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# Herbal Cosmeceuticals in Sudan: An Integrative Review of Phytochemical Properties and Industrial-Economic Opportunities

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**A B S T R A C T**

**Objective:** Herbal cosmeceuticals are gaining global attention due to their multifunctional, safe, and sustainable properties. Sudan, endowed with rich biodiversity and ethnobotanical heritage, hosts numerous medicinal plants traditionally used for skin and hair care. However, scientific validation, standardization, and industrial development of these plants remain limited. This review systematically identifies Sudanese medicinal plants with cosmeceutical potential, evaluates their phytochemical and pharmacological evidence, and explores industrial and economic opportunities.

**Methods:** A systematic search was conducted across PubMed, Scopus, Web of Science, ScienceDirect, Google Scholar, and AJOL up to August 2025. Boolean operators were used, and inclusion/exclusion criteria were applied following PRISMA guidelines. Study quality was assessed using CASP and AMSTAR 2 tools.

**Results:** Fifteen Sudanese medicinal plants were identified, with Nigella sativa, Lawsonia inermis, and Adansonia digitata being the most frequently studied. These plants exhibited antioxidant, anti-inflammatory, antimicrobial, moisturizing, and hair-strengthening effects. However, most evidence derived from in vitro and animal studies, with limited clinical validation and no standardized industrial formulations. SWOT analysis highlighted opportunities (biodiversity, global market demand, women's empowerment) and challenges (regulatory gaps, limited infrastructure, lack of standardization).

**Conclusion:** Sudanese medicinal plants possess strong potential for developing innovative herbal cosmeceuticals. Future research should focus on clinical validation, standardization protocols, and industrial feasibility. Harnessing these resources could promote therapeutic innovation, empower local communities, and enhance Sudan's role in the global "green beauty" market.

**Keywords:** Herbal cosmeceuticals, Sudanese medicinal plants, Phytochemistry, Dermatological applications, Industrial and economic opportunities

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## Introduction

The global demand for herbal cosmeceuticals has been increasing rapidly, with the market projected to exceed USD 80 billion by 2030 [1]. This growth is driven by consumer preferences for natural, safe, and multifunctional products. Herbal cosmeceuticals, derived from bioactive phytochemicals, provide therapeutic benefits such as antioxidant, anti-inflammatory, antimicrobial, wound-healing, and anti-aging effects [2–7].

Sudan is home to more than 3,000 species of flowering plants, many of which are traditionally used for skin, hair, and body care [8]. Examples include Lawsonia inermis for hair coloring, Nigella sativa oil for skin nourishment, and Adansonia digitata pulp for hydration [9]. Despite this rich ethnobotanical heritage, limited scientific validation, lack of standardization, and minimal industrialization hinder their integration into the global cosmeceutical market [10].





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Research gaps remain significant. Most available evidence is based on in vitro or animal studies, while clinical validation and industrial feasibility studies are scarce [11]. Regulatory frameworks for herbal cosmetics in Sudan are also underdeveloped, reflecting similar challenges reported across many developing countries [12].

This review aims to: (i) document Sudanese medicinal plants with cosmetic applications, (ii) critically analyze their phytochemical and pharmacological evidence, and (iii) explore industrial and economic opportunities. The review follows the PRISMA guidelines to ensure methodological transparency and reliability [13].

## Methods for Review
### Type of Review

This study was conducted as a systematic integrative review, combining ethnobotanical reports, phytochemical analyses, pharmacological studies, and economic perspectives of Sudanese medicinal plants with cosmeceutical potential. The review methodology was guided by the PRISMA statement to ensure transparency and reproducibility [14].

### Search Strategy

A comprehensive literature search was conducted across PubMed, Scopus, Web of Science, ScienceDirect, Google Scholar, and African Journals Online (AJOL) from inception until August 2025. The following Boolean operators and keyword combinations were used: ("herbal cosmetics" OR "herbal cosmeceuticals") AND ("Sudan" OR "Sudanese medicinal plants") AND ("skin care" OR "hair care" OR "dermatology"). Filters were applied to include peer-reviewed articles published in English or Arabic. Additional manual searching of reference lists, Sudanese theses, and local reports was performed to capture grey literature.

### Inclusion Criteria

Studies were considered eligible if they:

Reported on Sudanese plants with documented cosmetic or dermatological applications.

Included ethnobotanical knowledge, phytochemistry, pharmacological activity, or clinical evaluation.

Were peer-reviewed publications in English or Arabic.

### Exclusion Criteria
### Studies were excluded if they

Focused on plants outside Sudan without direct local relevance.

Reported unrelated therapeutic uses not linked to cosmetic applications.

Were non-peer-reviewed sources unless ethnobotanical data were validated by other references.

### Study Selection and Screening

All identified records were imported into EndNote software, and duplicates were removed. Titles and abstracts were screened independently by two reviewers for relevance. Full texts of potentially eligible studies were then assessed against the inclusion and exclusion criteria. Discrepancies were resolved through discussion and consensus.

### Quality Assessment

The methodological quality of included studies was evaluated using the Critical Appraisal Skills Programme (CASP) checklist for qualitative and observational studies, and AMSTAR 2 for systematic reviews. Each study was assessed for transparency of methods, reproducibility, and validity of results. Most studies were of moderate quality, with only a few meetings high-quality criteria. A summary of the appraisal is presented in Table 1.

**Table 1:** Summary of quality assessment of included studies using CASP and AMSTAR 2 tools

| Study type | Number of studies | High quality | Moderate quality | Low quality | Common limitations |
|---|---|---|---|---|---|
| Ethnobotanical studies | 10 | 2 | 6 | 2 | Reliance on self-reported field data, lack of standardized documentation |
| Phytochemical studies | 12 | 4 | 6 | 2 | Inconsistent analytical methods, absence of reference marker compounds |
| Pharmacological (in vitro/in vivo) | 15 | 3 | 9 | 3 | Small sample size, lack of reproducibility, absence of clinical validation |
| Systematic reviews | 2 | 1 | 1 | – | Limited number of Sudanese-focused studies, methodological weaknesses |

## Data Extraction and Analysis

For each eligible study, data were extracted on:

Scientific and local names of plants.

Plant parts used (e.g., leaves, seeds, oils, resins).

Reported bioactive phytochemicals.

Traditional cosmetic uses (skin, hair, body).

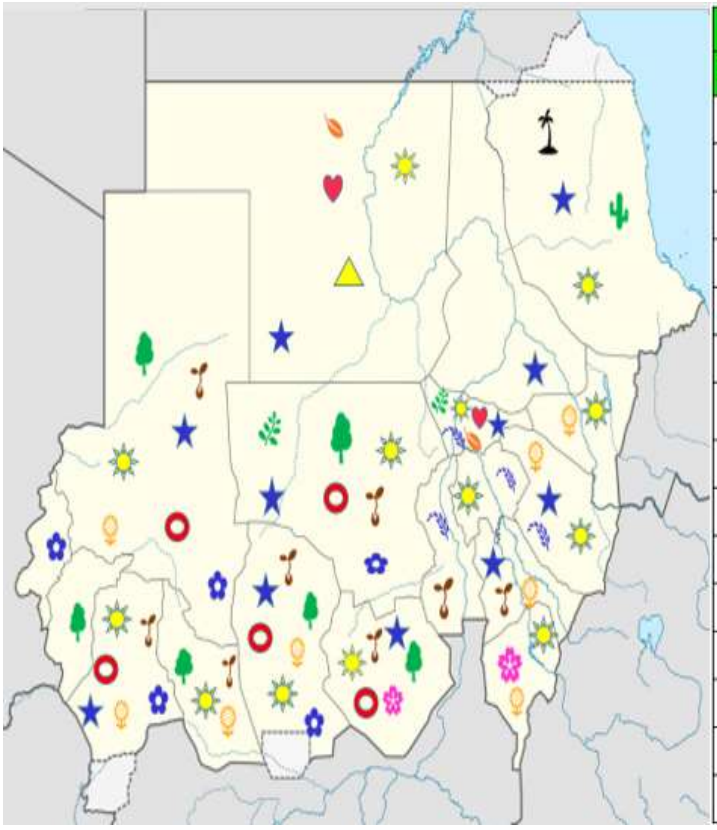
Validated biological activities (**in vitro**, **in vivo**, or clinical).

The data were synthesized by comparing ethnobotanical knowledge with validated scientific evidence. Plants were categorized based on their pharmacological strength (e.g., antioxidant, antimicrobial, anti-inflammatory) and industrial feasibility.

## Results

## Geographic Mapping

The map shows major regions where selected plants are traditionally used for skincare, haircare, and body beautification.
Shaded areas indicate the prevalence of plant use in different regions, highlighting local knowledge and cultural practices. Traditional applications include treatments for skin hydration, hair strengthening, and natural cosmetic preparations (Figure 1).



| Map Symbols for Plant Distribution | | |
|---|---|---|
| Symbol | Plant Name | Region on Map |
| | *Adansonia digitata* | Kordofan &Darfur regions |
| | *Nigella sativa* | Northern State & Khartoum State |
| | *Lawsonia inermis* | River Nile State |
| | *Aloe sinkatana* | Red Sea State |
| | *Hibiscus sabdariffa* | Kordofan &Darfur regions |
| | *Balanites aegyptiaca* | Darfur , Kordofan , Blue Nile, and White Nile states |
| | *Sesamum indicum* | Kordofan and Darfur states , Gedarif, Damazine, Sinnar, Kassala, and Renk |
| | *Ziziphus spina-christi* | *North Kordofan and Khartoum State* |
| | *Ricinus communis* | All parts of Sudan |
| | *Mentha piperita* | central Sudan |
| | *Eruca sativa* | All parts of Sudan |
| | *Senna alexandrina* | Northern State & Khartoum State |
| | *Boswellia serrata* | Blue Nile and Southern Kordofan. |
| | *Cymbopogon citrate* | Red Sea State |
| | *Lupinus albus* | Kordofan &Darfur regions |

**Figure 1. Geographic distribution of Sudanese medicinal plants with potential cosmeceutical applications.** *The map shows major regions where selected plants are traditionally used for skincare, haircare, and body beautification.*

## Herbal Cosmeceuticals: Global Perspective

The concept of cosmeceuticals emerged in the late 20th century to describe cosmetic products containing bioactive compounds with therapeutic or drug-like properties [13]. These products occupy a unique position between cosmetics and pharmaceuticals, offering both aesthetic enhancement and dermatological benefits. Unlike conventional cosmetics, which are primarily designed for beautification, cosmeceuticals provide functional outcomes such as anti-aging, photoprotection, moisturization, acne prevention, and hair strengthening [14].

Globally, the demand for herbal cosmeceuticals has increased significantly, driven by rising consumer preference for natural and sustainable products. The herbal cosmetics market is projected to grow at an annual rate of 7–9%, surpassing synthetic cosmetics in many developing economies [15]. Factors contributing to this trend include increasing awareness of the side effects of synthetic chemicals, growing interest in "green beauty," and cultural traditions that favor natural remedies [16].

Plants remain the most abundant and sustainable source of cosmeceutical ingredients. Bioactive phytochemicals such as flavonoids, alkaloids, terpenoids, tannins, saponins, and essential oils contribute to a wide range of cosmetic effects, including antioxidant, antimicrobial, anti-inflammatory, wound-healing, and photoprotective activities [17]. For example, Aloe vera has been incorporated into moisturizers and sunburn products due to its hydrating and soothing effects; green tea polyphenols are used in anti-aging creams for their strong antioxidant activity; while curcumin from turmeric has found application in formulations targeting hyperpigmentation and skin inflammation [18].

Herbal cosmeceuticals also align with the modern principles of sustainability and eco-friendliness. Many consumers now prefer products labeled "chemical-free," "paraben-free," or "derived from natural ingredients," reflecting a wider societal movement toward green lifestyles and circular economies [19]. At the same time, multinational cosmetic companies are investing heavily in ethnobotanical research, bioprospecting, and the development of plant-based formulations to expand their product portfolios and meet the increasing global demand [20].

Despite these advances, the global cosmeceutical industry faces several challenges, including variability in raw material quality, lack of standardization, limited clinical validation, and

regulatory ambiguity in defining and marketing herbal cosmetics. Addressing these issues requires harmonized regulations, rigorous scientific evaluation, and sustainable sourcing of plant materials to ensure both consumer safety and environmental protection [21].

## Identified Plants and Their Properties

A total of fifteen Sudanese medicinal plants with potential cosmeceutical applications were identified. These species demonstrated diverse biological activities, including antioxidant, anti-inflammatory, antimicrobial, moisturizing, and hair-strengthening effects. The most frequently studied plants were *Nigella sativa*, *Lawsonia inermis*, and *Adansonia digitata*. However, most evidence was derived from **in vitro** and animal studies, with limited clinical validation or standardized formulations.

To enhance readability, the data have been organized into two tables 2 and 3.

**Table 2:** Widely studied Sudanese medicinal plants with established cosmeceutical relevance

| Plant (Scientific name) | Part Used | Major Bioactive Compounds | Traditional Use | Scientific Evidence (Refs) |
|---|---|---|---|---|
| *Lawsonia inermis* (Henna) | Leaves (powder/paste) | Lawsone (2-hydroxy-1,4-naphthoquinone) | Hair dye, nail coloring, skin cooling | Antimicrobial, coloring validated [21,22] |
| *Nigella sativa* (Black seed) | Seeds, oil | Thymoquinone, alkaloids, flavonoids | Acne treatment, skin nourishment, hair strengthening | Antioxidant, antimicrobial, anti-inflammatory [23,24] |
| *Aloe sinkatana* (Sudanese Aloe) | Leaves (gel, latex) | Amino acids, saponins, vitamins | Moisturizer, sunburn, wound treatment | Antioxidant, wound healing [25,26] |
| *Hibiscus sabdariffa* (Karkadeh) | Flowers, seeds | Anthocyanins, flavonoids, AHAs | Skin brightening, anti-aging, hair dye | Antioxidant, exfoliation, anti-aging [27,28] |
| *Adansonia digitata* (Baobab) | Pulp, seeds, oil | Vitamins A, D, E, linoleic acid, flavonoids | Skin hydration, wound healing, hair conditioning | Antioxidant, moisturizing, wound healing [29,30] |

**Table 3:** Less-studied Sudanese medicinal plants with emerging cosmeceutical relevance

| Plant (Scientific name) | Part Used | Major Bioactive Compounds | Traditional Use | Scientific Evidence (Refs) |
|---|---|---|---|---|
| *Balanites aegyptiaca* (Desert date) | Seeds, oil | Saponins, flavonoids, sterols | Skin moisturizing, acne reduction, hair care | Antimicrobial, anti-inflammatory [31,32] |
| *Sesamum indicum* (Sesame) | Seeds, oil | Sesamol, lignans, unsaturated fatty acids | Skin protection, sunscreen, soaps | Antioxidant, emollient [33–35] |
| *Ziziphus spina-christi* (Sidr) | Leaves, fruits | Phenolics, saponins | Shampoo, dandruff treatment, cleanser | Antimicrobial, anti-inflammatory [36,37] |

| | | | | |
|---|---|---|---|---|
| *Eruca sativa* (Arugula) | Leaves, oil | Vitamin C, flavonoids, glucosinolates | Hydration, acne prevention, hair strengthening | Antioxidant, anti-aging [38,39] |
| *Senna alexandrina* (Senna) | Leaves, pods | Anthraquinones, flavonoids | Skin cleansing, brightening | Antioxidant, antimicrobial [40–44] |
| *Lupinus albus* (White lupine) | Seeds, extract | Proteins, peptides, alkaloids | Skin creams, conditioners, anti-aging | Collagen synthesis, anti-aging [40,41] |
| *Mentha piperita* (Peppermint) | Leaves, essential oil | Menthol, flavonoids, essential oils | Cooling, scalp refresher, oral care | Antioxidant, antimicrobial [42,43] |
| *Cymbopogon citratus* (Lemongrass) | Leaves, essential oil | Citral, flavonoids, essential oils | Soaps, cleansers, antimicrobial lotions | Antioxidant, antimicrobial [41,42] |
| *Ricinus communis* (Castor oil plant) | Seeds (oil) | Ricinoleic acid, fatty acids | Emollient, hair conditioner | Moisturizing, antimicrobial [45,46] |
| *Boswellia serrata* (Frankincense) | Resin, essential oil | Boswellic acids, terpenoids | Anti-aging, skin toning, scar reduction | Anti-inflammatory, skin protective [47,48] |

## Summary of Findings

Overall, Sudanese medicinal plants demonstrate diverse cosmeceutical properties, particularly antioxidant and anti-inflammatory activities, which were the most consistently reported. Despite strong ethnobotanical relevance, clinical validation remains scarce, and standardized industrial formulations are largely absent. These gaps highlight the urgent need for translational research to bridge laboratory findings with industrial application.

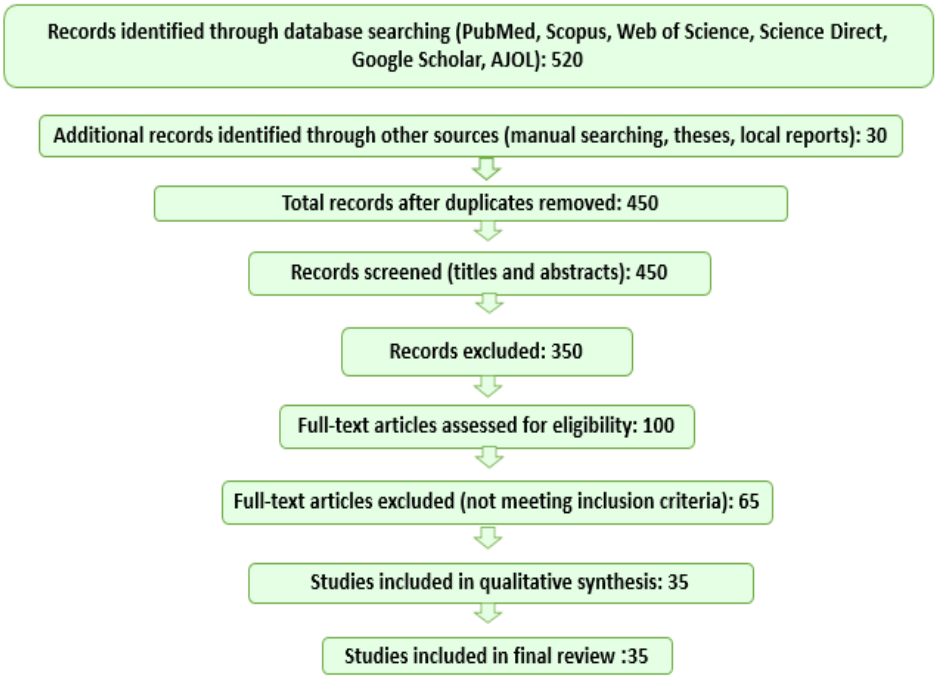



Figure 2. PRISMA flow diagram of the study selection process. *The diagram illustrates the number of records identified, screened, excluded, and finally included in the review.*

## SWOT Analysis

A SWOT analysis was conducted to evaluate the industrial and economic potential of Sudanese herbal cosmeceuticals (Figure ۲). The analysis highlights that Sudan's rich biodiversity, strong ethnobotanical heritage, and growing global demand for natural products represent major strengths. Women's role in traditional knowledge and the possibility of empowering them through entrepreneurship add further opportunities.

However, the field faces significant weaknesses, including the lack of clinical validation, poor infrastructure, limited standardization, and weak research–industry linkages. Regulatory gaps and strong competition from regional and international markets were identified as external threats. Addressing these issues through stronger regulatory frameworks, investment in research, and integration of modern technologies will be essential to realize the full potential of Sudanese herbal cosmeceuticals.

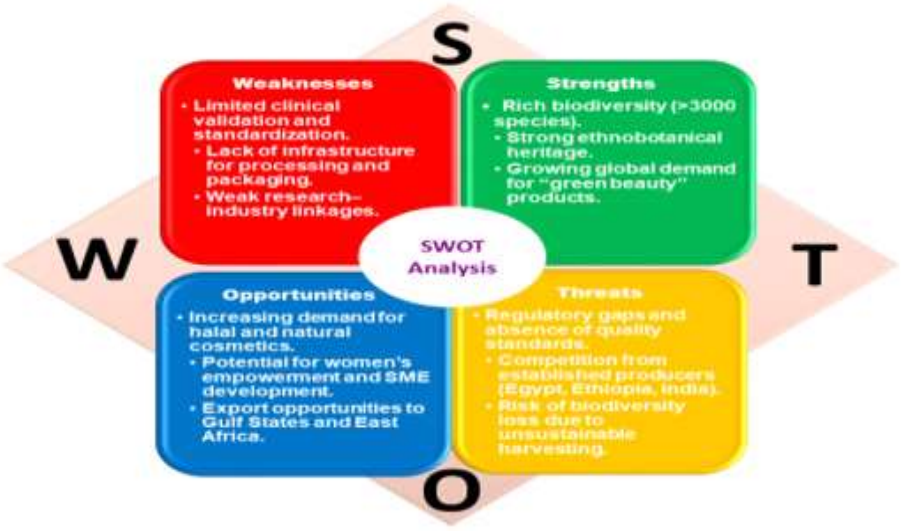


**Figure 2. SWOT analysis of the industrial and economic potential of Sudanese herbal cosmeceuticals.** *The framework highlights strengths (biodiversity, cultural heritage, global demand), weaknesses (limited validation, poor infrastructure, weak industry–research linkages), opportunities (women's empowerment, SMEs, regional exports), and threats (regulatory gaps, competition, biodiversity loss*

## Economic and Industrial Perspective of Sudanese Herbal Cosmeceuticals

Sudan's herbal cosmeceutical sector offers promising opportunities for industrial and economic development. The country's rich biodiversity and long-standing ethnobotanical traditions provide a solid foundation for establishing local and export-oriented industries [49,50]. Niche markets such as organic, halal, and fair-trade cosmetics are particularly relevant, as global consumer demand is increasingly shifting toward natural and ethically produced products [51].

Women in Sudan play a central role in the preservation and transmission of cosmetic knowledge, representing both a cultural asset and an economic driver. Empowering women through entrepreneurship, training in good manufacturing practices (GMP), and access to microfinance can facilitate the growth of small- and medium-sized enterprises (SMEs) [52]. Similar initiatives in countries such as India and Morocco have successfully transformed traditional herbal practices into globally competitive industries [53,54].

However, major barriers persist. Limited industrial infrastructure, lack of standardized extraction and formulation methods, and insufficient regulatory enforcement remain critical weaknesses [55]. Without internationally recognized certification systems such as ISO and GMP, Sudanese herbal products face significant challenges in competing with established regional and global markets [56]. Public–private partnerships, investment in modern technologies, and stronger research–industry linkages will be essential to unlock the full industrial potential of Sudanese herbal cosmeceuticals [57].

## Discussion

The results of this review provide valuable insights into the cosmeceutical potential of Sudanese medicinal plants. Building upon these findings, a critical discussion is necessary to highlight their scientific significance, existing research gaps, and industrial implications.

The findings of this review demonstrate that Sudanese medicinal plants possess diverse cosmeceutical properties, particularly antioxidant, anti-inflammatory, antimicrobial, and moisturizing effects. These activities are consistent with global evidence on herbal cosmeceuticals, where plants such as Aloe vera, Camellia sinensis, and Curcuma longa are already widely used in commercial formulations [15–18]. The repeated identification of antioxidant and anti-inflammatory effects in Sudanese plants highlights their potential for anti-aging and skin-protective applications, aligning with global market demands.

Despite this promise, several research gaps remain evident. First, most of the available evidence is derived from **in vitro** and animal studies, while clinical validation is extremely limited. This undermines the translational value of the findings and restricts their applicability to real-world human use. Second, standardization of extracts and formulations is largely absent. Variability in phytochemical content due to differences in geography, harvesting, and processing further complicates reproducibility and industrial scaling. Third, the lack of comparative quantitative analyses across multiple studies prevents robust conclusions regarding the relative efficacy of these plants.

From an industrial perspective, Sudan's biodiversity and cultural heritage represent a significant advantage. However, without proper regulatory frameworks, investment in advanced extraction technologies, and strong research–industry linkages, the cosmeceutical potential of these plants cannot be fully realized. Experiences from other regions, such as India and Egypt, illustrate how integrating ethnobotanical knowledge with standardized production and certification (e.g., GMP, ISO, halal, organic) can improve competitiveness in global markets [19–21].

Another key aspect is the role of women in maintaining and transmitting traditional cosmetic practices in Sudan. Empowering women through training in good manufacturing practices (GMP), safe extraction techniques, and entrepreneurship could facilitate the transition from household-level practices to sustainable enterprises. This aligns with the identified opportunities in the SWOT analysis, where women's participation is considered both a cultural strength and an economic driver.

Overall, Sudanese medicinal plants offer a unique opportunity to contribute to the global "green beauty" industry. Addressing current weaknesses through clinical research, phytochemical standardization, and industrial feasibility studies will be essential to bridge the gap between traditional practices and modern cosmeceutical development.

## Study Limitations

This review has certain limitations that need to be acknowledged. First, most of the available evidence on Sudanese medicinal plants and their cosmeceutical applications comes from in vitro and animal studies, with limited clinical validation, which weakens the generalizability of the findings [58]. Second, several studies did not provide detailed information on standardization, quality control, or reproducibility of plant extracts, which poses challenges for industrial application [59]. Third, the review may not have captured all relevant local and non-English sources, given the scarcity of published data from Sudanese research institutions and limited accessibility of grey literature [60]. Finally, quantitative comparisons across studies were not feasible due to methodological heterogeneity, which restricted the ability to conduct meta-analysis.

## Future Research Recommendations

Future studies should focus on bridging the gap between traditional knowledge and industrial application. Clinical trials are urgently required to validate the efficacy and safety of Sudanese medicinal plants in human populations [61]. Advanced standardization techniques (e.g., HPLC fingerprinting, metabolomics, and bioassay-guided fractionation) should be applied to ensure reproducibility and quality [62]. Furthermore, public–private partnerships and collaborations between academia and industry should be strengthened to facilitate technology transfer and commercialization [63]. Special emphasis should be placed on empowering women entrepreneurs and supporting small- and medium-sized enterprises (SMEs), which can drive inclusive growth in the herbal cosmeceutical sector [64]. Finally, the adoption of regulatory frameworks aligned with international standards (e.g., GMP, ISO, WHO guidelines) will be essential for successful integration of Sudanese herbal cosmeceuticals into global markets [65].

## Conclusion

This integrative review highlights the remarkable cosmeceutical potential of Sudanese medicinal plants, which are rich in bioactive compounds with antioxidant, anti-inflammatory, antimicrobial, and moisturizing properties. The evidence demonstrates strong ethnobotanical relevance and scientific promise, yet translation into clinically validated and standardized products remains limited.

To move forward, priority should be given to clinical validation, phytochemical standardization, and adoption of advanced extraction and formulation technologies. Strengthening regulatory frameworks and aligning with international standards (e.g., GMP, ISO, WHO guidelines) will be critical to ensure product quality and global competitiveness. Moreover, empowering women entrepreneurs and promoting small- and medium-sized enterprises (SMEs) can transform traditional cosmetic practices into sustainable economic ventures.

In conclusion, Sudanese herbal cosmeceuticals represent not only a rich cultural and scientific heritage but also a unique opportunity to contribute to the global “green beauty” industry, provided that current weaknesses are addressed through rigorous research, innovation, and industrial investment.

## Statements and Declarations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This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.


### Competing Interests

The authors declare that they have no competing interests.

### Ethics Approval

This article is a review and did not involve experiments on humans or animals; therefore, ethics approval was not required.

### Consent to Participate

Not applicable, as the study did not involve human participants.


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