation design, active concentrations, and outcome measures (e.g., SPF and UVA protection) limits comparability across studies.

Most evidence is derived from laboratory-based screening, with relatively few standardized human evaluations. Inconsistent analytical approaches and reporting further constrain reproducibility. Collectively,

these findings highlight the need for harmonized, regulatory-aligned evaluation protocols and standardized analytical frameworks to improve translational relevance and acceptance of herbal photoprotective formulations in both Ayurvedic and modern dermatological research.

Limitations

Limitations of the studies included were, lack of guidelines, protocol, and standard procedure to be followed to access the drugs. No guidelines for evaluating the extract limit or concentration in the formulation, vague evaluation methodologies, and a lack of sensory and sensitivity evaluation on human or small animals such as a Likert scale or hydronic scale, or animal dermal sensitization study OECD guidelines 406.

Author Contributions

PM & DC contributed to the conceptualization, study design, literature review, experimental investigations, data acquisition, data analysis, and manuscript drafting. GP, CSJ, and SC were involved in the conceptualization, experimental execution, data acquisition, statistical analysis, manuscript editing, and critical review. PRY contributed to study conceptualization, experimental design, statistical analysis, manuscript drafting, and final review. GR defined the intellectual framework, interpreted the data, edited the manuscript, and provided critical revisions. All authors have read and approved the final version of the manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Data Availability

Provided in the tables within the text & below.

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