Skin-Type Oriented Analysis Of Cosmetic Ingredients: A Review Of Methods, Limitations, And Emerging Consumer-Centric Approaches

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Abstract- *The need for cosmetic products has gone up, so there's more focus on being clear about what's in them and making sure they're safe. Many products say they work for different skin types, but people usually choose them based on brand and ads instead of looking at the science behind the ingredients. Most studies on cosmetics look at chemicals, safety, or how ingredients are grouped, but they don't often look at how well they work for specific skin types like oily, dry, sensitive, or acne-prone skin.*

This review looks at the methods used to check cosmetic ingredients, including how they're classified, safety tests, assumptions about ingredient order, and new data-based techniques.

It pays special attention to how different ingredients affect various skin types. The review also points out the main problems with current studies, like not having ways to test products across many skin types from the user's point of view.

By combining information from dermatology, cosmetic science, and computer-based research, this review shows the need for more flexible and personalized ways to evaluate cosmetics. The findings are meant to help guide future studies and support better choices for consumers based on their skin type.

Keywords: Cosmetic ingredients, Skin-type specific analysis, Ingredient transparency, Consumer-centric evaluation, Skincare products, Cosmetic safety, Personalized skincare

I. INTRODUCTION

The global cosmetic and skincare industry has witnessed significant growth in recent years, accompanied by increased consumer awareness regarding product ingredients and their potential effects on skin health. Regulatory guidelines in many regions mandate the disclosure of ingredient lists, encouraging transparency and enabling informed consumer choices. Despite this availability of information, most consumers lack the scientific knowledge required to interpret ingredient lists effectively, leading to product selection based primarily on branding, pricing, and marketing claims rather than ingredient suitability.

Cosmetic products are typically formulated to address specific skin concerns; however, individual skin types such as oily, dry, sensitive, and acne-prone skin respond differently to the same ingredients. Certain ingredients that are beneficial for one skin type may cause irritation or reduced effectiveness in another. While dermatological research has extensively studied individual ingredients and their safety profiles, the evaluation of cosmetic products as a whole remains largely generic, without adequate consideration of skin-type specific interactions.

Existing research in cosmetic science primarily emphasizes chemical characterization, formulation analysis, and safety assessment of cosmetic ingredients. Several studies also explore the dermatological effects of active compounds and the role of preservatives and fragrances in skin sensitivity. More recently, computational and data-driven approaches have been introduced to analyze cosmetic ingredient lists and product similarities. However, these approaches often focus on ingredient presence or similarity metrics, rather than assessing product suitability across different skin types.

As a result, there exists a significant gap between ingredient transparency and practical consumer decision-making. Current literature lacks comprehensive review and synthesis of methods that address skin-type oriented cosmetic evaluation. This review aims to analyze and consolidate existing studies related to cosmetic ingredient evaluation, highlight their limitations with respect to skin-type specificity, and emphasize the emerging need for consumer-centric and adaptive cosmetic assessment frameworks.

II. LITERATURE REVIEW

Cosmetic Ingredient Classification: Existing Studies

Cosmetic ingredients are commonly classified based on their functional roles within formulations. Existing research broadly categorizes them into active ingredients, base or supportive ingredients, preservatives, and sensory additives such as fragrances and colorants, providing the foundation for most ingredient-based evaluations reported in the literature. Active ingredients are intended to deliver specific skin benefits, including hydration, exfoliation, oil control, or anti-aging effects, with examples such as niacinamide, salicylic acid, retinoids, alpha hydroxy acids, and hyaluronic acid. Draelos (2018) emphasized ingredient efficacy for oily and dry skin types but primarily focused on single skin-type studies, while Barel et al. (2014) highlighted moisturizing and barrier-supportive actives for dry skin. Base ingredients, including water, emollients, humectants, and emulsifiers, constitute the majority of formulations, with research focusing on stability, texture, and delivery mechanisms. Draelos (2013) and Loden (2003) reported on emollient and humectant performance for dry and sensitive skin, though without multi-skin-type comparisons. Preservatives such as parabens, phenoxyethanol, and organic acids are critical for preventing microbial contamination. Fiume et al. (2019, 2020) extensively reviewed preservative safety, but their impact across different skin types remains largely unexplored, although sensitivity in sensitive skin was noted by Sanchez et al. (2019). Fragrances and certain botanical extracts can trigger irritation, particularly in sensitive and acne-prone skin. Elsner and Maibach (2005) identified fragrances as leading causes of contact dermatitis, yet most studies evaluated fragrances in isolation rather than within the context of full formulations.

Table 1: Summary Table of Literature Review

Study	**Methodology**	**Key Findings**	**Limitations**
Draelos (2018)	Literature review	Highlighted ingredient effects per skin type	Single skin-type focus, no integrated evaluation
Pavlis et al. (2017)	Computational similarity analysis	Clustered products by ingredient overlap	Skin-type specificity ignored
Barel et al. (2014)	Clinical studies	Emollients improve hydration effectively	Limited to dry skin, small sample size
Elsner & Maibach (2005)	Experimental review	Fragrances major cause of irritation	No cross-skin-type comparison
Wang et al. (2021)	Machine learning clustering	Identified formulation trends	Did not assess suitability, only similarity
Draelos (2013)	Clinical studies	Improves skin hydration and barrier	No multi-skin-type comparison
Fiume et al. (2019, 2020)	Regulatory review	Safety guidelines and toxicity data	Cross-skin-type evaluation missing
Sanchez et al. (2019)	Literature review	Identified irritants in sensitive skin	Single skin-type focus

III. PROPOSED METHODOLOGY

Ingredient Order and Concentration Assumptions in Cosmetic Research

Cosmetic products usually list their ingredients using a system called INCI, which stands for International Nomenclature of Cosmetic Ingredients. In this system, ingredients are listed in the order they appear in the product, starting with the one that is used in the biggest amount and ending with the one that is used in the smallest amount. Many regulatory bodies and studies agree that the earlier an ingredient is listed, the more of it is in the product, and the later it is listed, the less of it is there. This way of ordering ingredients is commonly accepted as a way to show which ingredients are most important in a product.

A lot of research uses whether an ingredient is present or not as a main way to evaluate it, especially when checking for safety or looking at specific ingredients.

Some studies also consider the order of ingredients, especially when talking about ingredients that might be risky, like preservatives, fragrances, or allergens. However, most of the time, the order is treated more like a general idea rather than something that can be measured exactly. Not much effort is made to turn the position of an ingredient into a clear, measurable level of importance or comparison.

A few studies that use computers and data have looked at the order of ingredients to find patterns or similarities between products.

These studies often look at how often ingredients appear together or how common they are to group different

products. While these methods give some idea of how products are made, they don't directly look at how much of an ingredient is in the product or how its position affects how well it works for different skin types.

Also, not all studies use the idea that ingredient order shows how much of it is in the product. Many reviews talk about the effects of ingredients without checking if they are a main part or a small part of the product. This can make it harder for people to use ingredient-based information when deciding what products to buy because the same ingredient can have different effects depending on how much of it is in the product.

In general, cosmetic research knows that ingredient order is an important part of being clear about what's in a product.

However, there isn't a standard way to use this information when comparing products or looking at how they work for different skin types. This shows that there is a need for better, organized methods that take into account where ingredients are placed when looking at cosmetic ingredient lists.

Skin Sensitivity and Skin-Type Focused Cosmetic Studies

Skin type is very important in deciding how well a cosmetic product works for someone. In dermatology, skin is usually divided into four main types: oily, dry, sensitive, and acne-prone. This classification is based on how much oil the skin produces, how well it protects itself, how hydrated it is, and how it reacts to inflammation. A lot of studies have looked into how different ingredients in cosmetics work with each skin type, especially when it comes to causing irritation, being tolerated, and being effective for treatment.

Most research on sensitive skin looks for ingredients that might cause problems, like redness, itching, or skin rashes.

Things like fragrances, alcohol, and some preservatives are often linked to these reactions. These studies usually suggest avoiding certain ingredients but test products on their own, without comparing them to other skin types.For acne-prone skin, there's a lot of research about ingredients that help control oil and reduce inflammation.

Common ingredients studied include salicylic acid, benzoyl peroxide, and niacinamide. While these studies show what works for acne, they often don't look at how the same products might affect other skin types, like dry or sensitive skin. Research on oily and dry skin usually focuses on ingredients that help moisturize, repair the skin barrier, and control oil. For dry skin, things like emollients, humectants, and occlusives are tested, while for oily skin, ingredients that absorb oil and give a matte finish are studied. But these studies are usually focused on specific goals and don't look at how the same product might work on different skin types.

Overall, most studies on skin types look at one type at a time. There's not much research that checks how a single product might work on different skin types together. This way of looking at things makes it hard for people to get clear advice on which products are best for their skin.

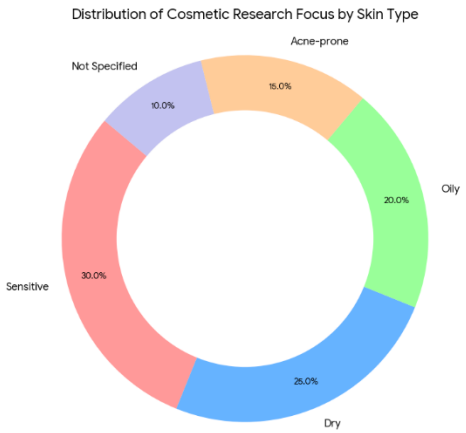

Figure 1: Skin-Type Distribution of Ingredient Focus

Data-Driven and Computational Approaches in Cosmetic Ingredient Analysis

The images have only one color channel, which makes the model simpler by focusing solely on the brightness levels of each pixel. Before training, the pixel values are adjusted so they fall With the increasing availability of digital cosmetic databases and ingredient repositories, recent research has begun incorporating data-driven and computational techniques to analyze cosmetic products. These studies primarily aim to process large volumes of ingredient data efficiently and identify patterns within cosmetic formulations.

Several computational approaches focus on ingredient frequency analysis, similarity measurement, and clustering of cosmetic products based on shared ingredients. Techniques such as vector representation of ingredient lists, cosine similarity, and unsupervised clustering algorithms have been employed to group products with comparable formulations. These methods are useful for identifying formulation trends and market similarities but do not address product suitability for individual users.

Some studies have attempted to develop basic recommendation systems for skincare products using ingredient data and user preferences. However, these systems often rely on simplified assumptions, such as avoiding a predefined list of “harmful” ingredients or matching products based on ingredient overlap. Skin-type variability is either minimally considered or treated as a static attribute rather than a dynamic evaluation factor.

Machine learning-based research in cosmetic analysis has also explored ingredient embeddings and visualization techniques to understand relationships between formulations. While such approaches demonstrate the potential of computational tools in cosmetic research, their primary objective remains product similarity or classification rather than skin-type specific performance assessment.

Overall, existing data-driven cosmetic studies emphasize automation and scalability but lack dermatological context and consumer-centric evaluation logic. The distinction between identifying similar products and determining suitable products for different skin types is often overlooked. This limitation highlights the need for integrative frameworks that combine ingredient analysis, skin-type sensitivity, and consumer relevance.

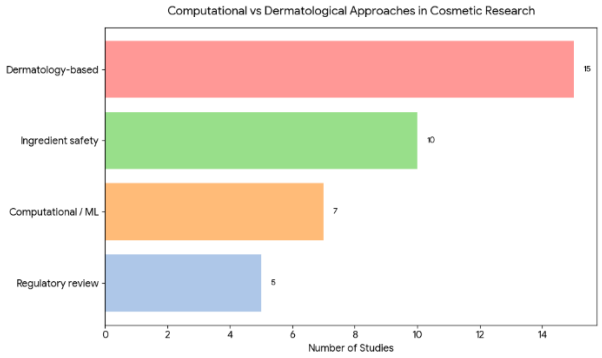

Figure 2: Computational vs Dermatological Approaches

IV. LIMITATIONS

Limitations of Existing Cosmetic Ingredient Evaluation Research

As more digital cosmetic databases and ingredient lists become available, recent studies are using data-driven and computer-based methods to examine cosmetic products. These studies mainly focus on handling large amounts of ingredient information quickly and finding common patterns in product formulas. Many computer-based methods look at how often ingredients appear, measure how similar products are based on their ingredients, and group products that share similar ingredients. Techniques like turning ingredient lists into numerical data, using cosine similarity to compare ingredients, and applying clustering algorithms to sort products have been used to find products with similar formulas. These methods help spot trends and similarities in the market, but they don't help determine whether a product is right for a specific person. Some studies have tried to create simple recommendation systems for skincare products using ingredient data and user preferences. However, these systems often make simple assumptions, like avoiding a list of "harmful" ingredients or matching products based on shared ingredients. Skin type differences are either barely considered or treated as a fixed trait rather than something that changes based on individual needs. Research using machine learning in cosmetic analysis has also looked into ingredient embeddings and visualization tools to better understand how different formulas relate to each other. Though these methods show the potential of using computers in cosmetic research, their main goal is usually to find similar products or classify them, not to assess how well they work for different skin types. In general, current data-driven studies in cosmetics focus on making processes faster and more efficient. However, they often lack real-world skin care knowledge and don't take into account what consumers really need. The difference between finding similar products and finding the right product for a specific skin type is often ignored. This shows that there's a need for better systems that combine ingredient analysis, how skin reacts to ingredients, and what's important to consumers.

Emerging Need for Consumer-Centric and Skin-Type Adaptive Cosmetic Evaluation

The issues found in earlier sections show a big chance to create better, customer-focused ways to assess cosmetic products. Studies have given useful information about what's in products, how safe they are, and how they work with different skin types. But these findings are usually separate and not used to help a wide range of people make choices. People still mostly decide what to buy based on what companies say and how well-known a product is, not on whether it's right for their skin. There’s a bigger push for systems that can not only sort out ingredients but also figure out if they're good for different skin types. These systems should consider things like how much of an ingredient is used, if it might irritate skin, and if it actually works. Also, new tech and data tools can help analyze cosmetics on a larger scale. Ut putting in skin type details, how ingredients work, and medical knowledge into these tools is still not well explored. Doing this could help give personalized, science-based advice, connecting clear product info with real help for consumers. So, the main need is to build evaluation methods that mix scientificchecks of ingredients, how they fit different skin

types, and what customers care about. Handling this need can guide future research, help people make better choices, and could even form the base for smart recommendation tools.
Addressing this gap requires a more integrated and user-centered evaluation framework that brings together ingredient science, dermatological knowledge, and consumer priorities in a single, accessible system. Such a framework would move beyond simple ingredient lists or safety labels by translating complex scientific data into practical insights tailored to individual skin needs and concerns.

V. CONCLUSION AND FUTURE WORK

Cosmetic ingredient evaluation has been studied a lot, with research covering things like how safe ingredients are, how they mix together in products, what they do to the skin, and using computer methods to analyze them. But there are still some problems with the current studies. For example, they don't always look at how different skin types react, they don't focus enough on what consumers need, and they don't take into account the order or amount of ingredients in a product. This review shows that we need better ways to evaluate cosmetics that look at more than just what's in the product.

We should also consider things like which skin types the product is best for, what might irritate the skin, and how the whole formula affects the user. By bringing together skin science, how ingredients are arranged, and using data and computer tools, we can create more complete and tailored ways to evaluate cosmetics.

Looking ahead, research should focus on creating better methods that connect ingredient information with real-life use for people.

Some ideas include:

1. Making scoring models that work for different skin types, like oily, dry, sensitive, or acne-prone skin.
2. Looking at how much and in what order ingredients are used to better predict how well a product works and if it might cause irritation.
3. Using data and computers along with skin science to create bigger, more personalized ways to assess cosmetics.
4. Developing tools that are easy for consumers to use, like apps or recommendation systems, to help them make smart choices.

By following these directions, future work can change how we evaluate cosmetics from a general, one-size-fits-all approach into something that's personal, based on evidence, and focused on what consumers really need.

Overall, while cosmetic ingredient evaluation has made significant progress, current approaches remain largely reductionist, focusing on isolated ingredients rather than the lived experience of real users. Most existing studies emphasize safety thresholds, individual ingredient functions, or computational predictions in controlled settings, but they often fail to reflect how products are actually formulated, applied, and perceived by diverse populations. Skin is highly variable across individuals due to differences in genetics, age, environment, lifestyle, and underlying conditions, yet these factors are rarely integrated into evaluation frameworks. In addition, consumer priorities—such as comfort, long-term skin health, tolerability, and perceived effectiveness—are often treated as secondary outcomes rather than central evaluation criteria. Ignoring ingredient order and concentration further limits predictive accuracy, as formulation structure strongly influences bioavailability, skin penetration, synergistic effects, and irritation potential.

To address these gaps, future cosmetic evaluation systems must move beyond static ingredient lists and adopt a more holistic, user-centered perspective. This includes incorporating skin-type–specific responses, recognizing cumulative and interactive effects within formulations, and linking laboratory findings with real-world usage data. Advances in data science, artificial intelligence, and dermatological research offer powerful opportunities to integrate large-scale ingredient databases, clinical evidence, and consumer feedback into dynamic evaluation models. Such models could not only assess safety and efficacy more realistically but also support personalized recommendations tailored to individual skin needs and sensitivities. Ultimately, by aligning scientific rigor with consumer relevance, next-generation cosmetic evaluation frameworks can enhance transparency, trust, and decision-making, transforming cosmetic assessment into an evidence-based, personalized, and practical tool for both researchers and end users.

Furthermore, adopting these advanced evaluation frameworks could also benefit regulators, formulators, and brands by providing more nuanced guidance for product development and risk assessment. Rather than relying solely on standardized safety benchmarks, stakeholders could use integrated models to identify potential formulation weaknesses early, optimize ingredient combinations for specific skin profiles, and reduce adverse reactions before products reach the market. This shift would encourage innovation that is both scientifically grounded and ethically responsible, while also improving communication between industry and consumers.

In the long term, a more transparent and personalized cosmetic evaluation ecosystem could foster greater consumer confidence, support sustainable formulation practices, and promote healthier relationships between users and the products they choose to apply to their skin.

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