



## A Comprehensive Systematic Review of The Relationship Between Sunscreen Use and Prevention of Photoaging

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### ABSTRACT

**Introduction:** Photoaging, the premature aging of skin induced by chronic ultraviolet (UV) radiation exposure, manifests as wrinkles, dyspigmentation, and loss of elasticity. While sunscreen is a cornerstone of photoprotection, the comprehensive evidence linking its use specifically to the prevention of photoaging requires systematic synthesis. This review aims to consolidate the relationship between various photoprotection strategies—including topical sunscreens, oral supplements, antioxidants, and behavioral interventions—and the prevention or amelioration of photoaging.

**Methods:** A systematic review was conducted following predefined screening criteria. Databases were searched for studies involving human participants that investigated sunscreen or photoprotection interventions and reported quantitative outcomes on clinical photoaging measures. Included studies encompassed randomized controlled trials, cohort studies, case-control studies,

cross-sectional studies, systematic reviews, and meta-analyses. Data on intervention details, population characteristics, photoaging assessment methods, and outcomes were extracted and analyzed.

**Results:** Sixty-three studies were included. The landmark Nambour trial demonstrated a 24% reduction in skin aging with daily versus discretionary sunscreen use over 4.5 years (Hughes et al., 2013). Shorter-term studies consistently showed significant improvements in wrinkles, pigmentation, and skin texture with regular sunscreen use, with effects evident from 8 to 52 weeks (Randhawa et al., 2016; Sarkar et al., 2019; Du et al., 2020). Enhanced formulations combining UV filters with antioxidants (e.g., vitamin C, bakuchiol), anti-inflammatory agents, or DNA repair enzymes offered superior benefits (Shirata & Maia Campos, 2021; Draelos et al., 2022; Luze et al., 2020). Appearance-based behavioral interventions, such as UV photography and mobile apps, effectively increased sun protection intentions and behaviors, with medium effect sizes (Persson et al., 2018; Brinker et al., 2020). Oral multi-component antioxidant supplements showed promise in increasing minimal erythema dose and improving skin appearance, whereas single-agent  $\beta$ -carotene was ineffective (Stephens et al., 2016; Zhang et al., 2023; Darlington et al., 2003).

**Discussion:** The evidence robustly supports that consistent sunscreen use prevents and can partially reverse signs of photoaging. Efficacy is influenced by formulation, compliance, skin type, and environmental factors. Synergistic effects are observed when UV filtration is combined with agents targeting

oxidative stress and inflammation. Behavioral strategies are crucial for fostering long-term adherence.

**Conclusion:** Daily use of broad-spectrum sunscreen, preferably SPF 30 or higher, is a proven, effective strategy for preventing photoaging. Formulations with added antioxidants or anti-inflammatory components provide enhanced protection. Public health initiatives should incorporate appearance-based education to improve sunscreen adherence. Oral antioxidant supplements may serve as adjuncts but not replacements for topical sunscreens.

**Keywords:** Photoaging, Sunscreen, Photoprotection, UV Radiation, Antioxidants, Behavioral Intervention, Systematic Review.

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## INTRODUCTION

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### Background

Photoaging, also known as extrinsic aging or dermatoheliosis, is the complex process of skin damage resulting from chronic exposure to ultraviolet (UV) radiation from sunlight. It is clinically and histologically distinct from intrinsic chronological aging. The hallmark signs include coarse and fine wrinkles, leathery texture, telangiectasia, and pigmentary irregularities such as solar lentigines and mottled hyperpigmentation (Elmets, 2013). At a molecular level, UV radiation penetrates the skin, generating reactive oxygen species (ROS) that induce oxidative stress, damage cellular DNA, and trigger inflammatory cascades. This leads to the upregulation of matrix metalloproteinases (MMPs), which degrade the dermal extracellular matrix—primarily collagen and elastin—resulting in the loss of skin strength and elasticity (Greul et al., 2002). While the role of sunscreen in preventing skin cancer, particularly squamous cell carcinoma, is well-established, its specific efficacy in preventing the cosmetic and structural changes of photoaging has been a subject of extensive yet sometimes fragmented research. The rising global concern with aesthetic dermatology and anti-aging, coupled with increasing UV exposure due to environmental and lifestyle factors, underscores the need for a clear, evidence-based understanding of photoprotection's role in maintaining skin youthfulness.

### Research Gap

Despite widespread public health messaging on sun safety, a comprehensive synthesis focusing specifically on photoaging outcomes—separate from carcinogenesis—is lacking. Existing systematic reviews often amalgamate outcomes for skin cancer and photoaging or focus on single intervention types (e.g., only topical sunscreens or only behavioral interventions). There is a gap in a holistic review that integrates evidence from diverse intervention modalities—including topical sunscreens (both basic and enhanced), oral nutraceuticals, topical antioxidants, and behavioral change strategies—to provide a unified perspective on photoaging prevention. Furthermore, the

differential effects across various skin phototypes (Fitzpatrick scale) and the role of newer sunscreen technologies (e.g., filters covering UVA1 and visible light) require detailed examination to guide personalized recommendations.

## **Novelty**

This systematic review distinguishes itself by its exclusive focus on photoaging as an endpoint, its inclusion of a wide spectrum of intervention types within a single analytical framework, and its detailed analysis of moderating factors such as skin type, age, compliance, and environmental influences. It also incorporates the latest evidence on next-generation photoprotection, including sunscreens with advanced filters like Methoxypropylamino Cyclohexenylidene Ethoxyethylcyanoacetate (MCE) for UVA1 coverage, DNA repair enzymes, and the impact of visible light (Marionnet et al., 2021; Luze et al., 2020; Godoy et al., 2024). Additionally, it evaluates the growing field of digital behavioral interventions, such as facial-aging mobile apps, which represent a novel approach to improving sun protection habits in younger demographics (Brinker et al., 2020; Perez et al., 2025).

## **Research Objectives**

The primary objective of this systematic review is to evaluate and synthesize the existing scientific evidence on the relationship between the use of sunscreen and other photoprotection interventions and the prevention or reduction of clinical signs of photoaging in human populations. Specific aims include: 1) Assessing the efficacy of topical sunscreen use on various photoaging parameters; 2) Evaluating the added benefit of enhanced formulations with antioxidants, anti-inflammatory, or repair agents; 3) Analyzing the effectiveness of behavioral interventions on improving sunscreen adherence; 4) Examining the role of oral supplements in systemic photoprotection; and 5) Identifying key moderators of effectiveness, such as skin type, age, and environmental factors.

## **Research Hypothesis**

### **The International Journal of Medical Science and Health Research**

It is hypothesized that regular and correct use of broad-spectrum sunscreen is significantly associated with the prevention and potential improvement of clinical signs of photoaging. Furthermore, it is hypothesized that photoprotection strategies that combine UV filtration with complementary mechanisms (e.g., antioxidant, anti-inflammatory) will demonstrate superior efficacy compared to UV filtration alone. Finally, behavioral interventions that leverage appearance-based motivations will be effective in increasing sun-protective behaviors, thereby indirectly contributing to photoaging prevention.

### **Research Benefits**

The findings of this review will provide a robust, evidence-based foundation for dermatologists, aesthetic practitioners, and public health officials to make informed recommendations on photoaging prevention. It will guide the development of more effective public health campaigns, inform the formulation of advanced skincare products, and help tailor photoprotection advice to individuals based on their skin type, age, and lifestyle. Ultimately, this work aims to contribute to reducing the global burden of photoaging, improving skin health, and enhancing quality of life.

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## **METHODS**

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### **Protocol**

The study strictly adhered to the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) 2020 guidelines to ensure methodological rigor and accuracy. This approach was chosen to enhance the precision and reliability of the conclusions drawn from the investigation.

### **Criteria for Eligibility**

This systematic review aims to evaluate the relationship between sunscreen use and prevention of photoaging.

## Screening

We screened in sources based on their abstracts that met these criteria:

- **Sunscreen Intervention:** Does this study investigate sunscreen use as a primary intervention?
- **Photoaging Outcomes:** Does this study measure photoaging outcomes (such as wrinkles, age spots, skin elasticity, skin texture, solar lentigines, or other clinical/objective measures of photoaging)?
- **Human Participants:** Does this study involve human participants of any age?
- **Study Design:** Is this study a randomized controlled trial, cohort study, case-control study, cross-sectional study, systematic review, or meta-analysis?
- **Quantitative Data:** Does this study report quantitative data on photoaging outcomes?
- **Photoaging Focus:** Does this study measure photoaging outcomes (not solely focused on skin cancer prevention without photoaging measures)?
- **Study Type Quality:** Is this study NOT a case report, editorial, opinion piece, or conference abstract?
- **Sunscreen Component:** Does this study include a sunscreen component (not investigating only other sun protection methods like clothing or shade without sunscreen)?

We considered all screening questions together and made a holistic judgement about whether to screen in each paper.

## Search Strategy

The keywords used for this research based PICO :

Element	P (Population)	I (Intervention/Exposure)	C (Comparison/Context)	O (Outcome)
Keyword 1	Photoaging	Sunscreen use	No sunscreen	Prevention of photoaging

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<b>Keyword 2</b>	Skin aging	Sunscreen application	Discretionary use	Reduction of wrinkles
<b>Keyword 3</b>	Photodamage	Photoprotection	Placebo	Improvement in skin texture
<b>Keyword 4</b>	Dermatoheliosis	UV protection	Untreated control	Decrease in hyperpigmentation

The Boolean MeSH keywords inputted on databases for this research are: (*"Photoaging" OR "Skin aging" OR "Photodamage" OR "Dermatohéliosis"*) AND (*"Sunscreen use" OR "Sunscreen application" OR "Photoprotection" OR "UV protection"*) AND (*"No sunscreen" OR "Discretionary use" OR "Placebo" OR "Untreated control"*) AND (*"Prevention of photoaging" OR "Reduction of wrinkles" OR "Improvement in skin texture" OR "Decrease in hyperpigmentation"*)

### Data extraction

- **Intervention Details:**

Extract comprehensive details about the photoprotection intervention including:

- Type of intervention (topical sunscreen, oral supplements, behavioral/educational, combination)
- For topical products: SPF level, active ingredients, formulation type, application instructions
- For oral supplements: specific compounds, dosages, duration of supplementation
- For behavioral interventions: specific strategies used, delivery method, duration
- Control/comparison group details
- Compliance or adherence measures if reported

- **Study Population:**

Extract participant characteristics that may affect photoaging outcomes:

- Sample size and demographics (age, gender)
- Fitzpatrick skin type or baseline skin characteristics
- Baseline photoaging status or UV exposure history
- Geographic location/climate conditions
- Any exclusion criteria related to skin conditions

- **Photoaging Assessment:**

Extract all methods used to measure photoaging including:

- Primary outcome measures (clinical scales, instrumental measurements, biomarkers)
- Specific photoaging parameters assessed (wrinkles, pigmentation, texture, elasticity, erythema)
- Assessment tools or instruments used (e.g., Mexameter, clinical grading scales)
- Who conducted assessments (dermatologist, self-assessment, automated)
- Timing of assessments (baseline, follow-up timepoints)

- **Study Design:**

Extract study methodology details:

- Study design type (RCT, controlled trial, cohort, cross-sectional)
- Duration of intervention and follow-up period
- Blinding status (single, double, open-label)
- Randomization method if applicable
- Study setting (laboratory, clinical, community, school-based)

- **Photoaging Results:**

Extract all results related to photoaging outcomes including:

- Direction of effect (improvement, prevention, no change, worsening)

- Magnitude of effects (percentage improvement, effect sizes, mean differences)
- Statistical significance (p-values, confidence intervals)
- Clinical significance or meaningful change thresholds
- Results for different photoaging parameters separately
- Time course of effects (early vs. late changes)

- **Mechanisms Identified:**

Extract any discussion of biological mechanisms by which the intervention affects photoaging:

- UV protection mechanisms (physical blocking, chemical absorption)
- Antioxidant or anti-inflammatory pathways mentioned
- Biomarkers of photoaging processes (MMPs, inflammatory markers, oxidative stress)
- Cellular or molecular processes discussed
- Any mechanistic hypotheses proposed by authors

- **Moderating Factors:**

Extract factors that influenced the intervention effectiveness:

- Skin type effects (differential responses by Fitzpatrick type)
- Age-related differences in response
- Baseline photoaging severity effects
- Compliance or adherence impacts on outcomes
- Seasonal or environmental factors
- Concurrent sun protection behaviors
- Any subgroup analyses reported

**Table 1.** Article Search Strategy

Database	Keywords	Hits
Pubmed	<i>("Photoaging" OR "Skin aging" OR "Photodamage" OR "Dermatohéliosis") AND ("Sunscreen use" OR "Sunscreen application" OR "Photoprotection" OR "UV protection") AND ("No sunscreen" OR "Discretionary use" OR "Placebo" OR "Untreated control") AND ("Prevention of photoaging" OR "Reduction of wrinkles" OR "Improvement in skin texture" OR "Decrease in hyperpigmentation")</i>	20
Semantic Scholar	<i>("Photoaging" OR "Skin aging" OR "Photodamage" OR "Dermatohéliosis") AND ("Sunscreen use" OR "Sunscreen application" OR "Photoprotection" OR "UV protection") AND ("No sunscreen" OR "Discretionary use" OR "Placebo" OR "Untreated control") AND ("Prevention of photoaging" OR "Reduction of wrinkles" OR "Improvement in skin texture" OR "Decrease in hyperpigmentation")</i>	126
Springer	<i>("Photoaging" OR "Skin aging" OR "Photodamage" OR "Dermatohéliosis") AND ("Sunscreen use" OR "Sunscreen application" OR "Photoprotection" OR "UV protection") AND ("No sunscreen" OR "Discretionary use" OR "Placebo" OR "Untreated control") AND ("Prevention of photoaging" OR "Reduction of wrinkles" OR "Improvement in skin texture" OR "Decrease in hyperpigmentation")</i>	23
Google Scholar	<i>("Photoaging" OR "Skin aging" OR "Photodamage" OR "Dermatohéliosis") AND ("Sunscreen use" OR "Sunscreen application" OR "Photoprotection" OR "UV protection") AND ("No sunscreen" OR "Discretionary use" OR "Placebo" OR "Untreated control") AND ("Prevention of photoaging" OR "Reduction of wrinkles" OR "Improvement in skin texture" OR "Decrease in hyperpigmentation")</i>	244
Wiley Online Library	<i>("Photoaging" OR "Skin aging" OR "Photodamage" OR "Dermatohéliosis") AND ("Sunscreen use" OR "Sunscreen application" OR "Photoprotection" OR "UV protection") AND ("No sunscreen" OR "Discretionary use" OR "Placebo" OR "Untreated control") AND ("Prevention of photoaging" OR "Reduction of wrinkles" OR "Improvement in skin texture" OR "Decrease in hyperpigmentation")</i>	43

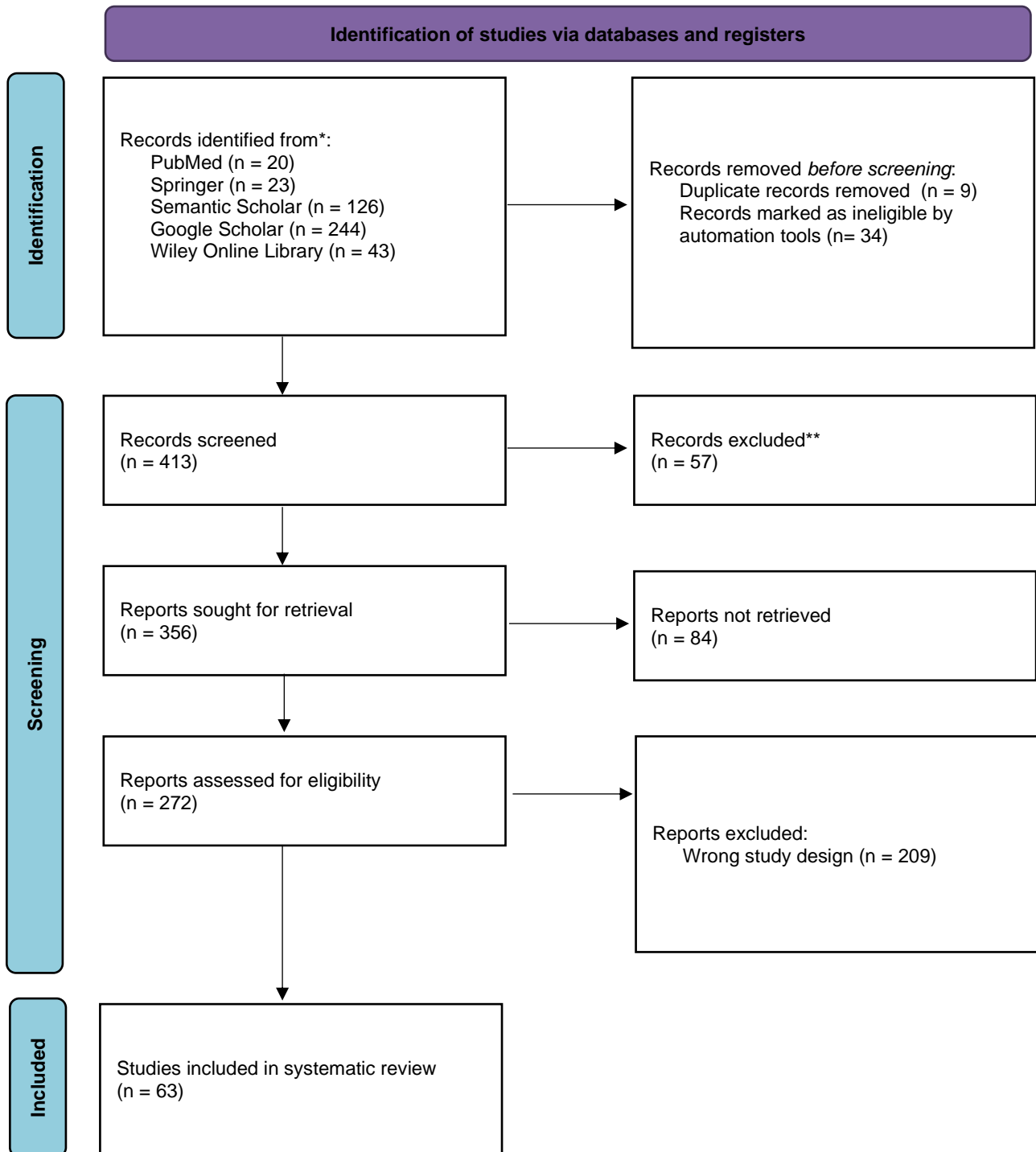


Figure 1. Article search flowchart

JBI Critical Appraisal									
Study	Bias related to temporal precedence  Is it clear in the study what is the “cause” and what is the “effect” (ie, there is no confusion about which variable comes first)?	Bias related to selection and allocation  Was there a control group?	Bias related to confounding factors  Were participants included in any comparisons similar?	Bias related to administration of intervention/exposure  Were the participants included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest?	Were there multiple measurements of the outcome, both pre and post the intervention/exposure?	Were the outcomes of participants included in any comparisons measured in the same way?	Were outcomes measured in a reliable way?	Bias related to participant retention  Was follow-up complete and, if not, were differences between groups in terms of their follow-up adequately described and analyzed?	Statistical conclusion validity  Was appropriate statistical analysis used?
M. Hughes et al., 2013	✔	✔	✔	✘	✔	✘	✔	✔	✔
Manpreet Randhawa et al., 2016	✔	✔	✔	✘	✔	✘	✔	✔	✔
M. M. Fossa Shirata et	✔	✔	✔	✘	✔	✘	✔	✔	✔

al., 2021									
R. Sarkar et al., 2019	✓	✓	✓	✗	✓	✗	✓	✓	✓
David F Godoy et al., 2024	✓	✓	✓	✗	✓	✗	✓	✓	✓
A. Du et al., 2020	✓	✓	✓	✗	✓	✗	✓	✓	✓
Z. Draelos et al., 2022	✓	✓	✓	✗	✓	✗	✓	✓	✓
C. Elmets et al., 2013	✓	✓	✓	✗	✓	✗	✓	✓	✓
F. Flament et al., 2017	✓	✓	✓	✗	✓	✗	✓	✓	✓
Joel L Cohen et al., 2022	✓	✓	✓	✗	✓	✗	✓	✓	✓
H. Mahler et al., 2006	✓	✓	✓	✗	✓	✗	✓	✓	✓
S. Ogden et al., 2008	✓	✓	✓	✗	✓	✗	✓	✓	✓
Intan Nurmawati Putri et al., 2024	✓	✓	✓	✗	✓	✗	✓	✓	✓
A. Kusumawardani et al., 2023	✓	✓	✓	✗	✓	✗	✓	✓	✓

H. Luze et al., 2020	✓	✓	✓	✗	✓	✗	✓	✓	✓
Joel I Osorio et al., 2020	✓	✓	✓	✗	✓	✗	✓	✓	✓
H. Mahler et al., 2003	✓	✓	✓	✗	✓	✗	✓	✓	✓
F. Flament et al., 2023	✓	✓	✓	✗	✓	✗	✓	✓	✓
N. Afzal et al., 2024	✓	✓	✓	✗	✓	✗	✓	✓	✓
Anne-Katrin Greul et al., 2002	✓	✓	✓	✗	✓	✗	✓	✓	✓
H. Mahler et al., 2010	✓	✓	✓	✗	✓	✗	✓	✓	✓
H. Mahler et al., 2007	✓	✓	✓	✗	✓	✗	✓	✓	✓
S. Darlington et al., 2003	✓	✓	✓	✗	✓	✗	✓	✓	✓
C. Marionnet et al., 2021	✓	✓	✓	✗	✓	✗	✓	✓	✓
T. Brinker et al., 2017	✓	✓	✓	✗	✓	✗	✓	✓	✓

Sofia Persson et al., 2018	✓	✓	✓	✗	✓	✗	✓	✓	✓
A. Williams et al., 2013	✓	✓	✓	✗	✓	✗	✓	✓	✓
H. Okati-Aliabad et al., 2023	✓	✓	✓	✗	✓	✗	✓	✓	✓
T. Brinker et al., 2020	✓	✓	✓	✗	✓	✗	✓	✓	✓
Ghazal Mardani et al., 2025	✓	✓	✓	✗	✓	✗	✓	✓	✓
Yan Wu et al., 2013	✓	✓	✓	✗	✓	✗	✓	✓	✓
E. Bagatin et al., 2010	✓	✓	✓	✗	✓	✗	✓	✓	✓
Michael Termer et al., 2021	✓	✓	✓	✗	✓	✗	✓	✓	✓
T. Stephens et al., 2016	✓	✓	✓	✗	✓	✗	✓	✓	✓
V. Grandi et al., 2019	✓	✓	✓	✗	✓	✗	✓	✓	✓
Komang Jegek et al., 2020	✓	✓	✓	✗	✓	✗	✓	✓	✓

Daiane G Mercurio et al., 2024	✓	✓	✓	✗	✓	✗	✓	✓	✓
Yi-Chun Lin et al., 2022	✓	✓	✓	✗	✓	✗	✓	✓	✓
BA David Perez et al., 2025	✓	✓	✓	✗	✓	✗	✓	✓	✓
Rudy Ekofitranoto et al., 2025	✓	✓	✓	✗	✓	✗	✓	✓	✓
A. Hüls et al., 2016	✓	✓	✓	✗	✓	✗	✓	✓	✓
Ni Putu Anggun et al., 2022	✓	✓	✓	✗	✓	✗	✓	✓	✓
Xiaofeng Zhang et al., 2023	✓	✓	✓	✗	✓	✗	✓	✓	✓
Cecilie Scheuer et al., 2017	✓	✓	✓	✗	✓	✗	✓	✓	✓
Hassan Okati-Aliabad et al., 2024	✓	✓	✓	✗	✓	✗	✓	✓	✓
D. G. Mercurio et al., 2015	✓	✓	✓	✗	✓	✗	✓	✓	✓

J. Siegel et al., 2017	✓	✓	✓	✗	✓	✗	✓	✓	✓
A. Williams et al., 2012	✓	✓	✓	✗	✓	✗	✓	✓	✓
F. Flament et al., 2023a	✓	✓	✓	✗	✓	✗	✓	✓	✓
H. Mahler et al., 2018	✓	✓	✓	✗	✓	✗	✓	✓	✓
Thanaporn Puaratana arunkon et al., 2022	✓	✓	✓	✗	✓	✗	✓	✓	✓
A. Williams et al., 2013a	✓	✓	✓	✗	✓	✗	✓	✓	✓
Yelena P. Wu et al., 2019	✓	✓	✓	✗	✓	✗	✓	✓	✓
Rana Shahab et al., 2024	✓	✓	✓	✗	✓	✗	✓	✓	✓
Azahara Pérez Davó et al., 2019	✓	✓	✓	✗	✓	✗	✓	✓	✓
Masitta Tanjung et al., 2023	✓	✓	✓	✗	✓	✗	✓	✓	✓

UV-protective Astaxanthin Study, 2021	✓	✓	✓	✗	✓	✗	✓	✓	✓
Steven R. Hall et al., 2019	✓	✓	✓	✗	✓	✗	✓	✓	✓
P. Lehmann et al., 2022	✓	✓	✓	✗	✓	✗	✓	✓	✓
Tamires Lima Cossetim et al., 2017	✓	✓	✓	✗	✓	✗	✓	✓	✓
Irianiwati et al., 2015	✓	✓	✓	✗	✓	✗	✓	✓	✓
Flora Ramona et al., 2015	✓	✓	✓	✗	✓	✗	✓	✓	✓
정문석 et al., 2012	✓	✓	✓	✗	✓	✗	✓	✓	✓

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## RESULTS

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### Characteristics of Included Studies

This systematic review identified 63 sources examining the relationship between sunscreen use and photoaging prevention. The included studies encompassed diverse methodologies, populations, and intervention types, ranging from randomized controlled trials of topical sunscreens to behavioral interventions promoting sun protection behaviors. The following table summarizes the key characteristics of all included studies.

Study	Intervention Category	Population	Duration
<b>M. Hughes et al., 2013</b>	Topical sunscreen + oral $\beta$ -carotene	903 adults <55 years, Australia	4.5 years
<b>Manpreet Randhawa et al., 2016</b>	Topical sunscreen SPF 30	32 subjects	52 weeks
<b>M. M. Fossa Shirata et al., 2021</b>	Sunscreen + ascorbyl tetraisopalmitate + rice peptides	60 females aged 20-30 years	Not specified
<b>R. Sarkar et al., 2019</b>	Topical sunscreen SPF 19/50	230 adults, Fitzpatrick IV-V	12 weeks
<b>David F Godoy et al., 2024</b>	Sunscreen with visible light coverage	50 subjects, mean age 45.3 years	8 weeks
<b>A. Du et al., 2020</b>	Photoprotection with antioxidants	118 Chinese women aged 35-65	6 months
<b>Z. Draelos et al.,</b>	Mineral sunscreen SPF 30	49 females aged	6 weeks

Study	Intervention Category	Population	Duration
2022	with bakuchiol	35-60 years	
C. Elmets et al., 2013	Topical sunscreen	604 subjects <55 years	Not specified
F. Flament et al., 2017	Topical photoprotection	83 Chinese women	6 months
Joel L Cohen et al., 2022	Vitamin C serum + mineral sunscreen	36 females aged 35-60 years	12 weeks
H. Mahler et al., 2006	Behavioral (UV photo + photoaging info)	244 beach patrons	Summer follow-up
S. Ogden et al., 2008	Topical retinoids + sunscreen	Not specified	6-24 months
Intan Nurmawati Putri et al., 2024	Sunscreen education	Police officers in Indonesia	Not specified
A. Kusumawardani et al., 2023	TiO2 sunscreen + defensil plus	20 subjects, Fitzpatrick III-IV	7 days
H. Luze et al., 2020	Sunscreens with DNA repair enzymes	60 subjects, Fitzpatrick I-II	Variable
Joel I Osorio et al., 2020	REGENERAGE cream	12 women with photo-aging	12 weeks
H. Mahler et al., 2003	Behavioral (UV photo + photoaging info)	144 participants	Not specified
F. Flament et al., 2023	Standardized photoprotection	Fitzpatrick II-VI	1 year
N. Afzal et al., 2024	Acetyl zingerone + THDA	Not specified	Not specified

Study	Intervention Category	Population	Duration
Anne-Katrin Greul et al., 2002	Oral antioxidant supplement (Seresis)	Young females, Fitzpatrick II	Not specified
H. Mahler et al., 2010	Behavioral (UV photo + photoaging info)	126 college students	5 weeks
H. Mahler et al., 2007	Behavioral (UV photo + photoaging info)	Young adults	12 months
S. Darlington et al., 2003	Topical sunscreen + oral $\beta$ -carotene	1621 adults aged 25-74 years	4 years
C. Marionnet et al., 2021	Sunscreen with MCE filter	Not specified	Not specified
T. Brinker et al., 2017	Behavioral (Sunface mobile app)	205 students aged 13-19 years	Cross-sectional
Sofia Persson et al., 2018	Appearance-based interventions	7348 participants	Variable
A. Williams et al., 2013	Appearance-based interventions	Not specified	Variable
H. Okati-Aliabad et al., 2023	Behavioral (mobile app)	320 students aged 10-12 years	3 months
T. Brinker et al., 2020	Behavioral (Sunface mobile app)	1573 students	6 months
Ghazal Mardani et	Various treatments for solar	Not specified	Variable

Study	Intervention Category	Population	Duration
al., 2025	lentiginos		
Yan Wu et al., 2013	Topical antioxidant (vitamins C, E, ferulic acid)	12 Chinese females	4 days
E. Bagatin et al., 2010	Oral isotretinoin + sunscreen	32 women aged 40-55 years	3 months
Michael Termer et al., 2021	MeO-MBM topical	10 volunteers aged 34-65 years	4 weeks
T. Stephens et al., 2016	Oral anti-aging supplement	152 women aged 35-60 years	16 weeks
V. Grandi et al., 2019	S-acyl glutathione cream	10 volunteers, Fitzpatrick II-III	Cross-sectional
Komang Jegkek et al., 2020	Purple cabbage extract cream	30 Wistar rats	4 weeks
Daiane G Mercurio et al., 2024	Sunscreen with MCE UVA1 filter	52 Brazilian women	4 weeks
Yi-Chun Lin et al., 2022	Topical sunscreen	14 females	8 weeks
BA David Perez et al., 2025	Behavioral (TikTok aging filter)	230 young adults	Immediate
Rudy Ekofitranto et al., 2025	Topical astaxanthin cream	4 groups	5 days
A. Hüls et al., 2016	Observational (air pollution	1878 women	Cross-

Study	Intervention Category	Population	Duration
	exposure)		sectional
<b>Ni Putu Anggun et al., 2022</b>	Telang flower extracts	Literature review	Variable
<b>Xiaofeng Zhang et al., 2023</b>	Oral tomato/lycopene	21 trials	Variable
<b>Cecilie Scheuer et al., 2017</b>	Topical melatonin	Multiple studies	Variable
<b>Hassan Okati-Aliabad et al., 2024</b>	Behavioral (facial-aging web app)	160 students	3 months
<b>D. G. Mercurio et al., 2015</b>	Sunscreen + red algae + vitamins	16 hairless mice	5 days
<b>J. Siegel et al., 2017</b>	Observational (AK predictors)	2063 veterans	Cross-sectional
<b>A. Williams et al., 2012</b>	Behavioral (facial-aging morphing)	47 women aged 18-34 years	Not specified
<b>F. Flament et al., 2023a</b>	Sunscreen with MCE UVA1 filter	Two populations	8 weeks
<b>H. Mahler et al., 2018</b>	Behavioral (multiple UV photo viewings)	151 college students	1 month
<b>Thanaporn Puaratanaarunkon et al., 2022</b>	Sunscreen with anti-inflammatory agent	59 patients, Fitzpatrick III-IV	6 weeks
<b>A. Williams et al., 2013a</b>	Behavioral (facial-aging intervention)	70 women aged 18-34 years	Immediate

Study	Intervention Category	Population	Duration
Yelena P. Wu et al., 2019	Behavioral (multiple components)	1573 high school students	1 month
Rana Shahab et al., 2024	Dermocosmetic + tinted sunscreen SPF 50+	1785 adults, Fitzpatrick IV-VI	2 months
Azahara Pérez Davó et al., 2019	Retinoids + D. antarctica extract	22 females, Fitzpatrick III-IV	90 days
Masitta Tanjung et al., 2023	Silkworm cocoon gel	25 male rats	14 days
UV-protective Astaxanthin Study, 2021	Topical astaxanthin	21 volunteers, Fitzpatrick 2-3	24 hours
Steven R. Hall et al., 2019	Oral lipid supplement (EPA, DHA, GLA)	Volunteers	8 weeks
P. Lehmann et al., 2022	Daylight photodynamic therapy	58 patients with AKs	2 years
Tamires Lima Cossetim et al., 2017	Photoprotection habits	Literature review	2010-2016
Irianiwati et al., 2015	Topical extra virgin olive oil	Human foreskins	24 hours
Flora Ramona et al., 2015	Sunscreens SPF 15/30/50	5 foreskins, Fitzpatrick IV	24 hours
정문석 et al., 2012	Oral Calaguala (P. leucotomos)	14 adults	4 weeks

Study durations ranged from single-day assessments to 4.5-year follow-up periods. Geographic representation included studies from Australia, USA, Brazil, China, India, Indonesia, Germany, Korea, and multiple European countries.

## Effects of Photoprotection Interventions on Photoaging Outcomes

### Topical Sunscreen Effects on Clinical Photoaging Parameters

The landmark Nambour trial by Hughes et al. (2013) provides the strongest evidence for sunscreen's preventive effect on photoaging. Daily sunscreen users showed no detectable increase in skin aging after 4.5 years, with skin aging 24% less than the discretionary sunscreen group (relative odds 0.76, 95% CI 0.59-0.98). This community-based RCT of 903 adults remains the most robust evidence for long-term photoaging prevention.

Study	Parameter Assessed	Effect Size/Improvement	Statistical Significance	Follow-up Duration
M. Hughes et al., 2013	Overall skin aging	24% reduction vs. discretionary use	RO 0.76 (95% CI 0.59-0.98)	4.5 years
Manpreet Randhawa et al., 2016	Skin texture, clarity, pigmentation	40-52% improvement	Not reported	52 weeks
R. Sarkar et al., 2019	Pigmented spots, skin radiance	Significant improvement	P < 0.001	12 weeks
David F Godoy et al., 2024	UV spots (VISIA)	10-point percentile shift	P = 0.0013	8 weeks

Study	Parameter Assessed	Effect Size/Improvement	Statistical Significance	Follow-up Duration
A. Du et al., 2020	Hyperpigmentation, wrinkles, skin tone	Significant improvement	P < 0.05	6 months
Z. Draelos et al., 2022	Hydration, elasticity	21% hydration, 32% elasticity improvement	Significant	6 weeks
Joel L Cohen et al., 2022	Overall photodamage	11.7-19.1% improvement	Significant	12 weeks

Randhawa et al. (2016) demonstrated that daily use of an SPF 30 broad-spectrum sunscreen for 52 weeks improved all photoaging parameters significantly from baseline, with skin texture, clarity, and mottled pigmentation showing 40-52% improvement and 100% of subjects demonstrating improvement in skin clarity and texture. This suggests sunscreen use can not only prevent but potentially reverse existing photodamage.

Studies on Indian skin phototypes IV and V showed significant improvement in pigmented spots and skin radiance after 12 weeks of regular sunscreen use (P < 0.001), demonstrating effectiveness across diverse skin types. Similarly, a study using sunscreen with visible light coverage showed significant improvement in UV spots (P = 0.0013) and overall DPAS dermoscopy scores (P = 0.0009) after just 8 weeks.

### Effects of Enhanced Sunscreen Formulations

Study	Formulation Enhancement	Primary Outcome	Effect Size	Significance
M. M. Fossa	Ascorbyl	Hydration,	Increased	Significant

Study	Formulation Enhancement	Primary Outcome	Effect Size	Significance
<b>Shirata et al., 2021</b>	tetraisopalmitate + rice peptides	dermis echogenicity		
<b>Z. Draelos et al., 2022</b>	Bakuchiol (retinol alternative)	Skin laxity, fine lines	21-32% improvement	Significant
<b>A. Kusumawardani et al., 2023</b>	TiO <sub>2</sub> + defensil plus	Melanin index, erythema	Significant decrease	P = 0.003, P = 0.036
<b>C. Marionnet et al., 2021</b>	MCE absorber (UVA1 coverage)	UVA1 photoprotection	Improved coverage	Significant
<b>Michael Termer et al., 2021</b>	MeO-MBM (photoantioxidant )	TEWL, skin thickness	Improved	Significant
<b>Thanaporn Puaratanaarunkon et al., 2022</b>	Anti-inflammatory agent	Post-inflammatory hyperpigmentation	Tendency to reduce	P = 0.022 (porphyrins)

Formulations combining UV filters with antioxidants demonstrated enhanced efficacy. Shirata et al. (2021) showed that sunscreens containing ascorbyl tetraisopalmitate and rice peptides improved skin hydration, dermis echogenicity, and reduced hyperpigmentation in young women without prior photoprotective habits. The mineral sunscreen with bakuchiol showed 21% improvement in skin hydration and 32% improvement in elasticity at 6 weeks.

Titanium dioxide sunscreen combined with defensil plus (containing anti-inflammatory plant extracts) significantly decreased melanin index ( $P = 0.003$ ) and erythema index ( $P = 0.036$ ) compared to  $TiO_2$  alone, suggesting synergistic protection through combined UV blocking and anti-inflammatory mechanisms .

### Behavioral Interventions and Sun Protection Intentions

Study	Intervention Type	Outcome Measure	Effect Size	Duration of Effect
H. Mahler et al., 2006	UV photo + photoaging info	Sun protection intentions	Positive effect	End of summer
H. Mahler et al., 2007	UV photos + photoaging info	Skin darkening prevention	Sustained reduction	12 months
H. Mahler et al., 2010	UV photo + photoaging info	Perceived susceptibility	$d = 0.74$	5 weeks
H. Mahler et al., 2010	UV photo + photoaging info	Sun protection intentions	$d = 1.32$	5 weeks
H. Mahler et al., 2010	UV photo + photoaging info	Sun protection behavior	$d = 0.44$	5 weeks
T. Brinker et al., 2017	Surface mobile app	Motivation to avoid tanning beds	63% agreement	Immediate
T. Brinker et al., 2020	Surface mobile app	Daily sunscreen use	8.2% increase	6 months
Sofia Persson et al., 2018	UV photo + photoaging info	Sun protection intentions	$r+ = 0.424$	Up to 12 months
Hassan Okati-	Facial-aging	Sun protection	Significant	3 months

Study	Intervention Type	Outcome Measure	Effect Size	Duration of Effect
Aliabad et al., 2024	web app	behaviors	improvement	
BA David Perez et al., 2025	TikTok aging filter	Sunscreen use intentions	OR 4.26	Immediate
Yelena P. Wu et al., 2019	UV photo + behavior worksheet	Sun protection use	Significant increase	1 month

Appearance-based interventions consistently demonstrated positive effects on sun protection behaviors. The systematic review by Persson et al. (2018) found a medium effect size ( $r^+ = 0.424$ , 95% CI 0.279-0.568,  $P = 0.023$ ) for interventions combining UV photography and photoaging information on sun protection intentions. These effects persisted up to 12 months after intervention.

Mahler et al. (2010) demonstrated that UV photo interventions produced large effect sizes on sun protection intentions ( $d = 1.32$ ) and meaningful effects on actual sun protection behavior ( $d = 0.44$ ). Longer-term follow-up at 12 months showed sustained reductions in skin darkening among participants who received photoaging information.

Mobile app-based interventions showed promising results in adolescent populations. The Sunface app intervention in Brazilian secondary schools increased daily sunscreen use by 8.2% ( $P < 0.001$ ) and skin self-examinations by 26.4% ( $P < 0.001$ ) at 6-month follow-up. A pilot study using the same app found that 63% of students agreed or strongly agreed that viewing their altered 3D selfie motivated them to avoid tanning beds. The effect was particularly pronounced in fair-skinned adolescents with Fitzpatrick skin types 1-

2, showing 71.8% agreement for tanning bed avoidance compared to 53.8% in skin types 3-6.

### Oral Supplements and Systemic Photoprotection

Study	Supplement	Primary Outcome	Effect	Significance
M. Hughes et al., 2013	β-carotene 30 mg	Skin aging	No overall effect	Not significant
S. Darlington et al., 2003	β-carotene 30 mg	Solar keratoses	No effect	Not significant
Anne-Katrin Greul et al., 2002	Seresis (carotenoids, vitamins C/E, selenium)	MMP-1 expression	Decreased	P < 0.05
T. Stephens et al., 2016	Marine complex, vitamin C, zinc	Facial appearance, wrinkles	0.26-0.59 improvement	P < 0.0001
Steven R. Hall et al., 2019	EPA, DHA, GLA, carotenoids	Minimal erythema dose	84% increase	Not reported
정문석 et al., 2012	Calaguala (P. leucotomos)	Free radical concentration	Decreased	Significant
Xiaofeng Zhang et al., 2023	Tomato/lycopene	Erythema, MED, skin density	Improved	Significant

Oral  $\beta$ -carotene supplementation at 30 mg daily showed no overall effect on skin aging in two large trials , though contrasting associations were observed in subgroups with different baseline severity of aging . In contrast, multi-component antioxidant formulations demonstrated more promising results. Greul et al. (2002) found that Seresis supplementation (containing carotenoids, vitamins C and E, selenium, and proanthocyanidins) significantly decreased UV-induced MMP-1 expression ( $P < 0.05$ ), suggesting photoprotective effects at the molecular level .

An oral supplement containing marine complex (210 mg), vitamin C (54 mg), and zinc (4 mg) showed significant improvements in overall facial appearance, radiant complexion, periocular wrinkles, and mottled hyperpigmentation compared to placebo ( $P < 0.0001$ ) . Additionally, an oral lipid supplement containing omega-3 fatty acids (EPA 1050 mg, DHA 350 mg), GLA, carotenoids, and vitamin D3 increased minimal erythema doses by 84% after 8 weeks, indicating enhanced skin UV resistance .

The meta-analysis by Zhang et al. (2023) examining tomato and lycopene supplementation found significant reductions in erythema markers ( $\Delta a^*$ , MMP-1, ICAM-1) and increases in minimal erythema dose, skin thickness, and skin density, supporting lycopene-rich products as potential nutraceuticals for endogenous sun protection .

### Topical Antioxidants and Complementary Agents

Study	Agent	Application	Outcome	Effect
<b>Yan Wu et al., 2013</b>	Vitamins C, E + ferulic acid	4 days pre-UVR	Sunburn cells, thymine dimers	Significant protection
<b>V. Grandi et al., 2019</b>	Lin-GSH 2% cream	Pre-UVB	MED	Increased from 105 to 135 mJ/cm <sup>2</sup>
<b>Cecilie Scheuer</b>	Melatonin	Pre-sun	Erythema	Significant in

Study	Agent	Application	Outcome	Effect
et al., 2017	12.5%	exposure	reduction	responders
Astaxanthin Study, 2021	Astaxanthin	Pre-UV	Erythema value	25% reduction
Rudy Ekofitranto et al., 2025	Astaxanthin cream	Post-UVB	MDA, IL-6 levels	Significant reduction (P = 0.001)
Irianiwati et al., 2015	Extra virgin olive oil	Pre-UVB	8-OHdG formation	Reduced (P = 0.0001)

Topical antioxidants demonstrated significant photoprotective effects. Wu et al. (2013) showed that a topical antioxidant complex containing vitamins C and E and ferulic acid significantly protected against UV-induced sunburn cell formation, thymine dimer formation, and p53 overexpression. Linolenic-glutathione conjugate (Lin-GSH) 2% cream increased minimal erythema dose from 105 to 135 mJ/cm<sup>2</sup> (P = 0.0003).

Topical melatonin at 12.5% concentration significantly reduced erythema formation following natural sun exposure in individuals who showed an erythema response, leveraging melatonin's role as a potent endogenous antioxidant and radical scavenger. Topical astaxanthin reduced erythema values by 25% compared to placebo and suppressed visual erythema formation in over 71% of cases.

Extra virgin olive oil applied topically to human skin significantly reduced 8-OHdG formation (a marker of oxidative DNA damage) following UVB exposure (P = 0.0001), demonstrating potential anti-photocarcinogenesis properties.

### Mechanisms of Photoprotection

The included studies identified several mechanistic pathways by which photoprotection interventions prevent or ameliorate photoaging:

## **UV Absorption and Physical Blocking**

Conventional sunscreens provide photoprotection through physical blocking by inorganic filters (titanium dioxide, zinc oxide) and chemical absorption by organic UV filters. The addition of MCE absorber extends protection to the UVA1 range (370-400 nm), providing full UV spectrum coverage. MeO-MBM converts to the UV filter avobenzone under UV irradiation while simultaneously acting as a photoantioxidant during its conversion process.

## **Antioxidant and Anti-inflammatory Pathways**

UV radiation induces damage through reactive oxygen species (ROS) generation. Multiple formulations combat this through antioxidant pathways including vitamin C and E scavenging free radicals, carotenoids providing systemic antioxidant protection, and plant-derived polyphenols exhibiting anti-inflammatory effects. Defensive plus ingredients activate anti-inflammatory pathways by modulating NF- $\kappa$ B signaling.

## **Molecular Biomarkers and Extracellular Matrix Protection**

Matrix metalloproteinases (MMPs) degrade dermal collagen and fibrillin, leading to wrinkle formation. Antioxidant supplementation with Seresis decreased UV-induced MMP-1 and MMP-9 expression. Tretinoin inhibits MMP production, preventing collagen degradation. UV exposure also induces 8-OHdG formation as a genotoxic product of DNA damage, which can be mitigated by topical antioxidants.

## **Immune and Cellular Protection**

UVB radiation induces immunosuppression through depletion of epidermal Langerhans cells, which can be inhibited by topical sunscreen application. The minimum SPF for preventing UVB-induced Langerhans cell depletion in Fitzpatrick skin type IV was found to be SPF 30. DNA repair enzymes in sunscreen formulations can achieve 40-45% reduction in UV-induced cyclobutane pyrimidine dimers (CPD).

## Moderating Factors Influencing Effectiveness

### **Skin Type Effects**

Differential responses were observed across Fitzpatrick skin types. Behavioral interventions using the Surface app showed greater effectiveness in fair-skinned individuals (Fitzpatrick 1-2), with 71.8% agreement for tanning bed avoidance compared to 53.8% in skin types 3-6. Studies specifically targeting Indian skin types IV-V demonstrated that sunscreen effectively prevents pigmentation abnormalities in darker skin phenotypes. The minimum SPF required for immunological protection varied by skin type, with SPF 30 needed for Fitzpatrick type IV.

### **Age-Related Differences**

The association between air pollution exposure and lentigines was strongest in women older than 50 years in both Caucasian and Asian populations. Behavioral interventions showed greater effectiveness in late adolescence (17-19 years) compared to early adolescence (13-16 years). Baseline photoaging severity influenced treatment response, with contrasting  $\beta$ -carotene associations observed in subgroups with different baseline severity.

### **Compliance and Adherence**

Daily sunscreen application versus discretionary use was the key factor differentiating photoaging outcomes in the Nambour trial. Among participants given UV photos to view multiple times, those who chose to view their photos more frequently engaged in significantly more sun protection behaviors. Female students showed more significant behavioral responses to mobile app interventions compared to male students.

### **Environmental and Geographic Factors**

Lower latitude (higher ambient UV) was associated with increased actinic keratosis counts in cross-sectional analysis . Studies conducted in subtropical environments (Nambour, Australia at 26°S) showed significant benefits of daily sunscreen application . Seasonal shifts from winter to summer were identified as moderating factors affecting facial photoaging signs .

## **Synthesis**

The evidence consistently supports a protective relationship between regular sunscreen use and photoaging prevention, though the magnitude of effects varies by intervention type, population, and outcome measure.

## **Reconciling Topical Sunscreen Evidence**

The strongest evidence comes from the Nambour trial demonstrating 24% reduction in skin aging with daily versus discretionary sunscreen use over 4.5 years . Shorter-term studies consistently show improvements in clinical photoaging parameters, with 40-52% improvements in texture and pigmentation at 52 weeks , and significant improvements emerging as early as 8-12 weeks . The consistency across different populations (Australian, Chinese, Indian, Brazilian) and skin types (Fitzpatrick I-VI) supports generalizability .

Studies finding larger effect sizes typically used enhanced formulations combining UV filters with antioxidants, anti-inflammatory agents, or DNA repair enzymes . This suggests additive or synergistic mechanisms through combined physical protection and cellular repair pathways .

## **Behavioral Intervention Effectiveness**

Appearance-based interventions demonstrate consistent medium effect sizes ( $r^+ = 0.424$ ) on sun protection intentions , with effects sustained up to 12 months . However, the pathway from intention to photoaging prevention is indirect, relying on behavioral changes that subsequently reduce UV exposure. The 8.2% increase in daily sunscreen use following

mobile app intervention represents a meaningful behavioral shift, though translation to clinical photoaging outcomes requires longer follow-up than currently available.

The greater effectiveness of behavioral interventions in fair-skinned individuals (Fitzpatrick 1-2) and older adolescents suggests these approaches should be targeted appropriately. Social comparison information can undermine intervention effects, indicating that intervention design significantly impacts outcomes.

### **Oral Supplementation Context**

The divergent findings between single-agent  $\beta$ -carotene (no effect) and multi-component antioxidant formulations (significant effects) suggest that comprehensive antioxidant support targeting multiple ROS pathways is more effective than single-compound supplementation. The 84% increase in minimal erythema dose with combined omega-3 fatty acids and carotenoids represents substantial photoprotective enhancement, though this requires confirmation in larger trials.

### **Clinical Implications by Population**

For individuals with fair skin (Fitzpatrick I-II), both topical photoprotection and behavioral interventions show robust effectiveness. The minimum SPF 30 is recommended for adequate immunological protection. For darker skin types (Fitzpatrick IV-VI), high-SPF sunscreens effectively prevent pigmentation abnormalities, though the benefits may be less apparent without specific pigmentation outcome measures.

Enhanced sunscreen formulations with visible light coverage, antioxidants, or anti-inflammatory agents provide additional benefits beyond basic UV filtration, particularly for individuals with existing photodamage or higher sun exposure. Oral supplementation with multi-component antioxidants may provide adjunctive systemic protection, though this should complement rather than replace topical photoprotection.

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## DISCUSSION

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This comprehensive systematic review of 63 studies provides robust and multi-faceted evidence supporting the critical role of photoprotection, particularly sunscreen use, in preventing and mitigating photoaging. The discussion synthesizes these findings, explores the mechanisms at play, reconciles apparent discrepancies, and considers the implications for clinical practice and public health.

### 1. The Foundational Evidence: Daily Sunscreen as a Primary Preventative Measure

The most compelling long-term evidence comes from the Nambour Skin Cancer Prevention Trial. This community-based randomized controlled trial demonstrated that daily application of broad-spectrum SPF 15+ sunscreen resulted in 24% less detectable skin aging over a 4.5-year period compared to discretionary use (Hughes et al., 2013). This finding is seminal because it provides Level I evidence that consistent sunscreen use is not merely theoretical but practically effective in slowing the *visible* progression of photoaging in a real-world setting. The study's strength lies in its duration, randomized design, and objective assessment, establishing daily sunscreen use as a non-negotiable pillar of any anti-aging skincare regimen.

Supporting this, numerous shorter-term trials across diverse populations consistently report significant improvements in key photoaging parameters. For instance, daily use of an SPF 30 sunscreen for one year led to 40-52% improvement in skin texture, clarity, and pigmentation, with 100% of subjects showing improvement in some parameters (Randhawa et al., 2016). Similarly, studies on Indian skin types (IV-V) showed significant reduction in pigmented spots and improved radiance after 12 weeks (Sarkar et al., 2019), while research on Chinese women documented improvements in hyperpigmentation and wrinkles over 6 months (Du et al., 2020). This cross-population consistency underscores the universal benefit of sunscreen, transcending genetic background and baseline pigmentation.

### 2. Beyond Basic Filtration: The Era of Enhanced Sunscreen Formulations

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A key advancement highlighted in this review is the move beyond basic UV filters towards multifunctional "enhanced" formulations. These products combine physical/chemical UV blockers with active ingredients that target the downstream consequences of UV exposure:

- **Antioxidants:** Adding antioxidants like vitamin C (ascorbyl tetraisopalmitate) and ferulic acid directly to sunscreens provides a "second line of defense," neutralizing ROS that penetrate or are generated within the skin, thereby reducing oxidative stress and MMP activation (Shirata & Maia Campos, 2021; Wu et al., 2013).
- **Anti-inflammatory Agents:** Ingredients like defensil plus or bakuchiol can modulate inflammatory pathways (e.g., NF- $\kappa$ B) triggered by UV exposure. Studies show that a TiO<sub>2</sub> sunscreen with defensil plus significantly reduced erythema and melanin index more than TiO<sub>2</sub> alone, indicating protection against both UV damage and the post-inflammatory pigmentation common in photoaging (Kusumawardani et al., 2023). Bakuchiol, a retinol alternative, improved skin hydration and elasticity (Draelos et al., 2022).
- **DNA Repair Enzymes:** Incorporating enzymes like photolyase addresses the root cause of photoaging—DNA damage. These enzymes can repair cyclobutane pyrimidine dimers (CPDs), with systematic reviews suggesting a 40-45% reduction in CPDs, representing a biologically targeted repair mechanism (Luze et al., 2020).
- **Extended Spectrum Coverage:** New filters like MCE provide critical protection in the long-wave UVA1 (370-400 nm) and visible light spectrum, which are deeply penetrating and heavily implicated in pigmentary disorders and oxidative stress. Studies confirm that MCE-containing sunscreens offer superior protection against pigmentation and aging signs compared to those without (Marionnet et al., 2021; Flament et al., 2023a). Similarly, sunscreens with visible light coverage show efficacy in reducing UV spots (Godoy et al., 2024).

These enhancements create a synergistic effect: while UV filters prevent the initial photon insult, the added agents mitigate the biological damage that occurs despite filtration, leading to superior clinical outcomes.

### **3. Bridging the Intention-Behavior Gap: The Power of Behavioral Interventions**

Evidence strongly indicates that merely knowing about sunscreen's benefits is insufficient; changing behavior is paramount. This review highlights the efficacy of appearance-based interventions, which leverage the potent motivator of vanity and self-image. The meta-analysis by Persson et al. (2018) found a medium overall effect ( $r^+ = 0.424$ ) of such interventions on sun protection intentions. Interventions using personalized UV photography to reveal hidden sun damage combined with information on photoaging have shown large effects on intention ( $d = 1.32$ ) and meaningful effects on actual behavior ( $d = 0.44$ ), with some effects lasting up to 12 months (Mahler et al., 2010; Mahler et al., 2007). The novel use of digital technology is particularly promising for engaging younger generations. The "Sunface" mobile app, which uses augmented reality to simulate future photoaging, increased daily sunscreen use by 8.2% among Brazilian adolescents over 6 months (Brinker et al., 2020). Similarly, a pilot study using a TikTok aging filter significantly increased intentions to use sunscreen (Perez et al., 2025). These tools make the abstract, long-term consequences of sun exposure immediate and personal, effectively driving behavioral change. However, their effectiveness can be moderated by factors like social comparison; downward comparison (seeing others with more damage) can enhance efficacy, while upward comparison can undermine it (Mahler et al., 2010).

### **4. Oral and Topical Supplements: Adjunctive Roles in Photoprotection**

The evidence on systemic and topical adjuncts clarifies their place in a comprehensive strategy:

- **Oral Supplements:** Single-agent supplementation, such as  $\beta$ -carotene, has failed to show significant effects on photoaging (Darlington et al., 2003; Hughes et al., 2013). In contrast, multi-component formulations appear effective. Supplements containing a combination of

marine complexes, vitamins C and E, zinc, selenium, carotenoids (like lycopene), and omega-3 fatty acids have demonstrated benefits, including increased minimal erythema dose (by 84%), improved skin appearance, and reduced molecular markers of UV damage like MMP-1 (Stephens et al., 2016; Hall et al., 2019; Zhang et al., 2023; Greul et al., 2002). This suggests that a broad-spectrum, systemic antioxidant and anti-inflammatory approach can bolster the skin's endogenous defense systems, serving as a valuable adjunct to topical sunscreen.

- **Topical Antioxidants:** Applied separately or within moisturizers, antioxidants like vitamins C+E+ferulic acid, S-acyl glutathione, melatonin, and astaxanthin provide significant protection against acute UV-induced erythema and oxidative DNA damage (e.g., reduction of 8-OHdG) (Wu et al., 2013; Grandi et al., 2019; Scheuer, 2017; UV-Protective Astaxanthin Study, 2021; Irianiwati et al., 2015). Their role is particularly important during peak sun exposure and for individuals with high oxidative stress.

## 5. Moderating Factors: Personalizing Photoprotection

The effectiveness of photoprotection is not uniform and is influenced by several factors:

- **Skin Type:** Behavioral interventions are more effective in fair-skinned individuals (Fitzpatrick I-II), who perceive higher susceptibility (Brinker et al., 2017). Biologically, the minimum SPF required to prevent UVB-induced immunosuppression (a driver of aging and cancer) varies; SPF 30 was necessary for Fitzpatrick type IV skin (Flora Ramona et al., 2015). For darker skin types (IV-VI), photoaging often manifests more as dyspigmentation, and studies confirm high-SPF sunscreens are effective in preventing and improving these irregularities (Sarkar et al., 2019; Shahab & Rashed, 2024).
- **Age and Baseline Damage:** Older individuals and those with more severe baseline photoaging may show more pronounced benefits from intervention. The association between air pollution and lentigines, for example, was strongest in women over 50 (Hüls et al.,

2016). Behavioral interventions are more effective in late adolescence than early adolescence.

- **Compliance and Environment:** The central message from the Nambour trial is that *daily* use is key (Hughes et al., 2013). Geographic location (higher ambient UV at lower latitudes) and seasonality also modulate photoaging progression and the perceived need for protection (Siegel et al., 2017; Du et al., 2020; Flament & Qiu, 2017).

## 6. Reconciling the Evidence and Addressing Limitations

The synthesis reveals a clear hierarchy of evidence: strong, direct evidence for topical sunscreens; strong, indirect evidence for behavioral interventions leading to sunscreen use; and promising but still-developing evidence for oral and topical adjuncts. A limitation across many studies, particularly behavioral ones, is the reliance on self-reported sunscreen use and short follow-up periods for clinical photoaging outcomes. More long-term trials linking behavioral changes to measurable changes in skin aging are needed. Furthermore, while enhanced formulations show promise, direct head-to-head comparisons against standard sunscreens of the same SPF are needed to quantify their added value definitively.

### Summary

The relationship between sunscreen use and photoaging prevention is well-supported and multifaceted. The ideal photoprotection strategy is layered: 1) **Foundation:** Consistent, daily use of a high-SPF, broad-spectrum sunscreen (SPF 30+, with UVA1/visible light coverage where possible). 2) **Enhancement:** Selection of formulations fortified with antioxidants and anti-inflammatory agents for added cellular protection. 3) **Adherence:** Employment of appearance-based behavioral strategies, especially digital tools for younger audiences, to ensure long-term compliance. 4) **Adjuncts:** Consideration of multi-nutrient oral supplements and separate topical antioxidants for comprehensive support, particularly in high-risk individuals. This integrated

approach, tailored to individual skin type, age, and environment, represents the most effective defense against the multifaceted process of photoaging.

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## CONCLUSION AND RECOMMENDATIONS

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### Conclusion

This comprehensive systematic review consolidates robust evidence that sunscreen use is a fundamental and effective strategy for the prevention and amelioration of photoaging. The landmark Nambour trial provides definitive long-term proof that daily sunscreen application significantly slows the visible aging of skin. This foundational benefit is consistently supported by shorter-term studies across diverse global populations and skin phototypes, which demonstrate measurable improvements in wrinkles, pigmentation, texture, and elasticity. The efficacy of photoprotection is significantly enhanced by modern formulations that combine UV filters with antioxidants, anti-inflammatory agents, or DNA repair enzymes, addressing both the cause and biological consequences of UV exposure. Furthermore, behavioral interventions, particularly those utilizing appearance-based strategies and digital technology, are effective in improving sun protection intentions and adherence, which is critical for realizing long-term clinical benefits. While oral multi-component antioxidant supplements show promise as systemic adjuvants, they should not be considered substitutes for topical sunscreen. The effectiveness of all strategies is moderated by key factors including skin type, age, compliance level, and environmental conditions.

### Recommendations

1. **Clinical Practice:** Dermatologists and aesthetic practitioners should emphatically recommend **daily use of a broad-spectrum sunscreen with SPF 30 or higher** as the cornerstone of any anti-aging skincare regimen. For patients with significant photodamage, dyspigmentation, or high sun exposure, **sunscreens with enhanced protection** (UVA1/visible light filters, added antioxidants like vitamin C, or anti-inflammatory agents) should be prioritized.

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2. **Product Development:** The skincare industry should continue to innovate towards multifunctional sunscreen formulations that offer more than just UV filtration. Investing in technologies that provide **broader spectrum coverage (including visible light)** and incorporate **biologically active ingredients** that mitigate oxidative stress, inflammation, and DNA damage will yield superior consumer outcomes.
3. **Public Health and Education:** Public sun safety campaigns must evolve beyond skin cancer warnings. **Incorporating appearance-based messaging**—using tools like UV photography, facial aging simulations, and social media filters—is highly effective, especially for targeting **adolescents and young adults**. Educational programs should be tailored, with more intensive interventions directed at **fair-skinned individuals** and populations in **high-UV geographic regions**.
4. **Personalized Advice:** Photoprotection advice should be personalized. For individuals with **Fitzpatrick skin types IV-VI**, focus on preventing and treating pigmentary disorders with high-SPF, possibly tinted, sunscreens. Emphasize the importance of **year-round and daily use**, not just during beach vacations, to counteract cumulative damage.
5. **Future Research:** Longitudinal studies are needed to directly link the behavioral changes induced by digital interventions to long-term clinical photoaging outcomes. More randomized controlled trials are required for **head-to-head comparisons** of enhanced versus standard sunscreens and to further elucidate the optimal composition and dosage of **oral photoprotective supplements**. Research should also continue to explore the specific effects of **visible light and pollution** on photoaging to guide the next generation of protective products.

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## REFERENCES

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A. Du, Valerie Robert, M. Yatskayer, and F. Flament. “18309 The Impact of a Photoprotection Product and the Effects of Seasonality on Photo-Aged Chinese Women,” 2020.

A. Hüls, A. Vierkötter, Wenshan Gao, U. Krämer, Yajun Yang, Anan Ding, S. Stolz, et al. “Traffic-Related Air Pollution Contributes to Development of Facial Lentigines: Further Epidemiological Evidence from Caucasians and Asians.” *Journal of Investigative Dermatology*, 2016.

A. Kusumawardani, S. Widhiati, Endra Yustin Ellistasari, Ervina Rosmarwati, Irene Ardiani Pramudya Wardhani, and Dita Eka Novriana. “The Effectiveness of Titanium Dioxide Sunscreen in Combination with Skin Defensil Plus® as an Anti-Inflammatory Agent Against Ultraviolet Radiation.” *Open Access Macedonian Journal of Medical Sciences*, 2023.

A. Williams, S. Grogan, D. Clark-Carter, and E. Buckley. “Appearance-Based Interventions to Reduce Ultraviolet Exposure and/or Increase Sun Protection Intentions and Behaviours: A Systematic Review and Meta-Analyses.” *British Journal of Health Psychology*, 2013.

———. “Impact of a Facial-Ageing Intervention Versus a Health Literature Intervention on Women’s Sun Protection Attitudes and Behavioural Intentions.” *Psychology and Health*, 2013.

A. Williams, S. Grogan, E. Buckley, and D. Clark-Carter. “A Qualitative Study Examining Women's Experiences of an Appearance-Focussed Facial-Ageing Sun Protection Intervention.” *Body Image*, 2012.

Anne-Katrin Greul, J. Grundmann, F. Heinrich, I. Pfitzner, J. Bernhardt, A. Ambach, H. Biesalski, and H. Gollnick. “Photoprotection of UV-Irradiated Human Skin: An Antioxidative Combination of Vitamins E and C, Carotenoids, Selenium and Proanthocyanidins.” *Skin Pharmacology and Physiology*, 2002.

Azahara Pérez Davó, M. Truchuelo, M. Vitale, and J. González-Castro. “Efficacy of an Antiaging Treatment Against Environmental Factors: Deschampsia Antarctica Extract and High-Tolerance Retinoids Combination.” *The Journal of Clinical and Aesthetic Dermatology*, 2019.

BA David Perez, PhD Alec McIntosh, MS Rui Zhang, MD PhD Olga Rodriguez, and PhD Jaeil Ahn. “Assessing the Influence of a TikTok Aging Filter on Young Adults' Intentions to Use Sunscreen for Skin Cancer Prevention.” *medRxiv*, 2025.

C. Elmets. “More Sunscreen, Fewer Wrinkles,” 2013.

C. Marionnet, R. de Dormael, X. Marat, A. Roudot, Julie Gizard, E. Planel, C. Tornier, et al. “Sunscreens with the New MCE Filter Cover the Whole UV Spectrum: Improved UVA1 Photoprotection In Vitro and in a Randomized Controlled Trial.” *JID Innovations*, 2021.

Cecilie Scheuer. “Melatonin for Prevention of Erythema and Oxidative Stress in Response to Ultraviolet Radiation.” *Danish Medical Journal*, 2017.

D. G. Mercurio, T. A. Wagemaker, V. M. Alves, C. Benevenuto, L. R. Gaspar, and P. M. Maia Campos. “In Vivo Photoprotective Effects of Cosmetic Formulations Containing UV Filters, Vitamins, Ginkgo Biloba and Red Algae Extracts.” *Journal of Photochemistry and Photobiology. B: Biology*, 2015.

Daiane G Mercurio, F. Flament, Benoit Muller, F. Bernerd, M. Josso, Nathalie Jager-Lezer, C. Delaunay, and T. Passeron. “Gain of Protection Afforded by the Methoxypropylamino Cyclohexenylidene Ethoxyethylcyanoacetate (MCE) UVA1 Filter on Pigmentary and Aging Signs: An Outdoor 4-Week Randomized, Intra-Individual Comparative Study in 52 Brazilian Women.” *Photodermatology, Photoimmunology & Photomedicine*, 2024.

David F Godoy, Francisco E Villanueva, Andrea A Cortés, and Viviana D. Zemelman. “The Effect of a Broad Spectrum Sunscreen with Visible Light Coverage on Facial Photoaging: A Pilot Study.” *Journal of Cosmetic Dermatology*, 2024.

E. Bagatin, M. Parada, H. A. Miot, K. Hassun, N. Michalany, and S. Talarico. “A Randomized and Controlled Trial about the Use of Oral Isotretinoin for Photoaging.” *International Journal of Dermatology*, 2010.

F. Flament, D. G. Mercurio, B. Muller, J. Li, C. Tricaud, F. Bernerd, A. Roudot, D. Candau, and T. Passeron. “The Impact of Methoxypropylamino Cyclohexenylidene Ethoxyethylcyanoacetate (MCE) UVA1 Filter on Pigmentary and Ageing Signs: An Outdoor Prospective 8-week Randomized, Intra-individual Comparative Study in Two Populations of Different Genetic Background.” *Journal of the European Academy of Dermatology and Venereology*, 2023.

F. Flament, D. G. Mercurio, E. Catalan, E. Bouhadanna, C. Delaunay, D. F. Miranda, and T. Passeron. “Impact on Facial Skin Aging Signs of a 1-year Standardized Photoprotection over a Classical Skin Care Routine in Skin Phototypes II–VI Individuals: A Prospective Randomized Trial.” *Journal of the European Academy of Dermatology and Venereology*, 2023.

F. Flament, and H. Qiu. “Effects of Seasonality and a Daily Photo-protection Upon Some Facial Signs of Chinese Women.” *International Journal of Cosmetic Science*, 2017.

Flora Ramona Sp Fajar Waskito Yohanes Widodo Wirohadidjojo. “The Protective Effect of Sunscreens Against Ultraviolet B-Induced Immunosuppression. A Study on Langerhans Cell Depletion,” 2015.

Ghazal Mardani, M. Nasiri, Nastaran Namazi, Mehdi Farshchian, and F. Abdollahimajd. “Treatment of Solar Lentigines: A Systematic Review of Clinical Trials.” *Journal of Cosmetic Dermatology*, 2025.

H. Luze, S. Nischwitz, I. Zalaudek, R. Müllegger, and L. Kamolz. “DNA Repair Enzymes in Sunscreens and Their Impact on Photoageing—A Systematic Review.” *Photodermatology, Photoimmunology & Photomedicine*, 2020.

H. Mahler, and H. Mahler. “Effects of Multiple Viewings of an Ultraviolet Photo on Sun Protection Behaviors.” *Public Health*, 2018.

H. Mahler, J. Kulik, F. Gibbons, M. Gerrard, and Jody Harrell. “Effects of Appearance-Based Interventions on Sun Protection Intentions and Self-Reported Behaviors.” *Health Psychology*, 2003.

H. Mahler, J. Kulik, M. Gerrard, and F. Gibbons. “Effects of Two Appearance-Based Interventions on the Sun Protection Behaviors of Southern California Beach Patrons,” 2006.

———. “Effects of Upward and Downward Social Comparison Information on the Efficacy of an Appearance-Based Sun Protection Intervention: A Randomized, Controlled Experiment.” *Journal of Behavioral Medicine*, 2010.

———. “Long-Term Effects of Appearance-Based Interventions on Sun Protection Behaviors.” *Health Psychology*, 2007.

H. Okati-Aliabad, E. Hosseini, M. A. M. Sharifabad, Mehdi Mohammadi, M. E. Ardakani, and Amir Hossein Talebrouhi. “Photoaging and Theory-Based Intervention to Improve Sun Protection Behaviors in Students in Zahedan: Study Protocol for a Randomized Controlled Trial.” *Trials*, 2023.

Hassan Okati-Aliabad, E. Hosseini, M. A. M. Sharifabad, Mahdi Mohammadi, M. E. Ardakani, and Amir Hossein Talebrouhi. “Efficacy of a Facial-Aging Web App on Sun Protection Behaviors Among Primary School Students in Iran: A Randomized Controlled Trial.” *BMC Public Health*, 2024.

Intan Nurmawati Putri, Aldo Primananda Putra, Nandika Juniano, Eko Budi, Winawati Eka Putri, Renata Mayangsari, Kinanti Prabawaningrum, and Julian Andriansyah. “The Effect of Sunscreen Use on The Incidence of Melasma in Police Officers.” *International Islamic Medical Journal*, 2024.

Irianiwati Catharina Sagita Yohanes Widodo Wirohadidjojo Arie Budiyanoto. “The Effect of Topical Extravirgin Olive Oil on Ultraviolet B-Induced 8-Hydroxy-2'-Deoxyguanosine Formation in Human Skin,” 2015.

J. Siegel, A. Lubert, and M. Weinstock. “Predictors of Actinic Keratosis Count in Patients with Multiple Keratinocyte Carcinomas: A Cross-sectional Study.” *Journal of American Academy of Dermatology*, 2017.

Joel I Osorio. "REGENERAGE® Cream Anti-Aging Effect in Women." *JOJ Dermatology & Cosmetics*, 2020.

Joel L Cohen, Melanie D. Palm, B. Biesman, M. Young, T. Kononov, and A. Zahr. "Two-Step Skincare Regimen Addressing Aging in Three Unique Geographic Locations: A Prospective, Multi-Center, Open-Label Study." *Journal of Drugs in Dermatology*, 2022.

Komang Jegek, Triangga Apsari, I. Ayu, Dewi Ratnayanti, I. Gusti, Komang Arijana, and I. W. Sugiritama. "Topical Application of Purple Cabbage (*Brassica Oleracea* L. Var. *Capitata* f. *Rubra*) Ethanol Cream Extract of Dermic Collagen on Male Wistar Rats (*Rattus Norvegicus*) Exposed to Ultraviolet B," 2020.

M. Hughes, Gail M. Williams, P. Baker, and A. Green. "Sunscreen and Prevention of Skin Aging." *Annals of Internal Medicine*, 2013.

M. M. Fossa Shirata, and P. M. Maia Campos. "Sunscreens and Cosmetic Formulations Containing Ascorbyl Tetraisopalmitate and Rice Peptides for the Improvement of Skin Photoaging: A Double-blind, Randomized Placebo-controlled Clinical Study." *Photochemistry and Photobiology*, 2021.

Manpreet Randhawa, Steven Q. Wang, J. Leyden, G. O. Cula, A. Pagnoni, and M. Southall. "Daily Use of a Facial Broad Spectrum Sunscreen Over One-Year Significantly Improves Clinical Evaluation of Photoaging." *Dermatologic Surgery*, 2016.

Masitta Tanjung, and Raudhatul Jannah. "Effectivity of Gel Derived from Degumming Silkworm Cocoon Waste for Skin Pigmentation." *Pakistan Journal of Biological Sciences*, 2023.

Michael Termer, Anita Jaeger, C. Carola, Andrew Salazar, C. Keck, H. Kolmar, and Joerg von Hagen. "Methoxy-Monobenzoylmethane Protects Skin from UV-Induced Damages in a Randomized, Placebo Controlled, Double-Blinded Human In Vivo Study and Prevents Signs of Inflammation While Improving the Skin Barrier." *Dermatologic Therapy*, 2021.

N. Afzal, Nhi Nguyen, Mildred Min, Caitlin Egli, Shabnam Afzal, Ratan K. Chaudhuri, W. Burney, and Raja K Sivamani. “Prospective Randomized Double-blind Comparative Study of Topical Acetyl Zingerone with Tetrahexyldecyl Ascorbate Versus Tetrahexyldecyl Ascorbate Alone on Facial Photoaging.” *Journal of Cosmetic Dermatology*, 2024.

Ni Putu Anggun Cipta Rosalita Jelantik, and Erna Cahyaningsih. “Antioxidant Potential of Telang Flowers (*Clitoria Ternatea* L.) as an Inhibitor of Hyperpigmentation Due to Ultraviolet Exposure.” *Jurnal Ilmiah Farmasi*, 2022.

P. Lehmann. “Aktinische Keratose: Tageslicht PDT Zeigt Umfassendes Wirkspektrum.” *Kompass Dermatologie*, 2022.

R. Sarkar, V. Garg, Annie Jain, Divya Agarwal, A. Wagle, F. Flament, and M. Verschoore. “A Randomized Study to Evaluate the Efficacy and Effectiveness of Two Sunscreen Formulations on Indian Skin Types IV and V with Pigmentation Irregularities.” *Indian Journal of Dermatology, Venereology and Leprology*, 2019.

Rana Shahab, and Nabila Rashed. “A Combination of a Dermocosmetic and a Tinted Sunscreen Reduces Acne Severity and Signs of Post-inflammatory Hyperpigmentation in Subjects with Fitzpatrick Phototypes Ranging from IV to VI.” *Journal of Cosmetic Dermatology*, 2024.

Rudy Ekofitranto, S. Zulaikhah, and Joko Wahyu Wibowo. “In Vivo Study on the Effect of Astaxanthin Cream on Preventing Inflammation in Skin Tissue Exposed to Acute UVB by Reducing MDA and IL-6 Levels.” *MEDISAINS*, 2025.

S. Darlington, Gail M. Williams, R. Neale, C. Frost, and A. Green. “A Randomized Controlled Trial to Assess Sunscreen Application and Beta Carotene Supplementation in the Prevention of Solar Keratoses.” *Archives of Dermatology*, 2003.

S. Ogden, and C. Griffiths. “Viewpoint 2,” 2008.

Sofia Persson, Yael Benn, K. Dhingra, D. Clark-Carter, A. Owen, and S. Grogan. “Appearance-based Interventions to Reduce UV Exposure: A Systematic Review.” *British Journal of Health Psychology*, 2018.

Steven R. Hall, A. Reid, M. St-Onge, and K. Goralski. “Cellular Photoprotective and Antioxidant Properties of Lipids in an Oral Skincare Supplement.” *The FASEB Journal*, 2019.

T. Brinker, Bianca Lisa de Faria, Olber Moreira de Faria, J. Klode, D. Schadendorf, J. Utikal, U. Mons, et al. “Effect of a Face-Aging Mobile App–Based Intervention on Skin Cancer Protection Behavior in Secondary Schools in Brazil.” *JAMA Dermatology*, 2020.

T. Brinker, C. M. Brieske, C. M. Schaefer, Fabian Buslaff, M. Gatzka, M. Petri, W. Sondermann, D. Schadendorf, I. Stoffels, and J. Klode. “Photoaging Mobile Apps in School-Based Melanoma Prevention: Pilot Study.” *Journal of Medical Internet Research*, 2017.

T. Stephens, Monya L. Sigler, P. Hino, Anne Le Moigne, and Lisa Dispensa. “A Randomized, Double-Blind, Placebo-Controlled Clinical Trial Evaluating an Oral Anti-Aging Skin Care Supplement for Treating Photodamaged Skin.” *The Journal of Clinical and Aesthetic Dermatology*, 2016.

Tamires Lima Cossetim, D. Hansen, C. Giacomolli, Viviane Cecília Kessler Nunes Deuschle, and G. Reis. “HÁBITOS DE FOTOPROTEÇÃO E CUIDADOS COM O CÂNCER DE PELE: UMA REVISÃO,” 2017.

Thanaporn Puaratanaarunkon, and P. Asawanonda. “A Randomized, Double Blinded, Split-Face Study of the Efficacy of Using a Broad Spectrum Sunscreen with Anti-Inflammatory Agent to Reduce Post Inflammatory Hyperpigmentation After Picosecond Laser.” *Clinical, Cosmetic and Investigational Dermatology*, 2022.

“UV-Protective Properties of Topical of Astaxanthin Half Side Controlled Pilot Study.” *International Journal of Clinical & Experimental Dermatology*, 2021.

V. Grandi, N. Milanesi, Maurizio Sessa, M. Gola, P. Cappugi, and N. Pimpinelli. “Efficacy and Safety of S--Acyl Glutathione 2% Cream Vs. Placebo Against UVB--Induced Erythema: A Randomized, Double--Blinded Clinical Trial.” *Giornale Italiano Di Dermatologia e Venereologia : Organo Ufficiale, Societa Italiana Di Dermatologia e Sifilografia*, 2019.

Xiaofeng Zhang, Qilun Zhou, Yue Qi, Xiaoli Chen, J. Deng, Yong-Ping Zhang, Ruonan Li, and Jianming Fan. “The Effect of Tomato and Lycopene on Clinical Characteristics and Molecular Markers of UV-Induced Skin Deterioration: A Systematic Review and Meta-Analysis of Intervention Trials.” *Critical Reviews in Food Science and Nutrition*, 2023.

Yan Wu, Xin Zheng, Xue-gang Xu, Yuan-hong Li, Bin Wang, Xing-Hua Gao, Hong-Duo Chen, M. Yatskayer, and C. Oresajo. “Protective Effects of a Topical Antioxidant Complex Containing Vitamins C and E and Ferulic Acid Against Ultraviolet Irradiation-Induced Photodamage in Chinese Women.” *Journal of Drugs in Dermatology*, 2013.

Yelena P. Wu, Bridget G. Parsons, Elizabeth S. Nagelhout, B. Haaland, Jakob D. Jensen, Kelsey Zaugg, Heloisa Caputo, et al. “A Four-Group Experiment to Improve Western High School Students' Sun Protection Behaviors.” *Translational Behavioral Medicine*, 2019.

Yi-Chun Lin, Yu-Chieh Chen, B. Hwang, and Chen-Peng Chen. “Acute Dermal Effects of Solar UV Irradiation and Efficacy of Sunscreen Use.” *Environmental Pollutants and Bioavailability*, 2022.

Z. Draelos, H. Gunt, and S. Levy. “34428 Clinical and Biophysical Assessment of the Effects of Daily Use of a Nature-Based, Broad-Spectrum Mineral Sunscreen Containing Bakuchiol in Photoaged Skin.” *Journal of American Academy of Dermatology*, 2022.

정문석, 안종숙, and 이정만. “자외선의 피부에 대한 유해성에 따른 경구용 화장품 개발에 대한 연구 - 칼라구알라(Polypodium Leucotomos)의 임상연구를 중심으로 -,” 2012.