



## Biocosmetics: solutions and challenges in the transition to sustainable practices

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### ABSTRACT

The reliance on petroleum-based ingredients in cosmetics raises significant environmental and health concerns. In this context, biocosmetics emerge as a promising solution, as they are not only effective but also composed of natural and sustainable ingredients. However, knowledge about the integration of biocosmetics remains limited. Under this perspective, this study aimed to explore the use of biological ingredients in cosmetic formulations, addressing the challenges related to dependence on fossil actives, excessive waste and future perspectives for the transition of these formulations. An integrative literature review was conducted to provide a comprehensive approach to the topic. Findings emphasize the dual impact of biological ingredients on product efficacy and environmental safety, underscoring the necessity for innovative solutions. While promising, the shift requires overcoming raw material availability and ethical certification barriers. By addressing these challenges, this study contributes to the development of scientific knowledge and encourages the continuation of sustainable practices in the cosmetics industry. This gradual shift is not limited to ingredient substitution but reflects an evolution in the concept of beauty and personal care, grounded on environmental, safety and efficacy principles.

### RESUMO

*Biocosméticos: soluções e desafios na transição para práticas sustentáveis*

A dependência de ingredientes à base de petróleo em cosméticos levanta preocupações ambientais e de saúde significativas. Nesse contexto, os biocosméticos surgem como uma solução promissora, pois não são apenas eficazes, mas também compostos de ingredientes naturais e sustentáveis. No entanto, o conhecimento sobre a integração de biocosméticos permanece limitado. Sob essa perspectiva, este estudo teve como objetivo explorar o uso de ingredientes biológicos em formulações cosméticas, abordando os desafios relacionados à dependência de ativos fósseis, ao desperdício excessivo e às perspectivas futuras para a transição dessas formulações. Uma revisão integrativa de literatura foi conduzida para fornecer uma abordagem abrangente ao tópico. As descobertas enfatizam o impacto duplo dos ingredientes biológicos na eficácia do produto e na segurança ambiental, ressaltando a necessidade de soluções inovadoras. Embora promissora, a mudança requer a superação da disponibilidade de matéria-prima e das barreiras de certificação ética. Ao abordar esses desafios, este estudo contribui para o desenvolvimento do conhecimento científico e incentiva a continuação de práticas sustentáveis na indústria de cosméticos. Essa mudança gradual não se limita à substituição de ingredientes, mas reflete uma evolução no conceito de beleza e cuidado pessoal, baseada em princípios ambientais, de segurança e eficácia.



## INTRODUCTION

The reliance on petroleum-based ingredients in cosmetics raises significant environmental and health concerns. Conversely, there is a growing demand for alternatives that replace traditional chemical technologies with more sustainable approaches aligned with green technology practices. In this context, biocosmetics emerge as a promising solution by integrating health, aesthetics, well-being, and environmentally conscious practices (Bom et al., 2019). These products belong to a specific category of bioproducts for personal care, formulated with natural, organic, and sustainable ingredients derived from plant, mineral, and biological sources, avoiding harmful synthetic substances that are difficult to degrade (Novak et al., 2014).

From a historical perspective, interest and demand for biocosmetics have undergone notable transformations in recent decades. Until the early 2000s, they remained a niche market with limited visibility and supply, primarily targeting consumers with alternative profiles—those concerned with environmental issues or sensitive to synthetic ingredients. However, since 2010, and particularly over the past decade, this interest has expanded significantly, driven by growing environmental awareness, increased appreciation for natural and ethical ingredients, and the influence of movements such as Clean Beauty and Slow Beauty (Gonçalves, 2023). In parallel, the global natural cosmetics market was valued at USD 31.84 billion in 2023, with a projected compound annual growth rate (CAGR) of 5.3% through 2030, reflecting the growing consumer preference for sustainable and eco-friendly beauty products (Natural Cosmetics Market Size, 2025). More recently, the use of natural actives in cosmetics has marked a new paradigm and highlighted emerging trends within the industry (Liu, 2022), reflecting the progress of alternative models for utilizing natural resources and fostering a socially sustainable approach (Miguel, 2012).

Building upon this trend, the growing consumer awareness and interest in green cosmetics demonstrate a significant shift in market preferences, as natural ingredients tend to present a lower risk of allergic reactions and irritations, offering a safer and more effective care experience (Liu, 2022). To meet this demand, many companies in the sector have redirected their strategies, adopting bio-based ingredients and promoting a circular economy. The sustainable and eco-friendly cosmetics market has experienced remarkable growth, earning consumer trust through practices that respect and preserve nature, thereby addressing environmental concerns (Goyal and Jerold, 2021).

However, the cosmetics industry faces considerable challenges in adapting and innovating to enhance the sustainability of its products and processes throughout the entire value chain, always focusing on consumer safety. As highlighted by Bom et al. (2019), sustainability has become a keyword in the cosmetics agenda, driving industries to integrate this concern into their practices over the past decades. In addition to concerns about product formulation, the generation of municipal solid waste (MSW) is a critical issue, with increasing amounts of biomass being generated worldwide, driven by population growth, urbanization, and changing consumption habits (Khan et al., 2020). According to the United Nations Environment Programme (UNEP) report "Global Waste Management Outlook 2024", global municipal solid waste (MSW) generation was estimated at 2.3 billion tonnes in 2023, with projections indicating an increase to 3.8 billion tonnes by 2050. The same report highlights that, in 2020, the global direct cost for waste management was approximately US\$252 billion, and could reach US\$640.3 billion annually by 2050 if inadequate practices persist.

In light of this scenario, the need to limit dependence on fossil fuels and reduce the volume of solid waste represents an urgent challenge for contemporary society. Therefore, this study aims, through an extensive literature review, to investigate how biological ingredients can effectively replace synthetic compounds in cosmetic formulations, considering industrial viability and sustainability, by specifically addressing: *i.* The most relevant biological ingredients in cosmetic formulations; *ii.* Risks and side effects associated with synthetic ingredients; *iii.* Challenges and future perspectives for transitioning towards biocosmetics, as well as their implications for quality of life and the environment.

## MATERIAL AND METHODS

To gather data, we used the integrative literature review method, which not only allows for the synthesis and analysis of the scientific production on the topic of interest but also enables new questions, reflections, and critiques. This approach helps identify existing knowledge gaps, thus contributing to the advancement of the field (Botelho et al., 2011). The integrative review was conducted in different stages, starting with the identification of the research question, which guided the entire process. Next, a bibliographical search was carried out, in which the inclusion and exclusion criteria for the materials were defined, in addition to the selection of studies from the

consulted databases. After this screening, the results were categorized, allowing a systematic organization of the information. The selected articles were analyzed through a critical evaluation, ensuring the relevance and quality of the data. Next, the results were subjected to analysis and interpretation, allowing an in-depth discussion of the results. Finally, all the information was synthesized, contributing to the generation of knowledge on the investigated topic.

The research question guiding the integrative review was: “Is there scientific evidence supporting the efficacy of natural ingredients in cosmetics as satisfactory substitutes for synthetic ingredients?” Based on this question, we defined the keywords for the bibliographic search: “cosmetics,” “ingredients,” “bioactives,” “synthetic ingredients,” and the Boolean operators AND and OR. The keywords were combined in various ways: (cosmetic AND ingredients AND bioactives OR “synthetic ingredients”) to investigate the efficacy of natural ingredients in replacing synthetic ones in cosmetics. We conducted the searches in the ScienceDirect and CAPES Journal Portal databases between February and October 2023.

These databases were chosen because of the need to access a wide range of high-quality scientific publications, while minimizing limitations in terms of regionality and thematic coverage. As a global platform, ScienceDirect provides peer-reviewed articles published by Elsevier, one of the world's largest scientific publishers, ensuring access to high-impact international research. However, its emphasis on

foreign journals may represent a limitation for studies that require a more regionalized approach. To fill this gap, the CAPES Journal Portal complements research in several national and international databases, allowing access to journals from different publishers and covering Brazilian and Latin American scientific productions. Thus, using all of these databases increases the representativeness of the publications consulted, ensuring a more balanced and comprehensive review.

After the search, the following inclusion criteria were adopted for selecting studies: research articles in any language explicitly addressing, in the title, abstract, and/or keywords, natural ingredients and bioactives used in cosmetic formulations, and articles available in open access. We excluded review articles and those that, although appearing in the searches, were misaligned with our research objectives (e.g., divergent topics).

A total of 2,457 articles were retrieved during the initial database search. After the first filtering step, 389 articles were shortlisted for screening. Following identification and exclusion based on title and abstract review (123 articles), 65 articles were selected for full-text evaluation. In the final phase, 30 articles were excluded for being unrelated to the topic of interest. Consequently, 35 articles were included for qualitative analysis, which considered topic frequency and the impact of bioactives on cosmetic performance. Figure 1 illustrates the flowchart followed in the present study.

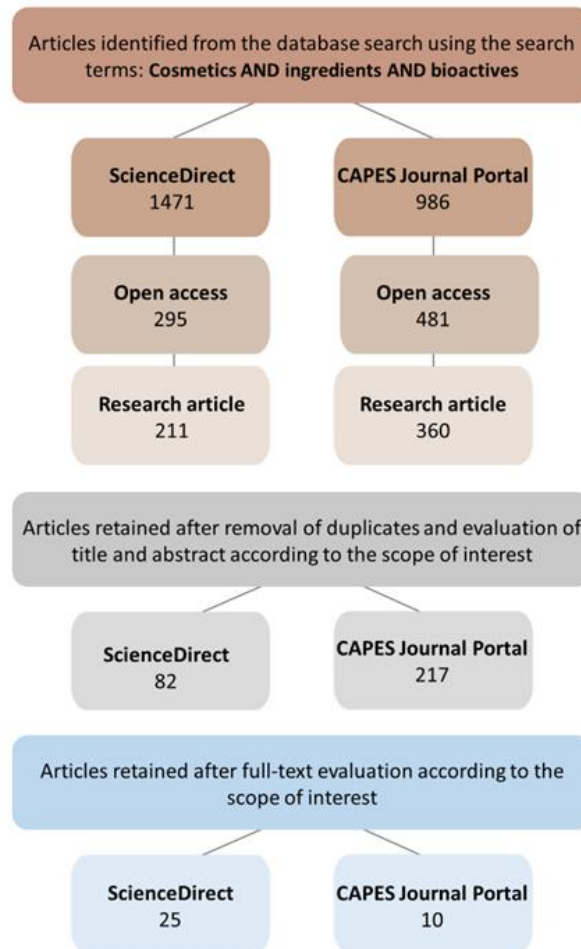


Figure 1 - Flowchart of the survey and screening results of the bibliometric material collected using the search terms Cosmetics AND ingredients AND bioactives in the ScienceDirect and CAPES Journal Portal databases.

## RESULTS AND DISCUSSION

The scientific literature widely supports the incorporation of biological ingredients into cosmetic formulations. This approach is corroborated by studies demonstrating the presence of multifunctional compounds, such as phenols, flavonoids, and elenolic acids derived from natural extracts. These compounds exhibit multiple uses due to their antioxidant, anti-aging, and antimicrobial properties against pathogenic bacteria, effectively replacing conventional petroleum-based ingredients. The growing adoption of biological ingredients is driven by various factors, including consumer preference for natural products and the need for greater transparency in the cosmetic industry. However, despite these advancements, integrating these ingredients poses complex challenges in scientific contexts, requiring careful considerations and strategic solutions.

### Biological Ingredients in a Cosmetic

### Formulation

A cosmetic product is a formulation containing substances of natural or artificial origin intended to enhance the appearance of any part of the body to which it is applied, appealing aesthetically to consumers (Ugoeze and Odeku, 2022). According to Martins and Marto (2023), a standard cosmetic product generally consists of a mixture of 15 to 50 components, including water, emollients, surfactants, solvents, preservatives, colorants, polymers, ultraviolet (UV) filters, fragrances, as well as antioxidant and chelating agents. These ingredients play critical roles in ensuring safety, efficacy, sensory attributes, and physicochemical stability.

### Surfactants

Surfactants play several roles in cosmetics, depending on their concentration and nature. They can act as emulsifiers, humectants, detergents, dispersants, solubilizers or penetration enhancers, influencing the sensory and functional properties of the product. Bezerra et al. (2018) highlight that the

incorporation of saponins and microbial biosurfactants into shampoos and cosmetics is viable to make the products more environmentally friendly. In addition to cleaning, biosurfactants have antimicrobial, antioxidant and anti-inflammatory effects, allowing the creation of self-preserving cosmetics.

### Emollients

Emollients, along with moisturizers in a cosmetic formulation, soften the skin and prevent water loss. Alongside emulsifiers and active agents, they are considered the most crucial ingredients (Martins and Marto, 2023). These ingredients are characterized by their sensory properties (such as softness, spreadability, and elasticity) and visual attributes (e.g., matte or glossy finishes).

Among the promising active agents in the biocosmetics sector, Damasceno et al. (2020) reported that formulations of *Prosopis juliflora* (Sw.) DC. extracts demonstrated potential in clinical evaluations, enhancing short- and long-term skin hydration, improving cutaneous microrelief, and acting as an anti-aging agent. This innovative solid-core extract proved to be a prototype for a potential new product.

Similarly, Caldeira et al. (2023) identified that the fixed oils extracted from the seeds of two catingueira species, *Cenostigma microphyllum* (Mart. ex G.Don) Gagnon & G.P. Lewis and *Cenostigma pyramidale* (Tul.) Gagnon & G.P. Lewis, contained triglycerides, predominantly linoleic acid, which supports their potential application in cosmetics. Physicochemically, the oils met quality standards for industrial and cosmetic applications.

### Colorants

Color is a fundamental property of a product, influencing consumer appeal and ensuring successful marketing. In cosmetics, colorants serve two primary functions: altering the product's color and imparting color to the skin (e.g., foundations), nails (nail polishes), or hair (hair dyes). These colorants can be synthetic or natural and are classified as pigments or dyes based on their solubility.

Pigments are insoluble, solid, opaque inorganic particles commonly used in makeup and toothpaste. Conversely, dyes are organic molecules soluble in water or oil and are typically found in skincare and personal hygiene products (Martins and Marto, 2023). Synthetic dyes are the most widely used in cosmetics due to their lower production costs, wide variety of colors and shades, and stability. However, many synthetic dyes are derived from petrochemical products, raising environmental and

safety concerns (Guerra; et al., 2018).

As the cosmetic industry seeks more sustainable and safer options, research focuses on discovering multifunctional natural dyes that are biodegradable, renewable, and non-toxic (Antunes et al., 2023). These natural dyes are valued for their additional properties, such as acting as anti-aging agents, preservatives, and UV filters in products like hair dyes, lipsticks, and foundations.

Antunes et al. (2023) demonstrated the potential of lignin derived from sugarcane (*Saccharum officinarum* L.) as a multifunctional candidate for colored cosmetics. This study evaluated alkaline lignin extracted from sugarcane bagasse as a natural ingredient with multifunctional properties, including acting as a natural UV blocker, antioxidant agent, and pigment. The lignin powder exhibited desirable characteristics for cosmetic applications, such as a light brown color and a sweet, woody fragrance.

### Fragrances

Cosmetics must appeal to consumers, and fragrance is an essential aspect of these products, often considered a decisive factor during product selection. Fragrances also play a significant role in masking undesirable odors produced by oils, fatty acids, and surfactants (Liu, 2022).

Although used in low concentrations, fragrances are among the ingredients most likely to cause skin sensitization (Nardelli et al., 2011). However, it is challenging for consumers to make informed and sustainable choices since fragrances are simply listed as "parfum" on cosmetic ingredient lists, without detailed composition (Bom et al., 2019).

Natural and synthetic fragrances are available. Synthetic fragrances, containing synthetic aromatic compounds, are more diverse, affordable, and can be more intense and long-lasting. According to Martins and Marto (2023), synthetic fragrances may be "nature-identical," chemically synthesized to mimic natural aromas or create new scents not found in nature. Meanwhile, most natural fragrances are derived from essential oils of plants like lavender, eucalyptus, bergamot, and jasmine. Essential oils not only provide pleasant aromas to formulations but also act as active ingredients or preservatives (Sharmeen et al., 2021).

### Synthetic Ingredients in Conventional Cosmetics: Risks and Side Effects

Despite advancements in biocosmetics and green technologies, a large number of chemical compounds continue to be incorporated into the manufacturing of beauty, personal care, and cosmetic products. These include additives, fragrances, preservatives, stabilizers, surfactants,

colorants, and glitter agents to enhance product quality, performance, and shelf life. Unsurprisingly, many of these substances are biologically active, environmentally persistent, and possess bioaccumulative potential, thereby posing serious threats to the environment and human health due to widespread, prolonged exposure.

Solvents, among the most problematic cosmetic compounds, are derived from petroleum, contributing significantly to environmental pollution and climate change (Clarke et al., 2018). Moreover, they can negatively impact human health by causing skin sensitivity and irritation and compromising the integrity of proteins and other cellular components due to their ability to penetrate the skin barrier (Komaikul et al., 2021). Similarly, synthetic antioxidants like butylated hydroxytoluene (BHT) and butylated hydroxyanisole (BHA) are linked to allergies, endocrine disruption, and even cancer (Augustyniak et al., 2023).

The type and usage pattern of personal care products vary by country, habits, practices, and cultural norms. Using questionnaires, Nawalage and Bellanthudawa (2022) identified the ten most commonly used personal care products and the public's awareness of microplastic emissions in Sri Lanka. The ingredient lists revealed synthetic polymers or microplastic-like polymers in most products examined.

In a related context, Bilal et al. (2020) documented the biological risks of substances that raise health concerns, including genotoxicity, cytotoxicity, neurotoxicity, mutagenicity, and estrogenicity. Their study identified toxic ingredients commonly used in cosmetics, such as parabens, triclosan, benzalkonium chloride, 1,4-dioxane, plastic microbeads, formaldehyde, diazolidinyl urea, imidazolidinyl urea, sunscreen agents, and heavy metals.

To assess heavy metal concentrations, margin of safety (MoS), hazard quotient (HQ), hazard index (HI), and lifetime cancer risk (LCR), Arshad et al. (2020) conducted research on various cosmetic brands. They quantified five heavy metals—Cd, Cr, Fe, Ni, and Pb—in lotions, foundations, whitening creams, lipsticks, hair dyes, and sunscreen creams using atomic absorption spectrometry. While MoS, HQ, and HI values were within permissible limits except for lotions and sunscreens, LCR exceeded limits in all products except lipsticks. Regular use of these products can pose significant threats to human health, particularly prolonged skin exposure risks like cancer.

Ahmed, Asada, and Hamza (2021) investigated cobalt (Co) and lead (Pb) concentrations in brands of henna, foundation creams, kohl, and skin-

whitening creams using inductively coupled plasma mass spectrometry (ICP-MS). They found that Co levels exceeded permissible limits in all evaluated cosmetics, while Pb levels were within acceptable limits except in kajal, where 22% of samples exceeded the threshold.

Contact Allergic Dermatitis (CAD) represents another significant concern. This inflammatory skin condition is caused by exposure to allergenic substances found in cosmetic formulations, including active ingredients, preservatives, fragrances, emulsifiers, and vehicle components. Hafner, et al. (2020) analyzed 1,405 medical records and identified cosmetics as the cause in 66.4% of CAD cases. Among common allergens, fragrances topped the list. Nail polish was the most common causative product, followed by hair dyes, perfumes, shampoos, body moisturizers, deodorants, sunscreens, soaps, and hair straighteners.

### Challenges and Future Perspectives

The integration of biocosmetics, presents complex challenges and significant opportunities within scientific and industrial contexts. Although biocosmetics align with consumer demand for safer and more sustainable products, their large-scale implementation is constrained by several scientific, technological, regulatory, and economic factors. A primary challenge lies in the limited and variable availability of natural ingredients. Sourcing raw materials from biological sources frequently depends on specific cultivation practices and seasonal climates, resulting in irregular supply chains. This compromises production stability and increases costs associated with ensuring supplier reliability (Sim and Nyan, 2021).

Moreover, the substitution of unsustainable synthetic ingredients with sustainable alternatives remains a critical obstacle. Although various studies highlight potential applications of organic or green chemistry-based compounds, further investigation is needed to assess their functionality, safety, formulation stability, and consumer acceptance in terms of aesthetic performance. Comparative studies between conventional and sustainable ingredients are essential to support this transition (Bom et al., 2019).

From a technological standpoint, the production processes of many natural ingredients remain a bottleneck. Biosurfactants, for instance, exhibit ecological benefits and biodegradability, but their commercial use is still limited by the absence of economically viable technologies for large-scale recovery and purification (Bezerra et al., 2018). Safety concerns persist even among natural

compounds. Essential oils, often considered safe, may contain complex mixtures of known allergens and skin sensitizers. Alarmingly, such components are not always clearly disclosed on product labels, raising significant toxicological and regulatory concerns (Sharmeen et al., 2023).

In addition to ingredient sourcing and formulation, manufacturing practices must be optimized to support a circular economy, with a focus on energy efficiency, resource conservation, and waste reduction. Innovations in eco-design also involve reducing packaging, eliminating it when feasible, and using recyclable, compostable, or refillable materials (Martins and Marto, 2023).

Certification and ethical sourcing standards are also crucial. As the biocosmetics sector grows, regulatory oversight has intensified to validate product claims and ensure adherence to ethical principles. This increases the need for robust quality control systems and greater transparency across production and labeling (Martins and Marto, 2023).

Despite these hurdles, future perspectives remain encouraging. Scientific innovation and consumer awareness are driving the cosmetics industry toward greater sustainability. Consumers increasingly value transparency, preferring cleaner labels free from controversial substances (Bom et al., 2019). This trend compels companies to adopt more transparent manufacturing practices and formulation disclosures.

Sustainability is a key force behind the adoption of biocosmetics. Growing concern over the environmental and health impacts of conventional cosmetics—such as contact allergic dermatitis caused by fragrances and preservatives, and heavy metal toxicity—has accelerated the shift toward safer alternatives (Hafner et al., 2020).

Biotechnology and medical science are expected to play pivotal roles in the development of next-generation biocosmetics, offering opportunities for new bioactive ingredients with multifunctional properties (Zappelli et al., 2018). However, for meaningful industry transformation, coordinated efforts are required from researchers, regulators, and industry stakeholders to improve ingredient sourcing, validate safety, and scale up sustainable technologies.

Environmentally, biocosmetic production promotes organic cultivation, sustainable agriculture, and responsible harvesting. Many of these ingredients are biodegradable, helping to mitigate pollution and protect biodiversity. Economically, the sector fosters innovation, supports small-scale producers, and contributes to a more ethical and competitive market. The transition toward natural cosmetics is not only a response to consumer preferences but also a

necessary step toward a more sustainable, transparent, and health-conscious cosmetic industry.

## CONCLUSIONS

This review summarizes the relevant literature on the use of natural extracts as cosmetic ingredients. The research highlights a growing trend towards natural alternatives in cosmetic formulations, signaling a significant industry shift towards sustainability and safety. Analyzing the risks and side effects of synthetic ingredients highlights the urgent need for safer and more ethical approaches to cosmetic product design. The benefits of natural ingredients, such as antioxidant properties and their positive impacts on quality of life, emphasize the growing relevance of a holistic approach to ingredient selection. While this transition to biocosmetics holds promise for environmental and human well-being, it is also particularly relevant in the context of climate change, as it promotes low-impact production and reduces dependence on fossil-derived ingredients. Continued efforts are needed to improve the efficacy and stability of these products. The limited availability of natural ingredients and additional certification requirements represent ongoing challenges. Future strategies should prioritize ethical certifications and innovative practices from the sourcing of these ingredients to the consumption of these biocosmetics.

Given this growing relevance of sustainability in the cosmetic industry, there is a wide availability of information on the topic, although it is still scattered and poorly organized. This scenario highlights the need for a structured database that gathers qualitative and quantitative information on ingredients, processes, certifications, and socio-environmental impacts in a clear and accessible manner. In addition, relevant directions for future research are proposed, such as cost-benefit analysis of bioprocesses, aiming to identify more viable and sustainable solutions, and the development of new certification models that consider environmental, social, and technological dimensions in an integrated manner. The creation of standardized sustainability metrics, as well as in-depth studies on public policies and tax incentives, can significantly strengthen the biocosmetics ecosystem, promoting greater transparency, standardization, and accountability throughout the entire production chain. Finally, this review highlights the importance of ongoing research and development, fostering innovation and continuous improvement in the cosmetics industry. The gradual shift to biocosmetics represents not only a change in

ingredients, but also an evolution in the conception of beauty and personal care, guided by principles of sustainability, safety, and efficacy.

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