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Review Article

Exploring the efficacy of medicinal plants in cosmeceuticals: a review of bioactive compounds and skin health

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The therapeutic potential of medicinal plants has attracted special interest in recent years as a result of their abundant reservoir of bioactive compounds. The purpose of this review is to discuss the value of medicinal plants in cosmeceutical applications based on their bioactive constituents and their relevance to skin health. Plant bioactive compounds such as flavonoids, phenolic acids, alkaloids, terpenoids, and tannins display a wide variety of biological activities, including antioxidant, anti-inflammatory, and antimicrobial effects. By enhancing moisture, elasticity, and barrier function of the skin, these features help overcome the typical pathology of the skin, such as oxidative stress, inflammation, hyperpigmentation, and infections caused by microorganisms. *Aloe vera*, *Curcuma longa* (turmeric), *Camellia sinensis* (green tea), and *Centella asiatica* (gotu kola) are some of the most studied plants in terms of their cosmeceutical potential. Throughout this review, we examine the mechanisms by which their bioactive compounds inhibit collagen synthesis, melanin production, and free radical production. Furthermore, the latest developments in formulation technology, namely the use of nanoencapsulation and liposomal delivery systems with enhanced stability and bioavailability of plant-derived ingredients, will be discussed. While these findings are promising, some concerns include variability in plant composition, standardization of extracts, and the potential risk of adverse effects. These concerns warrant further investigation both in terms of safety and efficacy. Currently, the regulatory environment for cosmeceuticals derived from plants is far from standardized; therefore, further harmonization of regulations or guidelines is required. Through promoting natural and environmentally friendly alternatives, this review examines the vast potential of medicinal plants as sustainable and effective sources of development in cosmeceuticals. To meet growing consumer demand, future studies should focus on clinical validation, new formulation strategies, and scaling up production.

Keywords: *medicinal plants, bioactive compounds, cosmeceuticals, skin health, commercial products*

Introduction

The demand for natural, effective, as well as sustainable ingredients has been increasing among consumers in recent years, resulting in a boom in the cosmeceutical sector. A cosmetic pharmaceutical is a product that crosses over between cosmetics and pharmaceuticals, delivering functional benefits beyond aesthetic enhancement by addressing underlying health concerns through the use of biologically active ingredients. The use of medicinal plants in traditional systems of medicine has made them cornerstones of cosmeceuticals due to their high levels of phytochemicals (Ahuja et al., 2024). The medicinal plants contain a large number of bioactive compounds. Several types of flavonoids, polyphenols, alkaloids, terpenoids, saponins, and tannins have been shown to provide remarkable therapeutic benefits for the skin. These compounds are capable of exhibiting various activities, such as antioxidant activity, an anti-inflammatory effect, antimicrobial properties, photoprotective properties, and anti-aging properties (Bharadvaja et al., 2023; Sharma et al.,

2024a; Kumar et al., 2024a). The use of medicinal plants in these ways makes them versatile drugs for the treatment of a wide range of skin disorders, including oxidative stress, pigmentation disorders, acne, and early aging. A number of plants have been extensively studied, including *Aloe vera*, *Curcuma longa* (turmeric), *Camellia sinensis* (green tea), *Centella asiatica* (gotu kola), and *Rosmarinus officinalis* (rosemary). The effectiveness of cosmetics is often attributed to the modulation of basic processes of the skin. These mechanisms include collagen synthesis, melanogenesis, hydration, and cellular repair (Sharma et al., 2024c). As far as the trend for sustainable and eco-friendly solutions in the beauty and personal care industries are concerned, medicinal plants found in cosmeceuticals are a huge winner. Plant-based products are considered safer than synthetic counterparts, according to most consumers. By developing formulation technologies such as nanoencapsulation and liposomal delivery systems, plant-derived ingredients become more bioavailable and stable when applied topically (Sharma et al., 2024e). Medicinal plants have their own challenges when used in cosmeceuticals. Pharmaceutical preparations may vary in efficacy based on factors such as geographical origin, cultivation practices, and extraction methods. Standardization and quality control of plant-based formulations also pose challenges. A number of classifications of cosmeceuticals place them between cosmetics and pharmaceuticals, which creates regulatory roadblocks that can sometimes result in inconsistent regulatory requirements for safety and efficacy. Medicinal plants are increasingly used in cosmeceutical applications, where their bioactive constituents and mechanisms of action are explored. There will be a critical appraisal of the advantages and challenges associated with plant-based ingredients. A discussion of recent technological innovations aims to enhance their potential. By synthesizing existing research into cosmeceutical science and pointing out the knowledge gaps in it, this paper aims at providing an integrated understanding of the current state of and prospects for medicinal plants. Utilizing medicinal plants in cosmeceuticals is a great way to combine traditional knowledge and modern science to meet the twin demands of efficacy and sustainability in skincare. Consumer expectations and global sustainability goals may require further research and development in this promising area (Sharma et al., 2020a; 2020b; 2020c).

Status and new aspects in cosmeceutical sector

Keeping pace with advances in science, technology, and consumer preferences, the cosmeceutical industry is dynamic. There has been a paradigm shift toward incorporating medicinal plants into cosmetic formulations in recent years. In addition, consumers are becoming more aware of the adverse effects chemical ingredients may cause, and are looking for natural, sustainable products. By combining medicinal plants and their bioactive compounds, the gap between traditional knowledge and modern developments in skincare can be filled (Sharma et al., 2024b). There is a growing interest in the use of lesser known, exotic medicinal plants in cosmeceuticals. *Aloe vera*, *Curcuma longa* (Turmeric) and *Camellia sinensis* (Green tea) still make the cut, but more attention is being paid to lesser-known plants like *Moringa oleifera*, *Psidium guajava* (Guava), *Withania somnifera*, and seaweeds derived from the ocean. Moringin, quercetin derivatives, and fucoidans are bioactive compounds that have been proven to boost the skin's healing, UV protection, and hydration (Chan et al., 2024). The use of advanced omics technologies is increasingly being applied to understand complex interactions between plant bioactives and skin physiology. Bioactive compounds can be identified, molecularly elucidated, and optimized for cosmeceutical application using these tools. Also, artificial intelligence and machine learning are accelerating the pace of discovery of cosmeceutical compounds from plants. High-speed formulation design by machines and rapid time to market reduction are third thrust areas (Kumar et al., 2024b). Green chemistry and eco-friendly extraction approaches are future innovations. Among the methods used for the recovery of bioactive compounds are supercritical fluid extraction, ultrasonic-assisted extraction, and enzymatic hydrolysis, which have no detrimental effects on the environment. By reducing contamination and retaining the integrity of the bioactivity of extracts, these approaches ensure sustainability of raw materials, safety, and efficacy of plant-based cosmeceuticals. Plant-based cosmeceuticals were also reformulated. The use of nano emulsions, liposomes, and dendrimers is improving the solubility, stability, and controlled release of bioactive compounds to combat poor penetration and degradation. By targeting specific layers of skin with active ingredients, better results will be achieved in repairing, anti-aging, or pigmentation treatments (Dhiman et al., 2023a). Currently, cosmeceutical science is exploring how plant bioactives can modulate the human skin microbiome and promote beneficial microbial communities. The prebiotic and antimicrobial properties of *Azadirachta indica* (neem) and *Ocimum sanctum* (holy basil) can help maintain a healthy skin microbiome by inhibiting acne, eczema, and psoriasis associated with dysbiosis (Chan et al., 2024). Cosmeceutical development has finally realized the importance of sustainability and ethical sourcing. Global sustainability goals focus on regenerative agricultural practices and biodegradable packaging for medicinal plants. Cosmeceuticals science proves the potential of medicinal plants and revolutionizes the skincare challenges of modern civilization: innovative, effective, and eco-friendly (Figure 1) (Chan et al., 2024; Thakur et al., 2021).

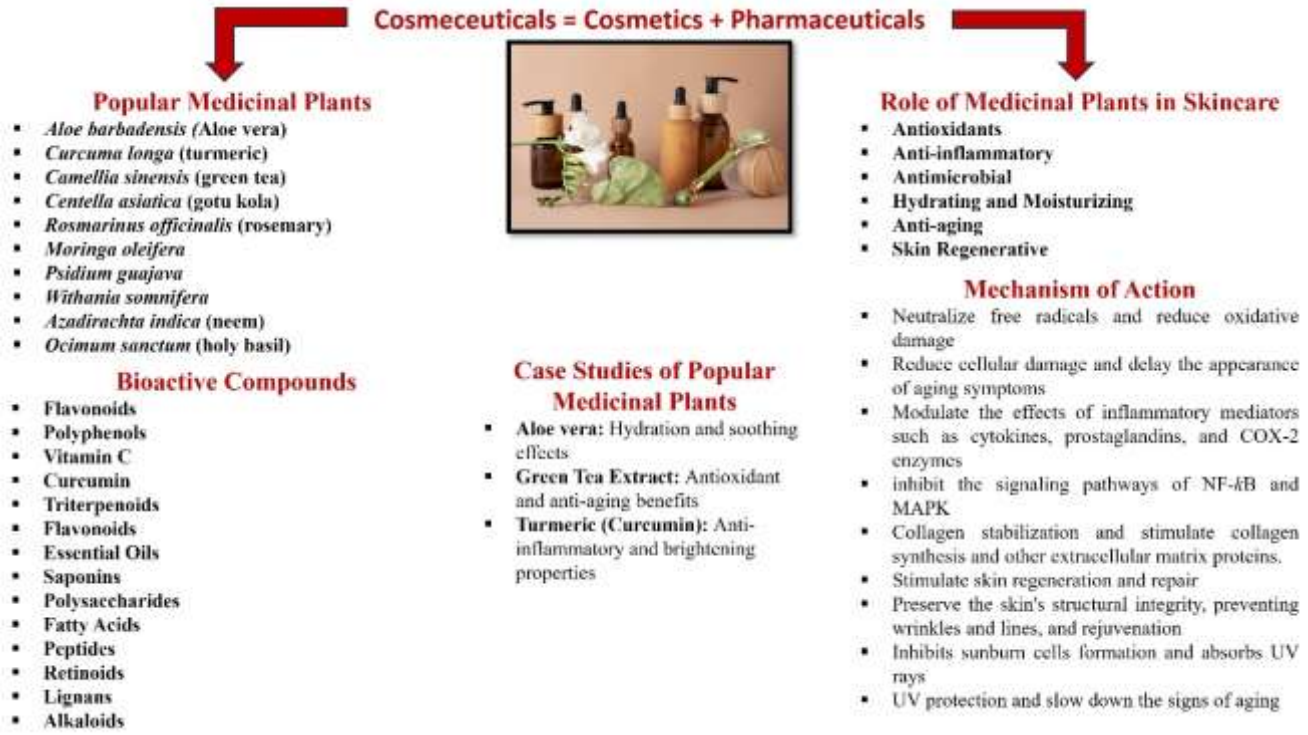


Figure 1. Overview of cosmeceuticals, medicinal herbs utilised, bioactive compounds and their role in maintaining skin health

1. Cosmeceuticals

Cosmeceuticals are a developing and dynamic market in the personal care and skincare industry. Dermatologist Dr. Albert Kligman coined the term cosmetic in the 1980s to describe products that not only enhance the appearance of skin but also provide a therapeutic effect. The difference between aesthetic cosmetics and pharmaceuticals is that cosmeceuticals are somewhere in between - these are products with biologically active ingredients that affect the skin physiologically (Chan et al., 2024). Cosmetics contain bioactive agents such as antioxidants, peptides, retinoids, vitamins, botanical extracts, and enzymes to address specific skin concerns such as aging, pigmentation, acne, dryness, inflammation, and sensitivity. So, cosmeceuticals stimulate repair mechanisms, protect against environmental damage, and restore skin balance by interacting with cells. It is this higher concentration of active ingredients that differentiates cosmetics from over-the-counter cosmetics, bringing cosmetic products closer to dermatological products (Kumar et al., 2024b). Several countries do not recognize cosmeceuticals as a separate regulatory category. Food and Drug Administration (FDA) classifies them as either cosmetics or drugs. As consumer interest in these multifunctional products increases, there is a need for robust clinical evidence to support claims of efficacy and safety (Sharma et al., 2024d). The appeal of cosmeceuticals lies in their holistic approach to skin concerns combining immediate cosmetic enhancement with long-term skin health benefits. As a result of this dual functionality, and advances in science and technology, cosmeceuticals have become a cornerstone of modern skincare (Chan et al., 2024; Sharma et al., 2022b).

2. Rising demand for natural ingredients

Plant-derived cosmeceuticals have become increasingly popular with consumers due to increasing safety, sustainability, and efficacy awareness. The consumer is demanding more holistic products while being concerned about the added risk and environmental consequences of some synthetic ingredients (Dhiman et al., 2023b). Natural ingredients are considered safer, hence the recent explosion. Some synthetic chemicals, such as parabens and sulfates, have become highly unpopular with consumers. Skin reactions and allergic reactions are believed to result and even pose serious health risks. Polyphenols, flavonoids, alkaloids, and essential oils found in plant cosmeceuticals are softer. These ingredients are often praised for their compatibility with diverse skin types, including sensitive and allergy-prone skin (Sharma et al., 2022a). Sustainable practices have also boosted demand for cosmeceuticals. Eco-friendly consumers want products that are biodegradable and built in a green environment. The use of natural resources in cosmeceuticals is considered more sustainable than that of synthetics. Through these innovations in green chemistry and eco-friendly extraction methods, such as supercritical fluid and cold-pressing, plant-based ingredients are now transformed into high-quality extracts with minimal environmental impact. Natural ingredients are also in demand because of their efficacy.

Antioxidant, anti-inflammatory, antimicrobial, and anti-aging properties of medicinal plants have been studied and proven in skincare. To combat oxidative stress, *Aloe vera*, *Camellia sinensis*, and *Curcuma longa* fight inflammation and hyperpigmentation. Traditional medicines use them long term and have more credibility, connecting ancestral wisdoms with modern science (Vaughn et al., 2016). There is also a trend toward transparency. Increasingly, consumers want to know where things come from and what they are. In the marketplace, brands that emphasize natural, plant-based formulations and transparent labeling stand out. Movements such as organic, vegan, or cruelty-free movements have only further enshrined the preference for plant-based cosmeceuticals for peace of mind (Rutter et al., 2003; Dal'Belo et al., 2006). This intersection highlights consumer values as a shaping factor in cosmeceuticals. Due to all this, plant-based cosmeceuticals will continue to grow in popularity as customers look for products that are both effective and safe. As a result of these trends, the industry can innovate to meet these changing needs of eco-aware consumers while addressing diverse skin health needs using better formulation technology (Sharma et al., 2020c). The various medicinal plants used in different products for maintaining of skin health are listed in Table 1.

Table 1. Medicinal plants used in cosmetics sector in different products, their functions and availability in market

Product Name	Brand	Key Medicinal Plant Ingredient(s)	Function	Availability
Aloe vera gel	Forever Living	*Aloe vera*	Moisturizing, soothing, healing	Pharmacies, Online Stores
Neem face wash	Himalaya	Neem (*Azadirachta indica*)	Antibacterial, anti-acne	Pharmacies, Supermarkets
Turmeric cream	Vicco	Turmeric (*Curcuma longa*)	Anti-inflammatory, skin brightening	Pharmacies, Online Stores
Green tea seed serum	Innisfree	Green Tea (*Camellia sinensis*)	Antioxidant, hydration	Beauty Stores, Online
Licorice brightening cream	Murad	Licorice (*Glycyrrhiza glabra*)	Skin brightening, anti-inflammatory	Sephora, Online Stores
Lavender body lotion	Dr. Hauschka	Lavender (*Lavandula spp.*)	Relaxing, soothing	Natural Product Retailers
Concentrated ginseng renewing cream	Sulwhasoo	Ginseng (*Panax ginseng*)	Anti-aging, revitalizing	Luxury Beauty Stores, Online
Chamomile soothing mask	The Body Shop	Chamomile (*Matricaria chamomilla*)	Calming, anti-inflammatory	The Body Shop Stores, Online
Calendula serum-infused water cream	Kiehl's	Calendula (*Calendula officinalis*)	Hydrating, soothing	Beauty Stores, Online
Tea tree oil	The Body Shop	Tea Tree (*Melaleuca alternifolia*)	Antimicrobial, acne treatment	The Body Shop Stores, Online
Rosehip oil	Trilogy	Rosehip (*Rosa canina*)	Skin regeneration, anti-aging	Pharmacies, Online Retailers
Witch hazel toner	Thayers	Witch Hazel (*Hamamelis virginiana*)	Astringent, pore tightening	Pharmacies, Online Stores
Sandalwood body lotion	Khadi Natural	Sandalwood (*Santalum album*)	Moisturizing, soothing	Herbal Stores, Online
Cucumber hydrating gel	Garnier	Cucumber (*Cucumis sativus*)	Cooling, hydrating	Supermarkets, Online Stores
Hibiscus lifting mask	Eminence Organic Skincare	Hibiscus (*Hibiscus rosa-sinensis*)	Skin firming, anti-aging	Luxury Beauty Stores, Online
Argan oil hair treatment	Moroccanoil	Argan (*Argania spinosa*)	Hydration, nourishment	Salons, Online Retailers
Gotu kola repair cream	La Roche-Posay	Gotu Kola (*Centella asiatica*)	Wound healing, scar reduction	Pharmacies, Online Stores
Coconut miracle oil	OGX	Coconut (*Cocos nucifera*)	Deep conditioning, hydration	Supermarkets, Online
Papaya exfoliating face wash	St. Ives	Papaya (*Carica papaya*)	Exfoliation, skin brightening	Pharmacies, Supermarkets

Grapeseed anti-aging serum	Caudalie	Grapeseed (*Vitis vinifera*)	Antioxidant, skin elasticity	Sephora, Online Retailers
Saffron night cream	Kama Ayurveda	Saffron (*Crocus sativus*)	Skin brightening, anti-aging	Ayurveda Stores, Online
Avocado hand balm	The Body Shop	Avocado (*Persea americana*)	Moisturizing, softening	The Body Shop Stores, Online
Mango butter lotion	Tree Hut	Mango (*Mangifera indica*)	Hydration, skin softening	Beauty Stores, Online
Pomegranate lip balm	Burt's Bees	Pomegranate (*Punica granatum*)	Antioxidant, hydration	Pharmacies, Online Retailers
Eucalyptus foot cream	Dr. Teal's	Eucalyptus (*Eucalyptus* spp.)	Antimicrobial, soothing	Pharmacies, Online Stores
Amla hair oil	Dabur	Amla (*Phyllanthus emblica*)	Hair strengthening, antioxidant	Supermarkets, Online Retailers
Black seed face oil	The Ordinary	Black Cumin (*Nigella sativa*)	Soothing, anti-inflammatory	Beauty Stores, Online
Raspberry sunscreen	Suntegrity	Raspberry (*Rubus idaeus*)	UV protection, antioxidant	Online Stores

(Source of information compiled from different bibliography: Ashawat et al., 2009; Joshi & Pawar, 2015; Sharma et al., 2024)

3. Role of medicinal plants in skincare

Since medicinal plants have been used in skincare for centuries, their integration into modern cosmeceuticals has gained momentum because of their impressive range of bioactive compounds. Their antioxidant, anti-inflammatory, and antimicrobial action, hydration capacity, and regeneration processes make these plants a natural alternative to chemical syntheses. In cosmeceuticals, medicinal plants are combined with the modern science of skincare to address a variety of skin issues (Sharma et al., 2024f; Chan et al., 2024). Antioxidant effects can contribute to skincare through several medicinal plants. Polyphenols, flavonoids, and carotenoids in them quench free radicals and ease oxidative stress caused by environmental pollutants, UV radiation, and aging. Green tea, for instance, is well known for its catechins, which have powerful antioxidant properties that minimize damage done by premature aging of skin. The grape seed extract *Vitis vinifera* contains resveratrol. Antioxidants fight oxidative damage and improve the tone and elasticity of the skin (Choi et al., 2024). A number of medicinal plants are used in anti-inflammatory skincare. A chronic inflammatory response accelerates skin aging and causes acne, eczema, and psoriasis. Plants with anti-inflammatory properties include *Curcuma longa* (turmeric), which contains curcumin, and *Centella asiatica* (gotu kola), which contains triterpenoid saponins. It reduces swelling and redness, calms irritated skin, and promotes healing. *Chamomilla recutita* (chamomile) has soothing and anti-inflammatory properties, making it ideal for sensitive skin (Kumar et al., 2024a; Batovska et al., 2024). In cosmetics, medicinal plants are highly valued for their antimicrobial and antifungal properties, often demanded by acne-prone or oily skin consumers. There are many medicinal plants that contain natural antimicrobial compounds. Traditional medicine has used *Azadirachta indica* (neem) for generations for treating infections on the skin due to its antimicrobial, antifungal, and anti-inflammatory properties. *Thymus vulgaris* (thyme) contains thymol, a chemical with antimicrobial and antifungal properties, which may control acne bacteria (Batovska et al., 2024).

Medicinal plants also provide skincare benefits such as hydrating and restoring moisture. *Cucumis sativus* and *Aloe vera*, which are used for hydrating and cooling purposes, date back to ancient times. Polysaccharides in *Aloe vera* help to moisturize dry skin by attracting and holding moisture. Furthermore, it soothes sunburns and other skin irritations. As cucumbers are high in water, they can be used in formulations for improving skin texture and elasticity (Batovska et al., 2024). Medicinal plants also promote skin regeneration and anti-aging. Several plant-derived chemicals have been shown to stimulate collagen synthesis and stretch the skin, thereby reducing fine lines and wrinkles. *Rosa damascena* oil contains antioxidants and vitamins that promote skin regeneration. Carotenoids like those found in *Morinda citrifolia*, like retinol, stimulate collagen synthesis, improving the texture and tightening the skin. Its rejuvenating properties keep the symptoms of aging away and the face young (Kumar et al., 2024a; Choi et al., 2024). Aside from those benefits, medicinal plants also protect the skin barrier naturally. Plant-derived oils like *Olea europaea* (olive oil) and *Simmondsia chinensis* (jojoba oil) contain high levels of essential fatty acids, which enhance the lipid component of the skin, allowing the skin to retain moisture and resist environmental damage. For a smoother, more resilient complexion, these plant oils rejuvenate the skin's natural barrier (Kumar et al., 2024a; Choi et al., 2024). Plant derivatives are used in cosmeceuticals to deliver safer, more sustainable, and more effective skincare products for consumers. In combination

with other active compounds, they provide relief for a variety of skin problems, including dryness, irritation, and aging. Combining traditional wisdom with modern formulation techniques, medicinal plants become high-tech skincare products that provide both cosmetic enhancement and therapeutic properties (Nikita et al., 2024; Batovska et al., 2024).

4. Bioactive compounds in medicinal plants relevant to skin health

Medicinal plants are renowned for their diverse array of bioactive compounds that offer numerous therapeutic benefits, particularly for skin health. These compounds, including antioxidants, anti-inflammatory agents, antimicrobial substances, and skin-regenerative molecules, contribute to the efficacy of plant-based cosmeceuticals. An overview of some key bioactive compounds found in medicinal plants and their relevance to various aspects of skin health is illustrated in Figure 2 (Bharadvaja et al., 2023; Sharma et al., 2024f; Batovska et al., 2024).

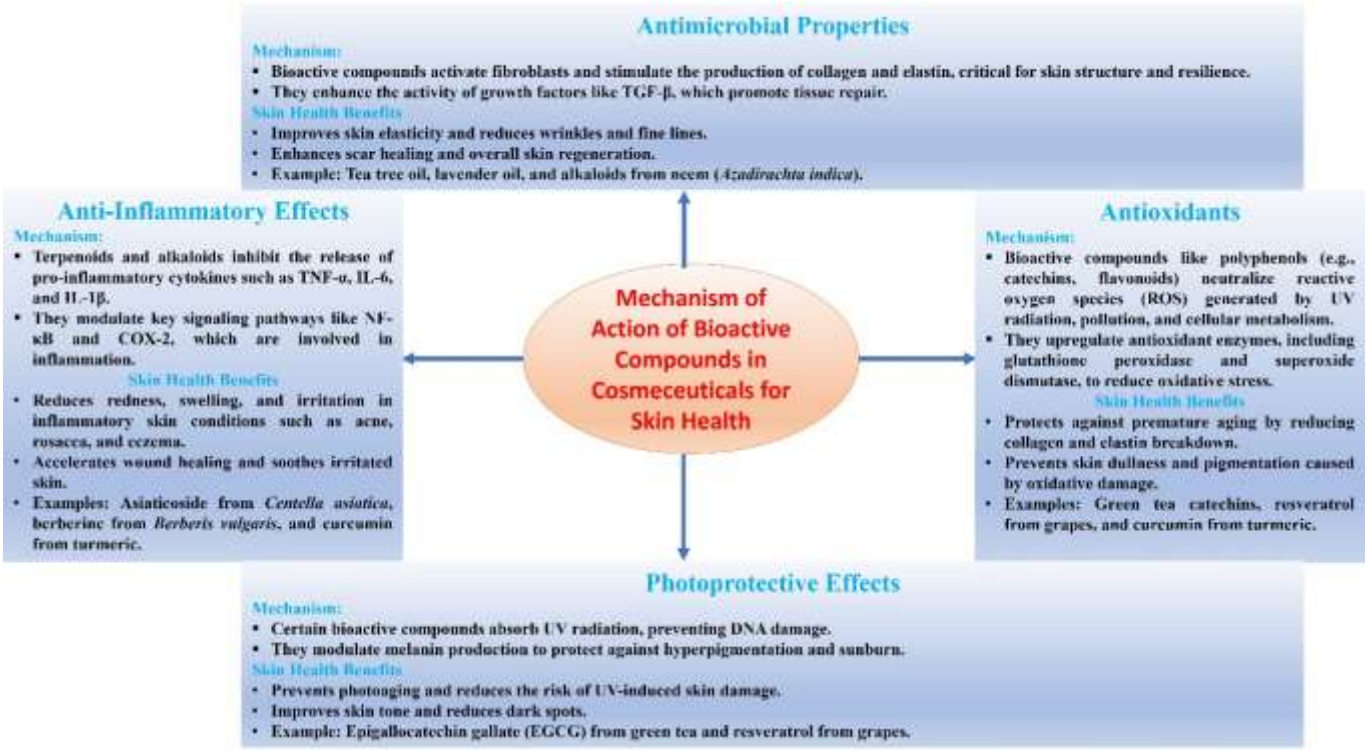


Figure 2. Mechanism of action of various bioactive compounds utilised in the management of skin health

4.1. Antioxidants

The antioxidants prevent the skin from being damaged by UV radiation, pollution, and aging. Skin cells are damaged by free radicals, which cause premature aging, wrinkles, and disease (Choi et al., 2024; Batovska et al., 2024).

- **Flavonoids**: The flavonoids from *Camellia sinensis* (green tea) and *Citrus sinensis* (orange), *Ginkgo biloba*, have strong antioxidant properties. Skin elasticity is improved, UV damage is prevented, and inflammation is reduced (Chan et al., 2024).
- **Polyphenols**: Plants such as *Vitis vinifera*- grape seed, *Coffea arabica*-coffee, and *Punica granatum*-pomegranate possess powerful antioxidant compounds. A polyphenol inhibits the breakdown of collagen and elastin, which reduces wrinkle visibility while improving skin elasticity (Chan et al., 2024).
- **Vitamin C**: This is a commonly used antioxidant, found in citrus fruits, *Rosa canina* (rose hips), and *Capsicum annuum* (bell pepper), which not only protects the skin from oxidative stress, but also stimulates collagen production, resulting in faster skin regeneration and repair (Chan et al., 2024).

4.2. Anti-inflammatory compounds

Bioactive compounds in medicinal plants are believed to reduce inflammation, thus offering relief to inflamed and irritated skin, including chronic inflammation linked to acne, eczema, and psoriasis (Fernandes et al., 2023; Choi et al., 2024; Batovska et al., 2024).

Curcumin: Turmeric contains curcumin, an anti-inflammatory. By inhibiting COX-2 and NF-*k*B inflammatory mediators, curcumin reduces inflammatory dermatological conditions like psoriasis and eczema (Chan et al., 2024).

- **Triterpenoids**: Triterpenoids in *Centella asiatica* and *Glycyrrhiza glabra* help reduce inflammation in the skin. The compound is effective against wounds and speeds up the healing process (Chan et al., 2024).
- **Flavonoids**: While flavonoids are antioxidants, those in *Citrus aurantium* (bitter orange) and *Corylus avellana* (hazelnut) like quercetin and kaempferol have anti-inflammatory effects to fight inflammation and edema of the skin; they help prevent acne and rosacea (Chan et al., 2024).

4.3. Antimicrobial compounds

Medicinal plants have antimicrobial properties. Their antibacterial, antifungal, and antiviral properties make them ideal for treating acne, wounds, and all other skin conditions (Choi et al., 2024; Batovska et al., 2024).

- **Essential Oils**: Essential oils obtained from *Melaleuca alternifolia*, *Lavandula angustifolia*, and *Rosmarinus officinalis* have a broad-spectrum antimicrobial activity. In treating acne, tea tree oil kills the causative agent, Propionibacterium acnes, which causes flare-ups.
- **Saponins**: There are two plants that contain saponins, *Sapindus mukorossi* (soapnut) and *Quillaja saponaria* (soap bark). The antifungal and antibacterial properties ensure healthy skin and prevent skin infections.

4.4. Hydrating and moisturizing compounds

To maintain skin barrier function, prevent dehydration, and improve skin texture, moisturize the skin regularly. Skin moisture is attracted to and retained by most medicinal plants (Choi et al., 2024; Batovska et al., 2024; Gomez-Molina et al., 2024).

- **Polysaccharides**: *Aloe vera*, *Cucumis sativus* (cucumber), and *Glycyrrhiza glabra* (licorice) all contain mannans and glucans as constituents of their plants. These substances maintain the moisture in the skin because they are hydrophilic. Sunburns and dry skin benefit from *Aloe vera's* mucopolysaccharides that hydrate and soothe (Chan et al., 2024).
- **Fatty Acids**: Plant oils containing omega-3, omega-6, and omega-9, like olive oil, jojoba oil, and rosehip oil, replenish the barrier lipids of the skin, ensuring moisture retention and smooth, nourished skin.

4.5. Anti-aging compounds

Wrinkles, sagging skin, and loss of firmness are caused by a decline in collagen and elastin synthesis with age. Bioactive compounds in medicinal plants enhance collagen synthesis and improve skin elasticity to fight aging (Choi et al., 2024; Batovska et al., 2024; Gomez-Molina et al., 2024).

- **Peptides**: *Glycine soja*, or soybean, skin contains peptides that stimulate collagen and elastin synthesis. Skin tone is brightened and wrinkles are reduced and removed with peptides.
- **Retinoids**: Carotenoids, such as those found in *Moringa oleifera* and *Daucus carota*, induce collagen, which gives the skin a more youthful appearance with fewer wrinkles and even skin tone (Chan et al., 2024).
- **Lignans**: Lignans are potent antioxidants found in plants like flax seed and sesame that promote skin elasticity and firmness while protecting skin cells from oxidative stress.

4.6. Skin regenerative compounds

The constituents in medicinal plants enhance the healing process of skin, thus effectively treating wounds (Choi et al., 2024; Batovska et al., 2024; Gomez-Molina et al., 2024)

- **Triterpenoids and Asiaticoside**: *Centella asiatica* (gotu kola) contain compounds that stimulate collagen synthesis and improve wound healing by regenerating skin cells.
- **Alkaloids**: Berberine is an alkaloid present in *Berberis vulgaris* (barberry) that promotes skin regeneration and helps treat acne, pigmentation disorders, and scarring (Chan et al., 2024).

The bioactive compounds in medicinal plants play a major role in enhancing skin health and treating dermatological conditions. Antioxidants, anti-inflammatory agents, antimicrobial materials, and hydrating molecules provide multifaceted benefits, making medicinal plants indispensable in cosmeceuticals. Providing safe, effective, and sustainable solutions for healthy, beautiful-looking skin, plant-based ingredients promise to grow and expand with each new compound and its mechanism of action (Chan et al., 2024; Sharma et al., 2022a).

5. Mechanisms of action of bioactive plant compounds on skin health

A variety of bioactive compounds in skincare products support healthy skin through various biological mechanisms, including antioxidant protection, collagen synthesis, inflammation attenuation, and UV protection (Gonçalves & Gaivão, 2023). A plant-derived bioactive compound supports healthy skin through the following mechanisms:

5.1. Antioxidant defense: reducing oxidative stress and preventing skin aging

During exposure to UV radiation and pollution, free radicals accumulate at the dermal level of exposed skin, causing oxidative stress. These molecules damage skin cells, proteins, and lipids, causing wrinkles, fine lines, and loss of elasticity (Tan et al., 2018).

- **Antioxidants in Plant Compounds**: Flavonoids, polyphenols, and carotenoids are antioxidants found in most medicinal plants, which neutralize free radicals and reduce their oxidative damage. Catechins in green tea (*Camellia sinensis*), resveratrol in grapes (*Vitis vinifera*), and lycopene in tomatoes reduce cellular damage and delay the appearance of aging symptoms (Papaccio et al., 2022; Masaki, 2010).
- **Molecular Mechanism**: Antioxidants work by stabilizing free radicals and preventing their action on skin cells by transferring electrons. An antioxidant-rich plant compound supports the natural barrier function of the skin, protecting its structural integrity and improving regenerative capabilities. Skin firmness is maintained by preventing degradation of collagen and elastin fibers (Kohen, 1999; Masaki, 2010; Chen et al., 2021).

5.2. Anti-inflammatory effects: reducing skin inflammation and redness

Several skin-related diseases cause chronic inflammation, including acne, eczema, rosacea, and psoriasis. These skin diseases are suppressed by plant-derived bioactive compounds that act as anti-inflammatory reagents (Fernandes et al., 2023).

- **Mechanisms of anti-inflammatory plant compounds**: The bioactive compounds curcumin, boswellic acids, and flavonoids, such as quercetin, found in *Citrus sinensis*, modulate the effects of inflammatory mediators such as cytokines, prostaglandins, and COX-2 enzymes. Additionally, these compounds inhibit the signaling pathways of NF-B and MAPK that play an important role in inflammatory disease (Fernandes et al., 2023).
- **Inhibition of inflammatory enzymes**: Plant extracts directly inhibit the enzymes that produce inflammatory molecules. Kaempferol, quercetin flavonoids inhibit the activation of pro-inflammatory cytokines, and, as a result, prevent skin irritation and make the skin appear smooth and even. Curcumin inhibits COX-2, which in turn inhibits inflammation and pain (Fernandes et al., 2023).
- **Clinical implications**: This anti-inflammatory property soothes the skin, reduces redness, and promotes healing of inflamed or irritated skin, making these plant compounds ideal for acne, rosacea, and sensitive skin (Fernandes et al., 2023).

5.3. Collagen synthesis and skin repair: promoting collagen production and aiding skin rejuvenation

Collagen is the main structural protein in the skin, providing firmness, elasticity, and strength. Collagen production decreases with age, causing sagging, wrinkles, and other signs of aging. By using medicinal plants, collagen synthesis and skin repair can be stimulated (Gonçalves & Gaivão, 2023; Gomez-Molina et al., 2024)

- **Stimulation of collagen production**: Triterpenoids from *Centella asiatica* or gotu kola, peptides from *Glycine soja* and ascorbic acid from rose hips stimulate collagen synthesis and other extracellular matrix proteins. Collagen stabilization is facilitated by vitamin C, which acts as a cofactor for enzymes, including prolyl hydroxylase and lysyl hydroxylase.
- **Wound healing and skin repair**: As well as stimulating collagen synthesis, *Centella asiatica* asiaticoside and *Aloe vera* polysaccharides stimulate skin regeneration and repair. Wound healing is facilitated by such compounds by facilitating fibroblast growth and migration and increasing tissue formation (Fernandes et al., 2023).
- **Role in anti-aging**: By stimulating collagen production and stimulating the regeneration process in the skin, plant compounds preserve the skin's structural integrity, preventing wrinkles and lines, and rejuvenating it. Compounds in plants repair damaged, polluted, or UV-exposed skin (Fernandes et al., 2023).

5.4. UV protection: protective effects of plant-derived compounds against UV radiation and photoaging

UV radiation from the sun contributes to skin aging, DNA damage, and elevated rates of skin cancer. UV-induced damage can be prevented by accumulating bioactive compounds in plants (Gonçalves & Gaivão, 2023).

- **UV Protection Mechanisms**: These oils contain antioxidants, including quercetin, found in *Citrus aurantium*, and flavonoids, including apigenin, found in *Chamomilla recutita*, that absorb UV irradiation and protect skin. In green tea, epigallocatechin gallate (EGCG) inhibits sunburn cells formation and absorbs UV rays in pomegranate (*Punica granatum*).
- **DNA Repair and Anti-Tumor Effects**: The compounds found in plants reduce UV-induced DNA damage as well as scavenge ROS. Apigenin and genistein isolated from soy improve DNA repair in skin cells and decrease the chance of mutations leading to cancer. They also inhibit tumor promotion by modulating tumor suppressor genes and preventing UV-induced growth.
- **Anti-Inflammatory Protection**: The anti-inflammatory properties of turmeric curcumin and green tea EGCG also inhibit UV-induced skin inflammation, preventing wrinkles, age spots, and loss of elasticity (Fernandes et al., 2023).

The bioactive compounds in plants play an important role in oxidative stress, inflammation, collagen synthesis, and UV protection. Through their antioxidative effects, anti-inflammatory capabilities, stimulation of collagen formation, and UV protection, these plant compounds slow down the signs of aging (Table 2). Increasing demand for natural, safe, and effective skincare products underscores the importance of these mechanisms of action for plant-derived compounds as cosmeceuticals (Fernandes et al., 2023).

Table 2. Medicinal plants, their bioactive compounds and cosmeceutical benefits

Medicinal Plant	Bioactive Compounds	Cosmeceutical Application	Examples
Aloe vera	Polysaccharides, Vitamins A, C, E	Moisturizer, wound healing, anti-aging	Aloe vera gel in creams
Neem (*Azadirachta indica)*	Azadirachtin, Nimbin, Quercetin	Antibacterial, anti-inflammatory, skin care	Neem oil in acne treatments
Turmeric (*Curcuma longa)*	Curcumin, Turmerones	Anti-aging, skin brightening	Turmeric extract in face masks
Green Tea (*Camellia sinensis)*	Catechins, EGCG, Polyphenols	Antioxidant, UV protection	Green tea extract in sunscreens
Rosehip (*Rosa canina)*	Vitamin C, Essential Fatty Acids	Skin regeneration, anti-aging	Rosehip oil in serums
Licorice (*Glycyrrhiza glabra)*	Glabridin, Glycyrrhizin	Skin lightening, anti-inflammatory	Licorice extract in brightening creams
Lavender (*Lavandula spp.)*	Linalool, Linalyl Acetate	Aromatherapy, soothing irritated skin	Lavender oil in calming lotions
Ginseng (*Panax ginseng*)	Ginsenosides, Polyphenols	Anti-aging, revitalizing	Ginseng extract in anti-aging creams
Chamomile (*Matricaria chamomilla*)	Apigenin, Bisabolol	Soothing, anti-inflammatory, wound healing	Chamomile extract in sensitive skin care
Calendula (*Calendula officinalis*)	Triterpenoids, Flavonoids	Wound healing, soothing and cooling effects	Calendula oil in balms and ointments
Sandalwood (*Santalum album*)	Santalols	Skin hydration, anti-inflammatory	Sandalwood oil in creams
Witch Hazel (*Hamamelis virginiana*)	Tannins, Flavonoids	Astringent, soothing	Witch hazel extract in toners
Seaweed (*Fucus vesiculosus*)	Fucoidans, Carotenoids, Polysaccharides	Anti-aging, moisturizing	Seaweed extract in hydrating masks
Lemon (*Citrus limon)*	Citric Acid, Vitamin C, Flavonoids	Skin brightening, antioxidant	Lemon extract in brightening products
Tea Tree (*Melaleuca alternifolia*)	Terpinen-4-ol	Antimicrobial, acne treatment	Tea tree oil in acne gels

Rosemary (*Rosmarinus officinalis*)	Rosmarinic Acid, Carnosol	Antioxidant, skin rejuvenation	Rosemary extract in anti-aging creams
Carrot (*Daucus carota*)	Beta-Carotene, Vitamin A	Skin nourishment, anti-aging	Carrot seed oil in serums
Pomegranate (*Punica granatum*)	Punicalagins, Ellagic Acid	Antioxidant, UV protection	Pomegranate extract in sun care products
Cucumber (*Cucumis sativus*)	Vitamin C, Cucurbitacins	Soothing, hydrating	Cucumber extract in cooling gels
Basil (*Ocimum sanctum*)	Eugenol, Rosmarinic Acid	Antioxidant, anti-inflammatory	Basil oil in skin care lotions
Saffron (*Crocus sativus*)	Crocin, Safranal	Skin brightening, anti-aging	Saffron extract in luxury creams
Ashwagandha (*Withania somnifera*)	Withanolides, Alkaloids	Anti-stress, revitalizing	Ashwagandha extract in anti-aging products
Hibiscus (*Hibiscus rosa-sinensis*)	Anthocyanins, Organic Acids	Skin elasticity, anti-aging	Hibiscus extract in firming creams
Fenugreek (*Trigonella foenum-graecum*)	Diosgenin, Flavonoids	Skin softening, hydration	Fenugreek extract in hair and skin products
Baobab (*Adansonia digitata*)	Vitamin C, Polyphenols, Linoleic Acid	Moisturizing, antioxidant	Baobab oil in hair and skin products
Argan (*Argania spinosa*)	Tocopherols, Squalene, Fatty Acids	Skin nourishment, anti-aging	Argan oil in moisturizers
Gotu Kola (*Centella asiatica*)	Asiaticoside, Madecassoside	Wound healing, anti-aging	Gotu Kola extract in scar treatments
Kokum (*Garcinia indica*)	Hydroxycitric Acid, Flavonoids	Skin hydration, soothing	Kokum butter in body balms
Tamarind (*Tamarindus indica*)	Tartaric Acid, Polyphenols	Skin smoothing, hydrating	Tamarind extract in exfoliating products
Papaya (*Carica papaya*)	Papain, Vitamin C	Exfoliation, skin brightening	Papaya extract in face masks
Blackberry (*Rubus fruticosus*)	Anthocyanins, Vitamin E	Antioxidant, anti-aging	Blackberry seed oil in serums
Marigold (*Tagetes erecta*)	Carotenoids, Lutein	Skin soothing, anti-inflammatory	Marigold extract in ointments
Banana (*Musa* spp.)	Potassium, Vitamin B6, Manganese	Hydration, skin softening	Banana extract in moisturizers
Avocado (*Persea americana*)	Oleic Acid, Vitamins E, K	Moisturizing, anti-aging	Avocado oil in rich creams
Cranberry (*Vaccinium macrocarpon*)	Proanthocyanidins, Vitamin C	Antioxidant, UV protection	Cranberry extract in serums
Eucalyptus (*Eucalyptus* spp.)	Cineole, Flavonoids	Antimicrobial, soothing	Eucalyptus oil in creams
Mango (*Mangifera indica*)	Mangiferin, Vitamin A, C	Skin nourishment, anti-aging	Mango butter in moisturizers
Grapeseed (*Vitis vinifera*)	Proanthocyanidins, Resveratrol	Antioxidant, anti-aging	Grapeseed oil in serums
Amla (*Phyllanthus emblica*)	Vitamin C, Gallic Acid	Skin brightening, antioxidant	Amla extract in skin tonics
Black Cumin (*Nigella sativa*)	Thymoquinone, Linoleic Acid	Skin soothing, hydration	Black cumin oil in balms
Jojoba (*Simmondsia chinensis*)	Wax esters, Vitamin E	Skin hydration, non-comedogenic oil	Jojoba oil in cleansers

Raspberry (*Rubus idaeus*)	Ellagic Acid, Flavonoids	Antioxidant, UV protection	Raspberry seed oil in sunscreens
Coconut (*Cocos nucifera*)	Lauric Acid, Caprylic Acid	Moisturizing, antibacterial	Coconut oil in creams and hair products

(Source of information compiled from different bibliography: Singh et al., 2023; Sharma et al., 2024)

6. Clinical evidence supporting the efficacy of medicinal plants in cosmeceuticals

Numerous clinical studies and case reports demonstrate the effectiveness of medicinal plants in improving health via the skin. This evidence validates therapeutic potential by addressing key concerns like hydration, antioxidant defense mechanisms, inflammation reduction, and anti-aging properties. The effectiveness of a drug depends on factors such as bioavailability and stability (Olivero-Verbel et al., 2024; Mansoor et al., 2023).

Overview of clinical studies

- In a double-blind, randomized clinical trial, *Centella asiatica* extract increased skin elasticity and hydration. Contains triterpenoids that inhibit aging and induce collagen synthesis (Ahuja et al., 2024).
- Inhibitory properties of *Punica granatum* polyphenols and their ability to retard melanin formation make them suitable as skin lighteners for UV-exposed skin (Nichols & Katiyar, 2010).
- Several clinical studies have shown that green tea extract (*Camellia sinensis*) reduces skin coarseness and improves hydration (Rutter et al., 2003).
- The use of turmeric creams in acne and melasma treatment decreased inflammation and hyperpigmentation (Vaughn et al., 2016).

7. Case studies of popular medicinal plants

Aloe vera: hydration and soothing effects (Dal'Belo et al., 2006)

- *Aloe vera's* polysaccharides are responsible for its hydrating and soothing properties.
- Researchers studied 30 people with dry skin, and found that four weeks after applying *Aloe vera* gel, their skin was significantly hydrated.
- In clinical trials, aloe vera has been found to alleviate erythema and speed healing in patients suffering from sunburn (Vaughn et al., 2016).

Green tea extract: antioxidant and anti-aging benefits (Rutter et al., 2003)

- Green tea extract contains high levels of epigallocatechin gallate. As a result of UV exposure, this antioxidant agent prevents oxidative damage.
- Patients treated with green tea extract creams for 12 weeks saw a 20% reduction in wrinkle formation and improved skin elasticity, according to an open-label, randomized controlled trial.
- By inhibiting acne-causing bacteria and reducing sebum production, it also cures acne as a result of its anti-inflammatory properties.

Turmeric (curcumin): anti-inflammatory and brightening properties (Vaughn et al., 2016)

- Turmeric contains curcumin, which has been proven to reduce inflammation and hyperpigmentation.
- In an eight-week study, turmeric-based cream reduced hyperpigmentation by 16%, with minimal side effects, in patients with melasma.
- Turmeric inhibits inflammatory pathways, including COX-2. It has provided significant relief from redness and irritation when used on conditions such as eczema and psoriasis.

8. Challenges in bioavailability and stability

8.1. Bioavailability

- The skin and poor absorption reduce the bioavailability of plant-derived bioactive compounds. It is well known that curcumin and EGCG penetrate poorly into the skin and are poorly absorbed (Gonçalves & Gaivão, 2023).

- The development of nanotechnology, nanoemulsions, and liposome delivery systems has also increased skin absorption. Due to their ability to increase permeability, active ingredients reach deeper into the dermis (Sharma et al., 2020b).

8.2. Stability

- Extracts of plants are susceptible to degradation when exposed to light, heat, or oxygen. In cosmetic formulations, this may reduce the effectiveness of plant extracts. The antioxidant properties of vitamin C are readily lost when it oxidizes (Sharma et al., 2020a).
- The potency and shelf life of bioactive compounds are enhanced by encapsulating them into carriers like silicon nanoparticles or incorporating stabilizers such as ferulic acid into their formulations (Sharma et al., 2020b).

The clinical evidence demonstrates that medicinal plants offer cosmeceutical benefits, such as hydration, anti-inflammatory properties, and anti-aging properties. When working with such substances, bioavailability and stability issues are major challenges. A growing demand for natural and sustainable skincare solutions will be met through advancements in formulation science (Sharma et al., 2020a; Gonçalves & Gaivão, 2023).

Conclusion

This cosmeceutical industry is undoubtedly driven by medicinal plants, which are proven to benefit skin health. There are hydrators, antioxidant protectors, anti-inflammatory agents, collagen stimulators, and UV-defense components among these bioactive compounds. They are clinically proven to be effective for treating diverse skin concerns, including aging, hyperpigmentation, acne, and dryness. Bioactive compounds such as polysaccharides, catechins, and curcumin can provide targeted benefits with a minimum of side effects in medicinal plants such as aloe vera, green tea, and turmeric. The formulation techniques used on cosmeceuticals derived from plants have evolved with nanotechnology and encapsulation methods, despite a disadvantage in bioavailability and stability. By improving delivery and stability, they optimize the performance of plant-based cosmeceuticals in skincare. In the future of the cosmeceutical market, consumers will increasingly demand natural, eco-friendly, and effective skincare products. Increasing awareness of synthetic ingredients' impact on the environment will push the plant-based cosmeceuticals industry into the beauty market. A further advancement in technology will lead to the development of biocompatible delivery systems and eco-friendly extraction methods for medicinal plant-based formulations. Plant-based cosmeceuticals support this global shift toward greener practices and are likely to appeal to green consumers. The advancement of biotechnology and artificial intelligence is going to be a huge factor in the development of cosmeceuticals made from plant-derived materials. Therefore, medicinal plants are expected to revolutionize the skincare industry. A revitalized skincare future awaits plant-based cosmeceuticals, as discoveries and improvements in bioactive compounds uncover ever more beneficial compounds and enhance their applications.

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