

Bibliometric Analysis of Natural Photoprotective Agents for Sustainable Cosmetic Applications

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Abstract

Ultraviolet (UV) radiation is a critical environmental stressor that accelerates oxidative damage, photoaging, and elevates the risk of skin malignancies. Although conventional sunscreens remain widely used, their drawbacks—including chemical safety concerns, limited photostability, and ecological impact—have intensified the search for natural alternatives. This study conducts a bibliometric exploration of natural photoprotective agents in cosmetic science, analysing publications from 2020 to 2025 indexed in Scopus. Using VOSviewer for co-word mapping, 66 studies were examined to reveal thematic trends and highlight emerging compounds. The analysis points to the rising significance of polyphenols alongside marine-derived resources like seaweed. These agents are increasingly recognized for their antioxidant, anti-inflammatory, UV-protective, and pigmentation-modulating properties. Keyword clustering further illustrates the interdisciplinary nature of this research, linking cosmetic applications with toxicological and natural product studies, and emphasizing the balance between efficacy and safety. Overall, the findings indicate that polyphenols are increasingly recognized as sustainable, multifunctional ingredients poised to shape the future of cosmetic formulations.

Keywords: photoprotective agents; cosmetics; bibliometric analysis; polyphenols

INTRODUCTION

Ultraviolet (UV) radiation remains one of the most significant environmental factors affecting skin health (Gromkowska- *et al.*, 2021; Al-sadek and Yusuf, 2024), creating a continuous need for effective protective strategies. Repeated and prolonged exposure to ultraviolet radiation, especially UVA and UVB rays, drives the excessive generation of reactive oxygen species (ROS) within skin cells. These highly unstable molecules upset the delicate balance between oxidants and antioxidants, creating a state of oxidative stress. As a result, vital cellular components including lipids, proteins, and DNA become damaged, impairing normal cellular processes and activating inflammatory responses (Sumali, 2023; Tang *et al.*, 2024). These processes gradually manifest as premature aging such as wrinkles, pigmentation irregularities, and loss of elasticity, as well as may also increase the risk of mutations that can lead to skin cancer (Amaro-ortiz, Yan and Orazio, 2014; Tanveer, Rashid and Tasduq, 2023; Tang *et al.*, 2024). While conventional sunscreens have long served as the primary defense, concerns

about chemical safety, environmental impact, and inconsistent application have prompted growing interest in natural, eco-friendly alternatives (Giacomo *et al.*, 2020; Nitulescu *et al.*, 2023; Sasounian *et al.*, 2024; Kosasih, Yulyana and Dewi, 2025).

Cosmetics with UV-protective properties therefore represent more than aesthetic products; they function as practical interventions that help preserve skin integrity (Antonoaea *et al.*, 2025; Chinjoo and Golzary, 2025). Unlike traditional beauty formulations, UV-protective cosmetics combine dermatological science with everyday usability, offering accessible defense against UVA-induced aging and UVB-related sunburn and DNA damage (Portilho, Aiello and Vasques, no date; Górska-ponikowska, 2022; Tanveer, Rashid and Tasduq, 2023). Their role extends beyond personal care, contributing to broader public health by reducing the cumulative burden of UV-related disorders.

Growing awareness of sustainable lifestyles and preventive healthcare highlights the vital role of incorporating UV-protective cosmetics into everyday routines. As modern living increasingly involves outdoor activities and is shaped by shifting climate conditions, the need for multifunctional products that safeguard, nourish, and empower individuals continues to expand. Among these, sunscreens remain the most established form of UV-protective cosmetics, utilizing specialized photoprotective agents to deliver effective defense against harmful radiation (Chavda *et al.*, 2023; Nitulescu *et al.*, 2023). Traditionally, these agents have been synthetic or mineral-based (Bhattacharjee *et al.*, 2021; Shah and Mewada, 2023), but limitations such as photostability issues, irritation, and ecological harm have accelerated the search for safer alternatives.

Natural-based photoprotective agents such as polyphenols, terpenoids, and mycosporine-like amino acids offer promising solutions by combining UV shielding with antioxidant, anti-inflammatory, and pigmentation-regulating properties (Shin *et al.*, 2022; Rosic *et al.*, 2023; Sogan *et al.*, 2025). Their biocompatibility and eco-friendliness make them particularly attractive for modern cosmetic science, aligning with consumer demand for sustainable and health-conscious products. Considering their urgency and potential, this article presents a bibliometric analysis that explores the promise of natural photoprotective agent for cosmetics.

METHODS

This study employed a bibliometric analysis to systematically evaluate the scientific literature on photoprotective agents, with a particular emphasis on natural photoprotective agent for cosmetics. The analysis centered on co-word mapping to uncover research trends. The procedure for conducting the co-word analysis is depicted in Figure 1, where the software tool VOSviewer was employed.

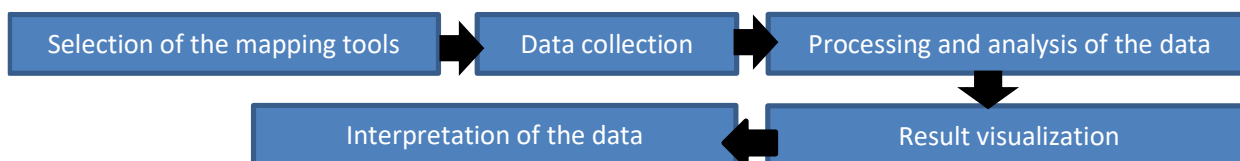


Figure 1. Steps of the bibliometric study

The bibliometric dataset was retrieved from the Scopus database, using the keywords of natural photoprotective agent for cosmetics, with the search limited to publications from 2020-2025.

RESULT AND DISCUSSION

The workflow of the bibliometric analysis followed a structured sequence that began with the selection of appropriate mapping tools (Kirby, 2023; Du *et al.*, 2024; Ali and Omer, 2025). In this study, VOSviewer was chosen because of its ability to generate clear visualizations of bibliometric networks such as co-citation, co-authorship, and keyword co-occurrence. Once the tool was identified, the next step involved data collection, which was carried out using the Scopus database. The search was restricted to publications released between the range as listed on the methods section, and the keywords applied were “natural, photoprotective, agent and cosmetics”. The obtained published paper in scopus database with the keyword applied is comprised of 66 publications.

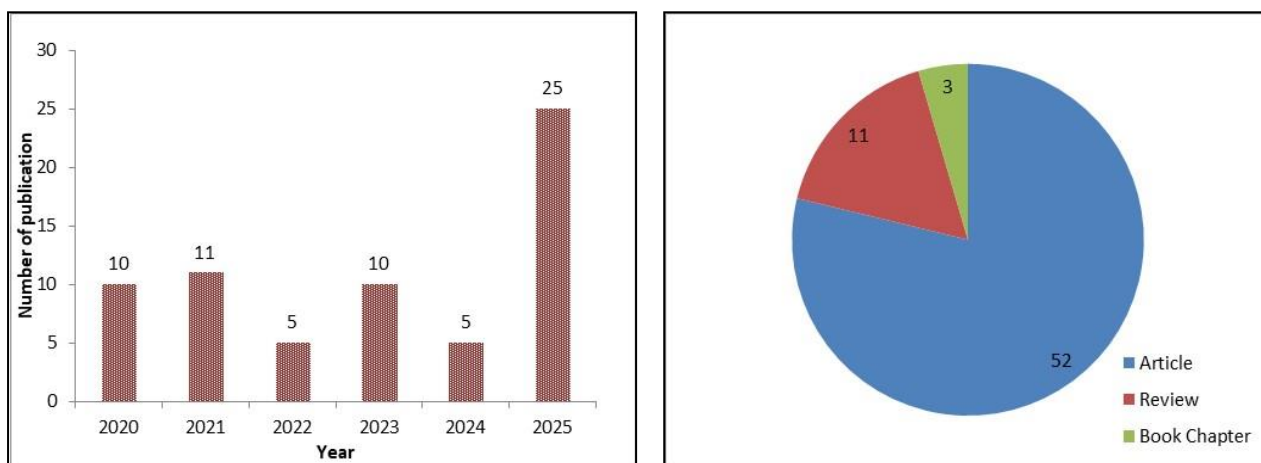


Figure 2. (a) Number of publication and (b) distribution of publication from Scopus databases using a combination of keywords of natural photoprotective agent for cosmetics

The figures derived from Scopus data between 2000 and 2025 illustrate the growing research interest in natural photoprotective agents for cosmetics. The annual publication trend shows a modest output in the early 2000s, with only a handful of papers per year,

The keyword analysis (Figure 3) underscores the multidisciplinary scope of research into natural photoprotective agents for cosmetics, linking terms related to cosmetic application (skin care, sunscreen, sun protection factor) with biological activities (antiaging activity, antimicrobial activity, cytotoxicity), natural sources and compounds (plant leaf, seaweed, polyphenol, flavonoid, essential oil), and analytical techniques (DPPH and ABTS radical scavenging assays, spectrophotometry, HPLC). The presence of safety-oriented keywords such as adverse event and cytotoxicity highlights that efficacy research is being pursued in parallel with careful evaluation of toxicology and tolerability, reflecting a balanced emphasis on both performance and consumer safety.

Moreover, Figure 3 also indicates the presence of several compounds, notably gallic acid, rutoside, and flavonoids, which are themselves members of the broader polyphenol class. Polyphenols are chemically diverse plant secondary metabolites (Goswami, Samant and Srivastava, 2013; Sogan *et al.*, 2025) that including flavonoids (e.g., quercetin, catechins), phenolic acids (e.g., caffeic acid), stilbenes (e.g., resveratrol), and proanthocyanidins, that provide multifaceted photoprotection (Table 1).

Table 1. Polyphenols as photo protection agent

Compound	Reference
Catechins	(Mita <i>et al.</i> , 2025)
Quercetin	(Wisudyaningsih, Zu and Lita, 2023; Wisudyaningsih, Barikah and Kamelia, 2025)
Caffeic acid and its derivatives (affeic acid-3,4-dihydroxyphenylpropanolester)	(Girsang <i>et al.</i> , 2020; Kim <i>et al.</i> , 2025)
Resveratrol	(Milutinov, 2024)
Siylmarin	(Vost <i>et al.</i> , 2019)
Rutoside (rutin)	(Geçotek <i>et al.</i> , 2019; Girsang <i>et al.</i> , 2020; Androm <i>et al.</i> , 2024; Singh <i>et al.</i> , 2025)

The appearance of rutoside and gallic acid in the density visualization of co-word analysis result is an interesting finding. It seems that both of polyphenol compounds have attracted considerable attention as a natural photoprotective agent in skincare. Rutoside, more commonly known as rutin, is a flavonoid glycoside (Androm *et al.*, 2024) that is reported as a strong antioxidant and anti-inflammatory agent. The characteristic enable it to counteract the harmful effects of ultraviolet (UV) radiation, which generates reactive oxygen species (ROS) that drive oxidative stress, inflammation, and DNA damage. Beyond its immediate protective role, rutin supports the maintenance of collagen and elastin, slowing photoaging and promoting skin elasticity (Geçotek *et al.*,

2019; Girsang *et al.*, 2020; Singh *et al.*, 2025). Although its relatively high molecular weight can limit skin penetration, modern delivery systems such as ethosomes, liposomes, nanoparticles, and cyclodextrin complexes have been developed to enhance its stability and bioavailability (Lopez-polo *et al.*, 2024; Musielak and Krajka-ku, 2024; Sguizzato *et al.*, 2026).

The co-appearance of rutoside and gallic acid in the co-word analysis not only reflects their growing scientific relevance but also underscores the broader trend of exploring polyphenols as multifunctional agents in cosmetic science. Gallic acid, a phenolic compound abundant in tea, grapes, and berries, has been widely reported for its potent antioxidant capacity and ability to inhibit melanogenesis, thereby offering both photoprotective and anti-pigmentation benefits. When considered alongside rutin, these compounds exemplify how naturally occurring polyphenols can complement conventional UV filters by providing secondary layers of defense against oxidative stress, inflammation, and photoaging. Their presence in the visualization suggests that research momentum is shifting toward integrating such bioactive molecules into advanced formulations, supported by innovative delivery systems and rigorous safety validation. This convergence of scientific interest highlights the potential of rutoside and gallic acid to serve not merely as isolated actives, but as part of a new generation of sustainable, multifunctional cosmetic products that align with consumer demand for natural sun protection, anti-aging efficacy, and antioxidant resilience.

Moreover, within the bibliometric mapping of research on natural photoprotective agents for cosmetics, the keyword seaweed emerges as a significant cluster in the density visualization (Figure 3). Its prominence underscores the increasing scientific and industrial focus on marine-derived bioactive compounds for cosmetics formulation (Nurjanah *et al.*, 2020; Sulastri *et al.*, 2023; Umam, Pringgenies and Sedjati, 2025). Seaweeds constitute a valuable source of bioactive molecules, including MAAs, polyphenols, carotenoids, and sulfated polysaccharides, which have been rigorously examined for their photoprotective efficacy against ultraviolet (UV) radiation (Pangestuti, Siahaan and Kim, 2018; Fonseca, Amaral and Reis, 2023; Cadar *et al.*, 2025).

The visualization further reveals that seaweed research is closely linked with other key terms such as antioxidant, UV protection, cosmetic formulation, and natural extracts. This interconnectedness highlights seaweed's dual importance that is not only as a source of photoprotective agents, but also as a multifunctional ingredient in skincare, offering hydration, anti-aging benefits, and defense against oxidative stress.

The clustering around seaweed positions it as a bridge between marine biotechnology and cosmetic innovation, reflecting how researchers are increasingly turning to sustainable, ocean-based resources to meet the demand for natural and eco-friendly products. In this context, seaweed stands out as a strategic keyword, representing both scientific opportunity and commercial potential in advancing next-generation photoprotective cosmetics.

CONCLUSION

The analysis reveals a marked rise in interest in natural photoprotective agents since 2020, driven by demand for eco-friendly and health-conscious cosmetics. Polyphenols such as rutin and gallic acid stand out for their antioxidant and anti-aging benefits, supported by advanced delivery systems that improve stability and skin penetration. Seaweed emerges as a strategic keyword, symbolizing the integration of marine biotechnology into cosmetic innovation, with bioactive compounds offering UV protection, hydration, and anti-aging effects. Co-word mapping highlights the interdisciplinary nature of this field, balancing efficacy with safety. Overall, natural photoprotective agents show strong potential to shape next-generation cosmetic formulations that unite UV protection, anti-aging effects, and sustainability. Continued innovation will be key to making these bioactive compounds widely accessible in skincare.

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