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Chemicals of Concern in Cosmetics: Health, Environmental and Regulatory Perspectives

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KEYWORDS

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ABSTRACT:

Introduction: Cosmetics and personal care products constitute an integral part of daily human exposure to chemical substances, with repeated and long-term application on skin, hair, nails, and mucosal surfaces. The rapid globalization of the cosmetics industry, coupled with increasing product diversity and aggressive marketing, has intensified scientific and regulatory scrutiny regarding the safety of cosmetic ingredients. Emerging evidence indicates that several commonly used compounds—such as preservatives, plasticizers, colorants, UV filters, and fragrances—may pose toxicological risks through dermal absorption, inhalation, or accidental ingestion.

Concerns are further amplified by the detection of undeclared hazardous chemicals and contaminants, particularly in products circulating within poorly regulated or informal markets. Additionally, cosmetics contribute not only to direct human exposure but also to environmental contamination via wastewater discharge and microplastic release. Against this backdrop, a comprehensive evaluation of chemical occurrence, analytical detection, exposure pathways, toxicological implications, and regulatory effectiveness is essential to inform risk assessment and public health protection.

Objectives: The objective of this review is to critically evaluate chemicals of concern present in cosmetics and personal care products by integrating evidence from analytical chemistry, toxicology, biomonitoring, environmental science, and regulatory studies.

Methods: This review is based on a systematic synthesis of contemporary peer-reviewed literature, regulatory documents, and scientific reports. Relevant studies were selected focusing on chemical occurrence in cosmetics, analytical detection methods (including LC-MS, GC-MS, ICP-MS, and non-target screening), toxicological and biomonitoring evidence, and international regulatory approaches.

Data were critically analyzed to compare exposure levels across populations, assess methodological robustness, and identify inconsistencies in regulatory oversight. Emphasis was placed on recent advancements, vulnerable population exposure, and sustainability-oriented alternatives such as green chemistry approaches.

Results: The review reveals widespread presence of multiple hazardous chemicals in cosmetic products, often at concentrations capable of eliciting adverse biological effects. Analytical advancements have significantly improved detection sensitivity; however, methodological variability and lack of harmonized standards limit global comparability. Biomonitoring studies demonstrate disproportionate exposure burdens among women, children, and marginalized populations, particularly in regions with limited regulatory enforcement.

Environmental assessments indicate that cosmetic-derived chemicals persist in aquatic ecosystems, contributing to bioaccumulation and ecological toxicity. Regulatory analysis highlights fragmented governance, insufficient ingredient disclosure requirements, and limited long-term toxicity data for many cosmetic compounds.

Conclusions: The findings of this review underscore critical gaps in cosmetic safety evaluation, environmental risk assessment, and regulatory enforcement. Despite advances in detection, insufficient standardization, limited toxicity datasets, and weak global harmonization continue to undermine effective risk management.

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1. Introduction

Cosmetics and personal care products (PCPs) have become indispensable components of daily hygiene, grooming, and aesthetic practices across diverse cultural and socioeconomic contexts. These products encompass a broad range of formulations, including skincare and hair care products, fragrances, sunscreens, decorative cosmetics, and personal hygiene items. To achieve desirable characteristics such as extended shelf life, stability, fragrance retention, texture, and enhanced performance, cosmetic formulations rely on complex mixtures of chemical ingredients. Although cosmetics are commonly perceived as safe due to their routine use and widespread availability, increasing scientific scrutiny has raised concerns regarding the presence of potentially hazardous substances and their implications for human health and environmental sustainability (Bilal et al., 2020; Das, 2024). Recent advances in analytical chemistry have enabled more comprehensive evaluation of cosmetic formulations, revealing the widespread occurrence of chemical classes of concern. Numerous studies have documented the presence of preservatives such as parabens, plasticizers including phthalates, formaldehyde-releasing agents, ultraviolet (UV) filters, synthetic fragrances, and heavy metals in commercially available cosmetic products. In addition, emerging contaminants such as microplastics and per- and polyfluoroalkyl substances (PFAS) have been increasingly detected, raising new toxicological and environmental concerns (Shen & Jeon, 2024; Keawmanee et al., 2024). Of particular significance is the frequent identification of undeclared or prohibited ingredients, indicating labeling fraud, inadequate quality control, and weak regulatory enforcement mechanisms in several regions (Batinić et al., n.d.; Johnson et al., 2022).

Human exposure to cosmetic related chemicals occurs primarily through dermal absorption, which is facilitated by repeated application and the lipophilic nature of many ingredients. Additional exposure pathways include inhalation of aerosols and fragrances from sprays and powders, as well as incidental ingestion through lip products and hand-to-mouth contact. Importantly, daily use of multiple cosmetic products leads to cumulative and chronic exposure scenarios that are often overlooked in traditional risk assessment frameworks (Resende et al., 2021). Biomonitoring studies have provided compelling evidence of internal exposure, detecting cosmetic-derived chemicals and their metabolites in biological matrices such as urine, hair, and blood. These findings have strengthened concerns regarding endocrine disruption, reproductive toxicity, and long-term health effects associated with sustained exposure (Li et al., 2023; Wang et al., 2024).

Beyond human health implications, cosmetic chemicals represent a significant source of environmental contamination. Following consumer use, many ingredients enter wastewater systems, where conventional treatment processes are frequently insufficient to completely remove persistent and bioactive compounds. As a result, cosmetic-derived chemicals accumulate in surface waters, sediments, and biota, contributing to ecotoxicological effects such as endocrine disruption, altered reproductive function, and impaired growth in aquatic organisms (Giustra et al., 2024; Vita et al., 2023). Despite mounting scientific evidence, cosmetic safety regulation remains highly variable across jurisdictions, resulting in uneven consumer protection and environmental safeguards. While some regions have implemented relatively stringent regulatory frameworks, others continue to permit the circulation of inadequately tested or mislabeled products (Kalofiri et al., 2023; Vieira et al., 2024). Against this backdrop, the present review critically synthesizes current knowledge on chemicals of concern in cosmetics and PCPs, with particular emphasis on analytical advances, toxicological and environmental evidence, exposure disparities among vulnerable populations, and persistent regulatory challenges.

2. Objectives

The primary objective of this review is to comprehensively synthesize existing scientific evidence on hazardous chemical ingredients commonly present in cosmetics and personal care products (PCPs). It aims to critically examine advanced analytical methodologies employed for the detection, identification, and quantification of cosmetic contaminants. The review further evaluates human exposure pathways, biomonitoring findings, and associated short- and long-term health risks. Additionally, it assesses the environmental fate, persistence, and ecological impacts

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of cosmetic-derived chemicals. Finally, the review analyzes existing regulatory frameworks, identifies key governance gaps, and highlights future research directions to promote safer, sustainable, and environmentally responsible cosmetic practices.

3. Methods

This review follows a narrative and integrative methodology, systematically synthesizing evidence from peer-reviewed journal articles, systematic reviews, regulatory documents, and analytical research published predominantly between 2018 and 2025. The selection of literature was guided by its relevance to the chemical composition of cosmetics and personal care products, associated toxicological effects, environmental implications, analytical detection techniques, and existing regulatory frameworks. Emphasis was placed on studies that provided robust scientific data, critical evaluations, or policy-relevant insights into chemical safety and exposure risks related to cosmetic use. Particular attention was given to investigations utilizing advanced analytical technologies, including liquid chromatography–mass spectrometry (LC-MS), gas chromatography–mass spectrometry (GC-MS), inductively coupled plasma mass spectrometry (ICP-MS), and non-target and suspect screening approaches. These techniques were prioritized due to their high sensitivity, accuracy, and capacity to detect trace-level contaminants, undeclared ingredients, and emerging pollutants within complex cosmetic matrices (Serb et al., 2024). Such methodological rigor is essential for reliable identification and quantification of potentially hazardous substances.

In addition to analytical studies, the review incorporates findings from human biomonitoring research that examined internal exposure through biological matrices such as urine, blood, and hair, thereby offering insight into real-world exposure patterns and cumulative health risks. Ecotoxicological studies addressing the environmental fate, persistence, and ecological toxicity of cosmetic derived chemicals were also included to capture broader environmental consequences. Furthermore, regulatory and policy-focused analyses were examined to evaluate the effectiveness of current cosmetic safety governance and to identify existing gaps. Collectively, this integrative approach enables a comprehensive assessment of chemical exposure, health implications, environmental impacts, and regulatory challenges associated with cosmetics and personal care products.

4. Results

Chemical classes of Concern in Cosmetics-

A growing body of scientific literature has consistently documented the presence of multiple hazardous chemical classes in cosmetic and personal care products, raising significant concerns regarding consumer safety and long-term exposure risks. Among these, parabens are the most extensively studied preservatives due to their widespread use and endocrine-disrupting potential. Analytical investigations have reported paraben concentrations as high as 7860 mg/kg in commonly used skincare products, indicating substantial exposure potential through routine application (Shen & Jeon, 2024). Biomonitoring and toxicological studies further associate paraben exposure with hormonal imbalance, reproductive toxicity, and metabolic disturbances.

Phthalates and synthetic fragrance compounds constitute another major category of concern. Frequently employed to enhance fragrance longevity and product flexibility, these substances are often detected as undeclared ingredients, reflecting significant labeling discrepancies. Their chronic exposure has been linked to endocrine disruption, allergic reactions, and developmental toxicity, particularly through cumulative and multi-product use (Johnson et al., 2022; Kazemi et al., 2022). Heavy metals represent a critical toxicological issue in cosmetic formulations. Elements such as lead, cadmium, mercury, nickel, and arsenic have been detected in lipsticks, foundations, eye cosmetics, and traditional beauty products. Elevated concentrations are especially prevalent in products sourced from unregulated or poorly regulated markets, posing neurotoxic, carcinogenic and systemic health risks to users (Ebo et al., 2023; Ahmed et al., 2024).

In addition to these well-documented contaminants, emerging chemical classes such as per- and polyfluoroalkyl substances (PFAS), microplastics, and ultraviolet (UV) filters have increasingly been identified in cosmetic products. These compounds are

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characterized by environmental persistence, bioaccumulation, and potential endocrine-disrupting effects, thereby further complicating the toxicological and ecological profile of modern cosmetic formulations (Giustra et al., 2024; Keawmanee et al., 2024).

Analytical Advances in Cosmetic Safety Assessment-

Contemporary advances in the field of analytical chemistry have improved the detection, identification, and quantification of chemicals found in personal care products. Advanced analytical instruments such as Liquid Chromatography-Mass Spectrometry (LC-MS) analysis and Gas Chromatography by Two-Dimensional Comprehensive Analysis with Time-of-Flight Mass Spectrometry (GC×GC-TOFMS) analyses have become efficient for highly sensitive screening of a large number of chemicals in complex personal care product samples. These analyses are useful for trace-level contaminant detection, transformation compounds, as well as undeclared ingredients of personal care product samples not found in product labels (Shen & Jeon, 2024; Johnson et al., 2022).

Regarding the determination of heavy metal and metalloid composition, inductively coupled plasma mass spectrometry (ICP-MS) and inductively coupled plasma optical emission spectrometry (ICP-OES) remain reference methodologies to measure the levels of heavy metals and metalloids in cosmetic products. The high sensitivity, accuracy, and large dynamic range of these analytical methods enable the determination of toxic heavy metals such as lead, cadmium, and arsenic, which are applicable to both carcinogenic and noncarcinogenic evaluation models (Kicińska & Kowalczyk, 2025). In spite of these improvements in research methodology, challenges remain. There is heterogeneity in sample preparation techniques, extractability, detection limits, and quality control practices, creating challenges. Lack of standardized approaches to analysis limits compatibility between research studies, making it a limitation to regulatory use of research data (Serb et al., 2024). Improvements through standardized research approaches and standard operating procedures must be sought to enhance research value and research contributions towards global cosmetic safety surveillance.

Human Exposure Pathways and Associated Health risks-

Personal exposure to dangerous chemicals in cosmetics and personal care products takes place mainly through the skin by absorption, inhalation, and incidental ingestion. The skin acts as a semi-permeable membrane since it facilitates the passage of lipophilic chemicals such as parabens, phthalates, and fragrances into the bloodstream, mainly when the products are used on a larger skin surface area and through damaged skin (Resende et al., 2021). Perfumes, sprays, and powder products increase exposure through inhalation pathways, in addition to exposure through ingestion in lipstick and dental care products. Biomonitoring studies also show convincing evidence for internal exposure from cosmetic use. Urine, blood, and hair analyses revealed various cosmetic-related chemical residues, such as parabens and heavy metals, which demonstrate long-term exposure patterns in regular users (Li et al., 2023; Wang et al., 2024). In particular, exposure dose depends on age, gender, socioeconomic, and use practices. Increased product use and lack of regulation contribute to higher body burdens among women of color and in unregulated markets (Johnson et al., 2022; “Chemicals of concern in personal care products”, 2023). According to Ahmed et al. (2024) and Ullah et al. (2023), the health risks of using cosmetics derived from human body chemistry include endocrine disruption, reproductive toxicity, neurotoxicity, and allergic sensitization as well as possible carcinogenic effects. Parabens and phthalates have been associated with hormonal problems and developmental disabilities, while heavy metals such as lead and mercury carry a risk of neurological and renal health issues. Due to the inherent complexity of real-world exposure to mixtures of multiple chemicals, we are still not able to understand or predict the additive or cumulative toxic effects of these mixtures over time. Therefore, we need longitudinal studies and integrated risk assessment models that are reflective of what actual consumers are exposed to.

Environmental Fate and Ecotoxicological Impacts of Cosmetic- Derived Chemicals-

A substantial but frequently overlooked factor causing chemical pollution in the environment is cosmetics and personal hygiene products. Many substances in cosmetics find their way into wastewater systems after

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being used by consumers through bathing, washing, and product disposal. Because complex organic materials are not particularly removed by traditional wastewater treatment facilities, residual chemicals, UV filters, aromatic compounds, microplastics and heavy metals are released into waterways and contaminants (Giustra et al., 2024; Khalid & Abdollahi, 2021). Parabens, triclosan, bisphenols and UV filters have been shown in numerous studies to endure in aquatic environments, where they bioaccumulate and harm the aquatic ecosystem. Even at ecologically relevant levels these compounds have been connected to endocrine disruption, poor development, and changed growth patterns in fish, invertebrates, and algae (Barabasz et al., 2019; Vita et al., 2023). By serving as carriers for hydrophobic pollutants and microbes, microplastics used as exfoliants or fillers increase toxicity within aquatic ecosystems and worsen threats to the environment (Giustra et al., 2024).

Because of their extreme persistence, resistance to degradation, and long-range environmental transport, recently discovered pollutants like per- and polyfluoroalkyl substances (PFAS) present further difficulties. Issues regarding long-term ecosystem exposure and biomagnification have been raised by the discovery of these compounds in surface waters, sediments, and biota (Keawmanee et al., 2024). Even though these risks are becoming more widely acknowledged, there are still few field-based ecotoxicological studies and little environmental monitoring data, especially in low- and middle-income areas. In order to reduce permanent ecological damage, the harmful effects of chemicals derived from cosmetics emphasizes the urgent need for enhanced sewage treatment technologies, thorough ecological danger assessments, and more stringent regulation of ecologically continuing ingredients used in cosmetics.

5. Discussion

The results of the investigation highlight serious flaws in the present safety governance structure by showing a recurring and globally significant trend in chemical exposure in cosmetic and personal care products. Regulatory control is still disjointed and, in many areas, inadequate to sufficiently protect the environment and public health despite mounting scientific evidence identifying hazardous ingredients, such as parabens, phthalates, heavy metals, UV filters, and emerging contaminants. Analytical chemical advancements have significantly enhanced the identification of undetected chemicals and minor contamination, but regulatory frameworks have not developed at the same rate, especially when it comes to handling prolonged exposure scenarios and mixture toxicity resulting from daily use of multiple products (Santamaria et al., 2023). This review raises important concerns about how little real-world exposure factors are taken into account in current risk assessment models. The majority of regulatory assessments concentrate on evaluating individual compounds separately, ignoring the cumulative and combined impacts that arise when consumers are exposed to complex chemical mixtures for prolonged periods of time. Given the growing body of biomonitoring data showing the internal presence of several chemicals derived from cosmetics in human biological matrices, this gap is particularly problematic. Establishing clear associations between cosmetic exposure and lasting medical results, such as hormonal imbalances, reproductive issues, and carcinogenic risks, is further hampered by the lack of long-term epidemiology research.

Another significant regulatory failure is the pervasiveness of unidentified components and labelling scams. Disparities between declared ingredient lists and actual chemical content have been reported in various studies, especially in products sold in less developed or unregulated areas (Batinic et al., n.d.; Ullah et al., 2023). Such actions not only erode consumer confidence but also make it more difficult to make educated decisions and effectively reduce exposure. Higher product usage patterns and restricted access to more secure options significantly affect vulnerable groups, such as women of color, children, and consumers from low-income backgrounds. Additionally, the growing trend of "natural," "organic," or "green" cosmetics has not always resulted in increased preservation of the environment or safety. These assertions frequently lack rigorous toxicological evaluation, standardized certification, or empirical proof, which raises questions about greenwashing and deceptive marketing techniques (Manful et al., 2024). Consumer safety initiatives are made more difficult by the lack of precise legislative standards for "natural" cosmetics. Overall, the findings highlight the urgent need for consistent international regulations, better post-market monitoring, mandatory

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full ingredient disclosure, and the inclusion of mixture toxicity and long-term exposure in risk assessment frameworks. Strengthening collaboration among scientists, regulators, and industry stakeholders is crucial to connect scientific evidence with effective cosmetic safety management.

Cosmetic safety regulations differ from country to country. This has caused a large gap in protecting consumers as far as cosmetic safety is concerned. The European Union can be considered one of the leaders in this sector because it has taken numerous legislative actions like the ban on animal testing, safety evaluation of cosmetic products, restricted use of certain ingredients, and certain provisions related to endocrine-disrupting substances. However, it has been noticed that there is lack of reporting of adverse reactions, lack of post-market surveillance, and delayed updating of regulatory lists according to new scientific findings (Vieira et al., 2024).

On the other side, regulatory regimes in many low- and middle-income countries are either fragmented or poorly enforced, giving way to cosmetic products containing hazardous or prohibited ingredients in local markets. Generally, weak quality control mechanisms limit laboratory capacity and ensure scant regulatory oversight; therefore, unsafe and mislabelled products are widely circulated among poor and vulnerable populations. The lack of harmonized standards on product safety further complicates cross-border trade and regulatory accountability. These challenges demand urgent international harmonization of cosmetic safety regulations. Improvement in post-market surveillance systems, introduction of compulsory full ingredient disclosure, and complete transparency along the supply chains are some of the key steps toward consumer protection. Furthermore, the adoption of NAMs-in vitro, in silico, and computational toxicology tools-promises to offer innovative, non-animal-test-based ways of analysing chronic toxicity and mixture effects. As underlined by Pistollato et al. (2021) and Kalofiri et al. (2023), these measures are necessary for an internationally harmonized, science-based approach to cosmetic safety governance.

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