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Review

The Genus *Astragalus* Species as an Emerging Source of Bioactive Phytochemicals: A Review of Dermatological and Cosmetic Applications

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Abstract

Astragalus species have been used in traditional medicine for the treatment of various conditions, and they have recently been used to treat dermatological diseases. Health benefits of *Astragalus* extracts, especially *Astragalus membranaceus* Fisch. ex Bunge (synonym of *Astragalus mongholicus* Bunge), result from the multitude of secondary metabolites identified in their genus, including saponins, flavonoids and polysaccharides. *Astragalus* species, traditionally valued for their systemic medicinal properties, are increasingly recognized as potent sources of ingredients for the cosmeceutical industry. While *A. membranaceus* remains the most prominent representative, this review explores the broader genus as an emerging reservoir of bioactive secondary metabolites. For this purpose, current publications regarding the topical effects of *Astragalus* species in the treatment of dermatological diseases were collected. Several *Astragalus* extracts and their compounds have been shown to display biological activities with skin rejuvenating, photoprotective and antimicrobial properties, wound-healing activity, and therapeutic effects on atopic dermatitis and alopecia. However, these articles have limitations because of their use of non-human mammals and the short duration of trials, and future research is needed to fill these gaps.

Keywords: *Astragalus*; Fabaceae; dermatological diseases; photoprotective activity; antimicrobial activity; cosmetics; phytochemical analysis

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1. Introduction

Medicinal plants are a rich source of bioactive substances, such as polyphenols, alkaloids, essential oils, vitamins, saponins and polysaccharides. These compounds exhibit a variety of valuable bioactivities [1,2], such as antioxidant, antimicrobial, photoprotective, anti-aging, wound-healing and anti-inflammatory activities, which are beneficial for skin, hair, and dental care. Plant-derived cosmeceuticals offer a wide range of practical benefits, and for this reason, they have the potential to be incorporated into cosmetic formulations. Among these compounds, plant metabolites with antioxidant, antimicrobial, anti-inflammatory, and photoprotective properties are the most widely used in the cosmetic industry [3].

The growing emphasis on a healthy and environmentally friendly lifestyle has led to increased interest in natural products, including phytocosmetics, which are often preferred by individuals concerned with the environment, health, and beauty. Therefore, it

is essential to actively explore, discover, and integrate these botanical ingredients into cosmetic formulations. Ensuring high-quality cosmetic products requires interdisciplinary collaboration among chemists, cosmetologists, botanists, toxicologists, and biologists.

Astragalus L. (Fabaceae) is one of the most widely distributed genera in the plant kingdom, with more than 3000 annual and perennial species found in Asia, Europe, Africa, and America [4]. Generally, most species of this genus are herbaceous perennials, but some are annuals or shrubs. To date, over 300 chemical constituents have been isolated from *Astragalus*, including polysaccharides [5], flavonoids, alkaloids, coumarin [6,7], saponins, steroids, organic acids, essential oils [8], and other bioactive compounds [9]. These components possess key properties, i.e., antioxidant, antitumor, antiviral and anti-inflammatory activities; antifatigue capability; and hypoxia resistance ability [10–12].

Generally, *Astragalus* species have a long history of use in traditional medicine as a natural remedy for the treatment of a variety of ailments. For instance, in Iranian traditional medicine, the crude herbal remedies produced from the roots of *Astragalus* species are used to treat respiratory infections, diabetes, and leukemia [13], while in traditional Chinese medicine they have been utilized for skeletal muscle atrophy, osteoporosis and fatigue-related syndromes [14–16]. Moreover, some species of *Astragalus* are used in the production of tragacanth gum (Tragacantha), a valuable traditional product employed as a thickener, stabilizer, or emulsifier in the food, pharmaceutical, and cosmetic industries. One of the most well-known *Astragalus* species is *Astragalus membranaceus* Fisch. ex Bunge (syn. *Astragalus mongholicus* Bunge), whose roots are widely used as a Qi-tonifying adaptogenic herb with anti-inflammatory, antioxidant, immunomodulatory, anticancer, antitumor, antihyperglycemic, hypolipidaemic, hepatoprotective, and diuretic properties [17,18]. However, current research data indicate that other *Astragalus* species also possess biological activities relevant to pharmaceutical and cosmetic applications. Extracts from *Astragalus* species, due to their active compounds, may be readily available and effectively used as active ingredients not only in the pharmaceutical industry but also in cosmetics. Therefore, traditional herbs like *Astragalus* provide a sustainable and safe alternative to synthetic anti-aging agents. From a regulatory perspective, *A. membranaceus* is widely recognized in the global cosmetic industry. According to the European Commission's database for cosmetic substances and ingredients (CosIng), the official International Nomenclature Cosmetic Ingredient (INCI) name for the extract derived from this species is "*Astragalus membranaceus* Root Extract". This standardized nomenclature ensures consistency in ingredient labelling across international markets, identifying the root as the primary botanical source for the bioactive saponins, flavonoids, and polysaccharides discussed in this review.

While *A. membranaceus* has been extensively studied and is currently the primary species utilized as a bioactive ingredient in commercial skincare, it represents only a fraction of this vast genus. Despite the existence of over 3000 *Astragalus* species worldwide, there is a significant lack of summarized scientific data regarding the cosmetic and dermatological potential of these lesser-known taxa. This review aims to bridge that gap by providing a comprehensive analysis of diverse *Astragalus* species, highlighting their untapped potential as innovative sources for modern cosmeceutical applications (Figure 1). The genus shows efficacy across a spectrum of dermatological pathologies, ranging from simple photoaging to complex inflammatory conditions like atopic dermatitis and psoriasis. Therefore, this review summarizes studies on effects of not only *A. membranaceus* but also other *Astragalus* species on the skin, highlighting the importance of this genus for future applications in dermatology and cosmetics.

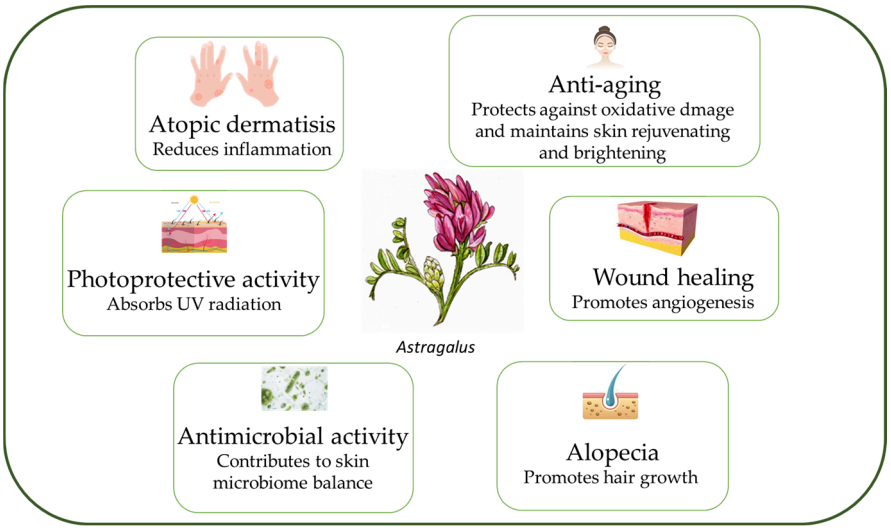


Figure 1. Biological activities of *Astragalus* species.

On the other hand, research on other *Astragalus* species, as well as clinical research studies on all *Astragalus* species, remains limited. Most of the studies were performed in vitro, whereas only a few studies provide preliminary evidence from animal models supporting the use of *Astragalus* in the treatment of alopecia, atopic dermatitis, and wound healing. It should also be mentioned that, while many studies on *Astragalus* focus on systemic organ systems (such as renal protection or hepatic fibrosis), the molecular insights gained from these models are translationally relevant to dermatology. For instance, the modulation of TGF-β1/Smad signalling as a primary target in systemic fibrosis research is identical to the pathway targeted in anti-aging cosmeceuticals to prevent collagen degradation. Similarly, the gut–skin axis highlights how the systemic anti-inflammatory effects of *Astragalus* polysaccharides can indirectly improve dermatological conditions like psoriasis or acne. By examining these systemic-to-dermal parallels, we can better understand the multi-target potential of *Astragalus* as both a topical active and a nutricosmetic agent. Further investigations are required to evaluate long-term efficacy, compare outcomes with existing therapies, and confirm effectiveness in human clinical trials. This review aims to serve as a bridge between ancient ethnopharmacology and cosmetic potential for the *Astragalus* genus, whose traditional use is supported by molecular evidence.

2. Electronic Literature Search

To assess the current state of knowledge regarding the cosmetic properties of *Astragalus* species for this review, a comprehensive literature search was conducted across major scientific databases, including PubMed, Scopus, Web of Science, and Google Scholar, targeting key word combinations (e.g., "*Astragalus* cosmetics", "*Astragalus* dermatology", "bioactive ingredients", "natural cosmetics"). Inclusion criteria included studies published in English between 2005 and 2026, focusing on natural cosmetic ingredients, *Astragalus* composition, and the use of *Astragalus* in dermatological diseases. The search results were meticulously analyzed and summarized under the following headings.

3. Chemical Profile of *Astragalus* Species

Astragalus species appear to be very consistent in terms of chemical composition. To date, more than 200 compounds have been discovered from several *Astragalus* species, including terpenoids, flavonoids, and polysaccharides (APSs) [19]. These species also contain amino acids, alkaloids, *β*-sitosterol, metallic elements, and anthraquinones, among others [20,21].

The major active ingredients in *Astragalus* sp. are saponins. They are classified as cycloartane tetracyclic triterpenoids, five of which constitute more than 80% of the total saponin content: astragalosides I (Figure 2a), II (Figure 2b), and IV (Figure 2c), as well as isoastragalosides I and II (Figure 2d,e) [22,23]. Saponins are among the most widely used groups of compounds—as natural soaps and detergents, foaming agents, and emulsifiers—in the cosmetic industry [24]. Astragaloside IV is the primary active component of *Astragalus* root and serves as a qualitative control biomarker for assessing the quality of raw plant material. Its benefits include positive effects on organ function, as well as anti-inflammatory, antiviral, and hypoglycemic effects. In addition, astragaloside IV has been shown to exert beneficial effects on the immune system and cell apoptosis and is used in cosmetics for its antioxidant, anti-inflammatory, anti-aging, and collagen-boosting properties [25–27].

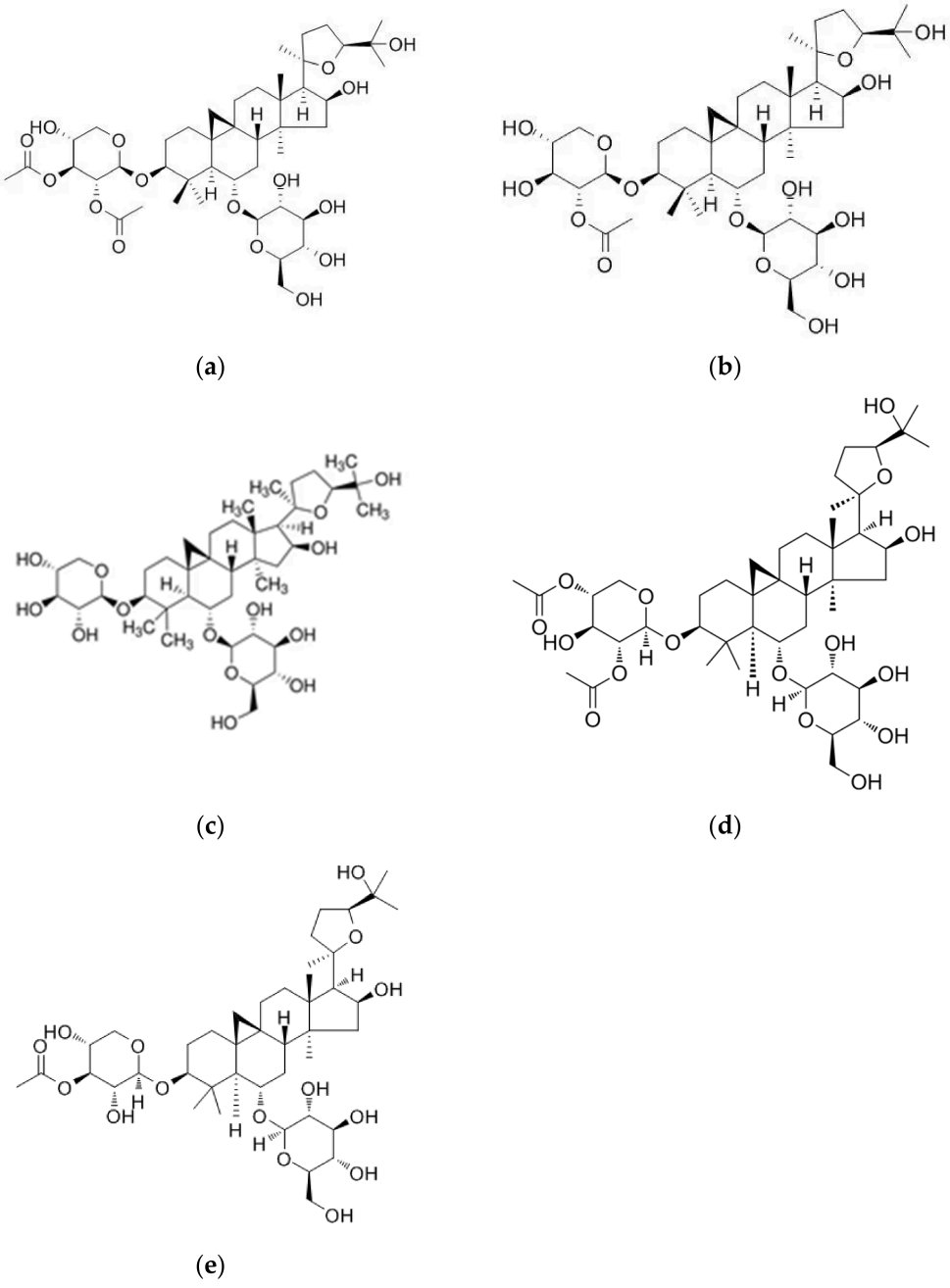


Figure 2. Major saponins identified in *Astragalus* species: (**a**) astragaloside I; (**b**) astragaloside II; (**c**) astragaloside IV; (**d**) isoastragaloside I; (**e**) isoastragaloside II.

Flavonoids are considered active ingredients in cosmetics. A significant portion of the chemical composition of *Astragalus* species comprises flavonoids, encompassing a variety of types, including flavonols, isoflavones, dihydroflavonoids, and dihydroflavones [28]. To date, approximately 50 flavonoids have been identified in *Astragalus* species, including 26 isoflavones (e.g., calycosin, formononetin, cajanin, and alfalone), 15 flavonols (e.g., kaempferol-3-O-β-D-glucopyranoside, quercetin-3-O-β-D-glucopyranoside, rhamnocitrin-3-O-β-D-neohesperidoside, and kaempferol 3,4′-diglucoside), eight isoflavans (e.g., pendulone and astramembraflavane A), and two chalcones (e.g., loureirin A and (Z)–2,4-dimethoxy-4-hydroxychalcone) [29]. They are used in skin care products mostly due to their soothing and antioxidant properties [30]. The most significant biologically active flavonoids include calycosin (Figure 3a), formononetin (Figure 3b), calycosin-7-O-β-D-glucoside (Figure 3c), kaempferol (Figure 3d), quercetin (Figure 3e), and ononin (Figure 3f). Flavonoids such as quercetin, cyanidin-3-glucoside and rutin are widely used in the cosmetic industry because they protect the skin from UV light [31], while calycosin and formononetin have been suggested as promising agents for the treatment of cutaneous inflammation [32]. Calycosin is also a promising component for skin-brightening formulations and has demonstrated antihypertensive and neuroprotective effects, proving its effectiveness in the prevention and treatment of cardiovascular and neurodegenerative diseases. Moreover, formononetin is used in cosmetics as an antioxidant and anti-aging agent, protecting skin from damage and promoting skin health by combating oxidative stress and improving skin condition [33–35]. In addition, it has a positive impact on the skeletal system, protecting osteoblasts and stimulating their osteogenic differentiation and exhibiting phytoestrogenic and anti-inflammatory effects. Quercetin is used in cosmetics for its antioxidant, anti-inflammatory, anti-aging and soothing properties, protecting skin from UV/pollution and reducing redness [36]. In addition, this flavonoid improves moisture retention, promotes skin repair, and helps control sebum excretion while reducing irritability by stimulating tight junction proteins for stronger cell-to-cell adhesion and strengthening the skin barrier function. This is beneficial for regulating water and minimizing dehydration and skin reactivity [37].

Among APSs (Figure 4), the most common sugars were identified as glucose, fructose, arabinose, and mannose [38]. Xu et al. divided these compounds into APS-I and APS-II and revealed that APS-I contained arabinose and glucose in a ratio of 1:3.45 (w/w) [39], while APS-II contained rhamnose, arabinose and glucose in a ratio of 1:6.25:17.86 ($w/w/w$), respectively. APS exerts anti-aging effects due to its antioxidant and lifespan-prolonging properties. APS exhibits resistance to oxidation and is able to scavenge free radicals, alleviate oxidative stress, inhibit lipid peroxidation and chelate iron ions in vitro [40]. Furthermore, APS increases superoxide dismutase activity while simultaneously reducing the production of malondialdehyde [41]; it can improve glutathione levels and total antioxidant capacity, as well as eliminate hydroxyl radical activity [42]. In addition, APS may exert anti-aging effects by regulating telomerase activity, modifying telomere-binding proteins, and preventing replicative shortening [43]. For these reasons, *Astragalus* polysaccharides are used in cosmetics for their moisturizing, antioxidant, anti-inflammatory, and anti-aging effects [44].

Recent investigations into the Mediterranean species *Astragalus armatus* Willd. have further expanded the known chemical diversity of the genus. Beyond the well-characterized saponins, this species has been identified as a significant source of potent phenolic acids, specifically rosmarinic and chlorogenic acids, which are highly valued in the cosmetic and pharmaceutical industries for their ability to combat lipid oxidation and oxidative stress [45]. The identification of these metabolites in non-conventional species like *A. armatus* reinforces the potential of the broader genus as a reservoir for safe natural antioxidant

compounds. Comprehensive antioxidant profiling of *A. armatus* using multiple assays, including CUPRAC, β-carotene bleaching, and hydroxyl radical scavenging, demonstrated the strong free-radical scavenging capacity of the plant.

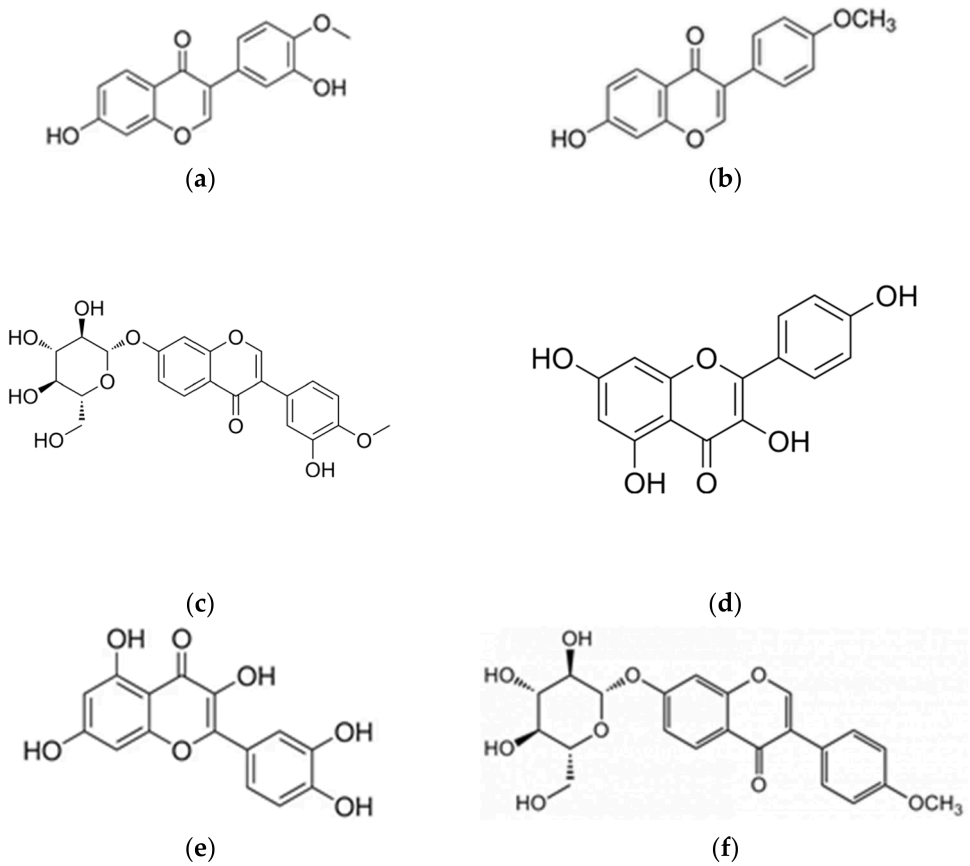


Figure 3. Major flavonoids found in *Astragalus* species: (**a**) calycosin; (**b**) formononetin; (**c**) calycosin-7-O-β-D-glucoside; (**d**) kaempferol; (**e**) quercetin; (**f**) ononin.

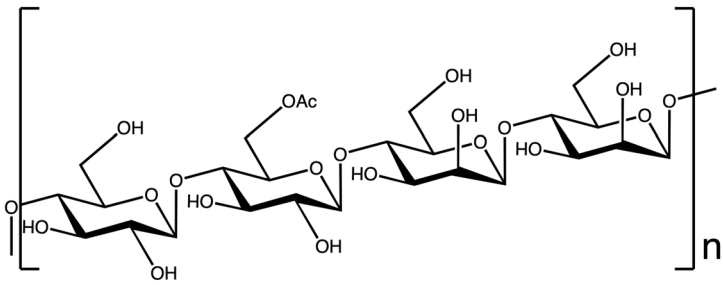


Figure 4. *Astragalus* polysaccharide (APS).

4. Dermatological and Cosmetic Properties

4.1. Skin Rejuvenating Activity

Maintaining optimal skin hydration and collagen levels is crucial for preserving skin health and appearance. In recent years, the incorporation of natural plant-based ingredients into skincare products has increased noticeably. Consequently, consumer demand for effective and natural plant-based skin rejuvenation solutions has grown [46,47]. Chan et al. [48] evaluated the effects of a saponin-based formulation of *A. membranaceus* and *Centella asiatica* (L.) (ACS) as a cosmetic ingredient and a functional supplement on skin health. For these randomized, double-blind, placebo-controlled trials, 150 healthy adults with no history of chronic skin diseases were recruited. They were assigned to groups receiving topical

ACS cream, oral ACS capsules, combined treatments, or corresponding placebos. The ACS capsules consisted of 125 mg of proprietary extract mixtures, while the placebo capsules contained maltodextrin. For topical application, an ACS cream formulation containing 5% ACS was used. Parameters such as skin brightness, moisture, elasticity, melanin value, pore count, texture, and collagen content were assessed over 4 to 12 weeks. According to the results, after 12 weeks of dual administration, participants noted a 4.2% increase in brightness, a 12.9% improvement in moisture retention, a 9.0% increase in elasticity, an 8.2% decrease in melanin, a 28.5% reduction in pore count, and a 13.7% elevation in collagen content. In addition, after 4 weeks of topical application, subjects exhibited a significant increase (8.7%) in collagen content and a 6.5% improvement in skin elasticity. Significant improvements in these physiological parameters were consistently observed across all ACS treatment groups, with the combined oral and topical group exhibiting the most prominent benefits. These findings confirm the potential of *A. membranaceus* and *C. asiatica* saponins, whether used topically, orally, or in combination, as both a topical cosmeceutical and a functional oral supplement for skin enhancement in healthy adults. Recently, innovative delivery systems, such as *Astragalus*-polysaccharide-hybridized microneedles [49], have emerged as clinical candidates for enhancing dermal penetration and promoting tissue regeneration, further supporting the plant's potential in advanced cosmeceutical applications.

Recent phytochemical and computational investigations have further clarified the molecular mechanisms by which *Astragalus* species mitigate skin aging at the enzymatic level. Astragalosides from *A. membranaceous* play a significant role in this process. These saponins have been shown to protect human skin fibroblasts from UVA-induced photoaging by reducing the levels of senescence-associated markers in cells [50]. The molecular mechanism involves the downregulation of matrix metalloproteinases (MMPs), including MMP-1, an enzyme responsible for collagen degradation, while simultaneously upregulating the expression of tissue inhibitor of metalloproteinase-1 (TIMP-1) and transforming growth factor-β1 (TGF-β1), which are crucial for maintaining the structural integrity of the skin's extracellular matrix. In a recent comprehensive study of *A. sarcocolla* leaf extract, UPLC-MS analysis identified 27 bioactive metabolites, predominantly flavonoids and phenolic acids. This extract demonstrated exceptional anti-aging potential by inhibiting MMP-1 (92.31%) and MMP-9 (95.89%) at low concentrations (1.3 μM), directly addressing the degradation of the dermal extracellular matrix [51]. Furthermore, network pharmacology and molecular docking analyses identified acacetin and apigenin as the key constituents responsible for these effects, showing high binding affinities for MMP-9, PTGS-2, and EGFR. These findings provide a scientific basis for the use of *Astragalus* extracts as standardized ingredients in multi-target anti-aging cosmeceuticals (Figure 5).

The findings reported by Han et al. [52] revealed that APSs exert their protective effects by activating the Nrf2-Keap1 signalling pathway, which significantly reduces reactive oxygen species (ROS) and decreases inflammatory markers such as IL-6 and MCP-1. Importantly, the study highlights that lower-molecular-weight polysaccharides demonstrate superior repair efficiency and antioxidant activity, providing a molecular rationale for their use in cellular regeneration.

Recent systems biology and network pharmacology analyses have further elucidated the multi-target mechanisms by which *Astragalus* provides therapeutic benefits. Research specifically focusing on the characteristic components, such as calycosin, formononetin, and astragaloside IV, indicates that these bioactives exert a strong regulatory influence on the MAPK, PI3K-Akt, and TNF signalling pathways [53]. These pathways are central to cellular stress responses, inflammation, and the regulation of the cell cycle. Furthermore, *Astragalus* has been shown to modulate core genes involved in apoptosis and tissue repair, such as

TP53, RELA, and the caspase family (CASP3/9). While these findings were primarily established in models of internal fibrosis, the overlap in biological signalling suggests that these same molecular targets are responsible for the anti-inflammatory and regenerative effects observed in skin tissue, supporting the use of *Astragalus* as an efficient cosmeceutical agent. The cosmeceutical potential of *Astragalus* is further supported by its ability to modulate key enzymes responsible for skin structural integrity [54]. By inhibiting these collagenases, *Astragalus* phytochemicals serve a dual role, promoting the production of new structural proteins while simultaneously preventing the breakdown of existing ones, a critical mechanism for topical anti-aging formulations. The regenerative properties of the genus are linked to the stimulation of fibroblast proliferation and migration. Research highlights that *Astragalus* polysaccharides accelerate the transition from the inflammatory phase to the proliferative phase of wound healing. From a cosmetic perspective, this is highly relevant for barrier-repair products, as it suggests that these extracts can enhance the recovery of the stratum corneum and improve the skin's resilience against physical and chemical irritants. At the molecular level, *Astragalus* species exert anti-inflammatory effects by suppressing the production of pro-inflammatory cytokines [54]. For the cosmetic industry, these findings support the inclusion of *Astragalus* in formulations designed for sensitive skin and anti-redness treatments, as the extracts help calm the skin's immune response to external stressors by inhibiting the NF-kappaB signalling pathway.

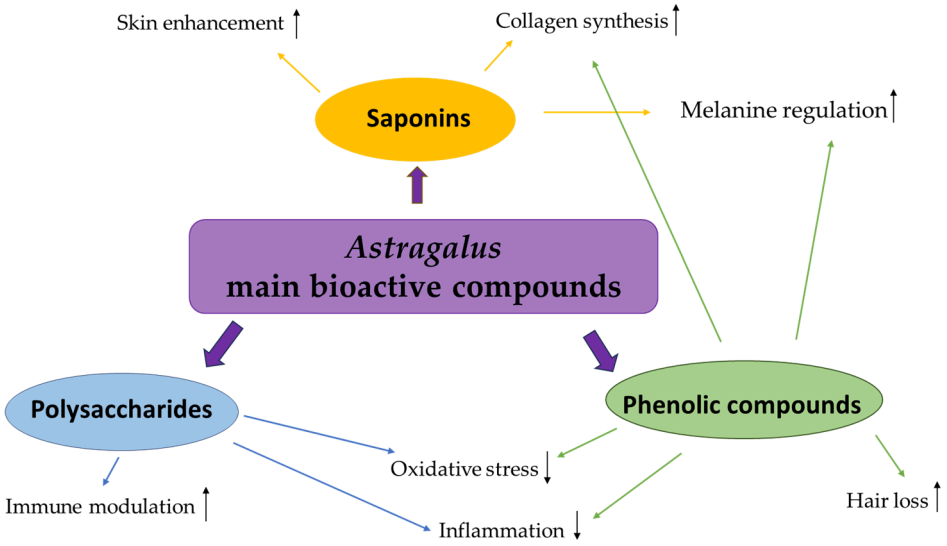


Figure 5. The anti-aging effects of the main bioactive ingredients of *Astragalus* on the skin.

Recent pharmacological investigations have highlighted the potential of *A. mongholicus* (syn. *A. membranaceus*) in the management of autoimmune-mediated skin disorders, particularly psoriasis. In the study by Cheng et al. [55], isolated human neutrophils were used to investigate the anti-inflammatory effects of a water extract prepared from *A. mongholicus* Bunge. To examine free radical scavenging capabilities for the superoxide anion, ROS, and nitrogen-centred radicals, cell-free assays were used, while an imiquimod (IMQ)-induced psoriasis-like skin inflammation mouse model was applied to investigate anti-psoriatic effects. In the study, BALB/C male mice were used, and 5% IMQ was applied to induce psoriasis-like skin inflammation. The *A. mongholicus* water extract was dissolved in the vehicle, consisting of 40% ethanol and 60% ddH_2O, before topical application. The animals were divided into three groups: the control group, in which mice received no treatment; the IMQ-plus-vehicle group, in which mice were treated with IMQ (62.5 mg/day) and vehicle (100 µL/day); and the IMQ-plus-*A. mongholicus* water extract group, which received equal doses of IMQ and *A. mongholicus* extract (10 mg/day), dissolved in vehicle. This study

demonstrated that water extracts of *A. mongholicus* effectively alleviate imiquimod-induced psoriasis-like skin inflammation by inhibiting the infiltration and activation of human neutrophils [55]. From a cosmetic and dermatological perspective, these findings are significant, as they suggest that *Astragalus* bioactives can modulate the IL-23/IL-17 axis, the primary driver of skin thickening and scaling. By reducing neutrophil-mediated oxidative stress and inflammatory signalling, *A. mongholicus* extracts offer a promising natural therapeutic strategy for soothing flaking skin conditions and restoring the cutaneous immune balance.

Another study demonstrated that APS treatment significantly improves imiquimod-induced psoriasiform dermatitis in mice by reducing the psoriasis area and severity index scores and suppressing the infiltration of macrophages into skin tissue [56]. These findings position *Astragalus* polysaccharides as promising candidates for topical or systemic formulations aimed at restoring skin barrier function and alleviating inflammatory dermatoses.

4.2. Skin-Brightening Activity

Skin-brightening and "glow" products are top priorities for cosmetic consumers, particularly in Asian markets. The cosmetic value of *A. membranaceus* is significantly enhanced by its ability to regulate skin pigmentation. Research into its anti-melanogenic properties has revealed that *A. membranaceus* extracts effectively inhibit melanin synthesis in B16F10 melanoma cells without inducing cytotoxicity [57]. This effect is primarily achieved through the activation of the extracellular signal-regulated kinase (ERK) signalling pathway, which leads to subsequent downregulation of microphthalmia-associated transcription factor (MITF) and tyrosinase (TYR)—the rate-limiting enzyme in melanogenesis. Unlike traditional skin-lightening agents that may cause irritation, *Astragalus* offers a natural mechanism to reduce melanin content and tyrosinase activity, making it a promising candidate for treating melasma, age spots, and uneven skin tone through targeted cell signalling modulation.

The specific contribution of calycosin to the brightening efficacy of the *Astragalus* genus was established through bioassay-guided fractionation, which identified this isoflavone as a potent inhibitor of melanin biosynthesis [58]. In vitro studies demonstrate that calycosin inhibits mushroom tyrosinase and significantly reduces melanin production in Melan-a cells. These findings solidify calycosin's role as a primary marker compound for the standardization of *Astragalus*-based cosmeceuticals, ensuring that extracts are optimized for maximum whitening performance while maintaining the high safety standards required for topical application. Relevantly, another study on calycosin revealed that its skin-lightening effect is driven by the downregulation of the PKA/CREB and p38 MAPK signalling pathways [59]. By blocking these specific cascades, calycosin effectively suppresses the expression of MITF. This mechanism was further validated in vivo using zebrafish embryos, where calycosin significantly reduced body pigmentation. From a dermatological perspective, this upstream intervention offers a distinct advantage over single-target inhibitors like kojic acid; by silencing the cellular command for melanin production rather than just competing for enzyme binding sites, *A. membranaceus* bioactives provide a more holistic and potentially more stable approach to managing hyperpigmentation in complex skin environments.

The structural basis for the anti-melanogenic activity of the genus lies in its unique profile of cycloartane-type triterpene glycosides. Structure–activity relationship (SAR) studies have demonstrated that these specific saponins, isolated from various *Astragalus* species, act as potent TYR inhibitors [60]. For instance, compounds such as astragaloside IV and other cycloartane derivatives show significant inhibitory effects on the monophenolase activity of tyrosinase. This inhibition is particularly effective when the chemical structure includes specific glycosidic patterns, which allow the molecule to interfere with the enzyme's catalytic site. From a cosmetic formulation perspective, this indicates that the "bright-

ening" efficacy of *Astragalus* is highly dependent on the concentration of these specific glycosides. By targeting the rate-limiting step of melanin production at a molecular level, these compounds offer a scientifically validated alternative to synthetic skin-lightening agents, aligning with the industry's shift toward high-performance, natural bioactives.

While traditional research has focused on *A. membranaceus* roots, a recent investigation reported the isolation of several bioactive metabolites, including new isoflavane derivatives and oleanane-type triterpenoid saponins, which exhibit significant inhibitory effects on TYR [61]. Kinetic and molecular dynamics simulations revealed that these compounds utilize diverse inhibitory modes; for instance, certain isoflavanes act as competitive inhibitors by binding directly to the enzyme's catalytic site, while others function through non-competitive or uncompetitive mechanisms at allosteric sites. These findings confirm that the aerial metabolites of *A. membranaceus* possess the stability and binding affinity required to effectively disrupt melanogenesis, offering a multifaceted approach to treating hyperpigmentation and enhancing skin radiance. Interestingly, the dermatological application of *Astragalus* extends beyond simple lightening to include the treatment of depigmentation disorders, such as vitiligo, demonstrating a complex regulatory effect on melanocytes. Astragaloside IV was actually revealed to promote melanin synthesis in normal human epidermal melanocytes (NHEMs) [62]. Unlike the inhibitory effects of its isoflavones, astragaloside IV activates the aryl hydrocarbon receptor (AhR), which subsequently triggers the AKT/GSK-3β/β-catenin signalling pathway. For the cosmetic and pharmaceutical industry, this highlights the adaptogenic nature of the genus; while certain fractions (rich in calycosin) are suitable for skin-brightening products, others (rich in astragaloside IV) may be developed as therapeutic agents for restoring natural pigmentation in conditions of pigment loss.

Modern cosmetic processing techniques, such as fermentation, have been shown to significantly enhance the skin-brightening efficacy of *Astragalus* extracts. Research utilizing metabolomics-based analysis demonstrated that when *Astragalus* radix is fermented with *Aspergillus oryzae*, there is a marked increase in the concentration of key aglycone isoflavones, specifically calycosin and formononetin, alongside the production of kojic acid [63]. Correlation analyses identified calycosin as a primary driver of tyrosinase inhibition within these fermented systems. From a cosmeceutical perspective, this biotransformation is critical; the conversion of glycosides (like calycosin-7-O-α-D-glucoside) into their more lipophilic aglycone forms not only improves their inhibitory potency against TYR but also potentially enhances their skin penetration.

The selection of extraction solvents plays a critical role in the anti-melanogenic potency of *Astragalus* species, as demonstrated in a 2024 study on *Astragalus aduncus* [64]. Research using multi-solvent systems revealed that methanol and water extracts exhibit superior TYR inhibitory activity compared to less polar solvents such as ethyl acetate. This enhanced efficacy is attributed to the higher recovery of specific phenolics and flavonoids. For cosmetic formulators, this suggests that hydromethanolic or aqueous extraction remains the most effective method for obtaining the brightening fractions of the genus. These findings emphasize that maximizing the anti-melanogenic potential of *A. aduncus* Willd. (syn. *A. cumanus* Willd. ex Steud.) in dermocosmetics requires a strategic focus on polar secondary metabolites capable of effectively targeting the enzyme's active site. The distribution of anti-melanogenic compounds across different plant organs is also a critical factor for the industrial standardization of *Astragalus*-based cosmetics. A comparative study on *A. macrocephalus* subsp. *finitimus* demonstrated that TYR inhibitory activity is present throughout the plant, with IC_{50} values ranging from 1.02 to 1.41 mg/mL across the aerial parts, leaves, flowers, stems, and roots [65]. This widespread efficacy is linked to a diverse polyphenol profile, in which hyperoside, apigenin, *p*-coumaric acid, and ferulic acid

were identified as the primary bioactive constituents. From a cosmeceutical perspective, the presence of ferulic acid is particularly significant, as it is a well-established industry standard for improving skin radiance and stabilizing other antioxidant vitamins.

In addition to non-volatile phenolics and saponins, the volatile fraction of the *Astragalus* genus has recently been identified as a significant contributor to its anti-melanogenic potential. Another comparative study of six *Astragalus* species from Uzbekistan utilized GC-MS to identify nearly one hundred volatile metabolites, such as sylvestrene and (E)-2-hexenal, with the volatile oil of *A. lehmannianus* demonstrating the most notable TYR inhibitory activity (138.42 mg KAE/g) [66]. While these values may appear modest, when compared to pure synthetic benchmarks like kojic acid, the cosmetic value of *A. lehmannianus* lies in its superior safety profile and multi-target approach. Unlike kojic acid, which is frequently associated with skin irritation and instability, *Astragalus* volatiles and extracts offer a biocompatible alternative for addressing pigmentation. From a cosmetic perspective, these findings are highly innovative, as they suggest that the aromatic profile of *Astragalus* does not merely serve a sensory purpose but also provides functional skin-brightening benefits, making it an ideal candidate for high-performance formulations designed for sensitive skin.

In an excellent recent review in 2026 by Jackson et al. [67], the transition from laboratory-scale findings to clinical dermatological applications was further validated by a systematic review (2015–2025), which characterizes *A. membranaceus* as a multifunctional anti-aging botanical. It was highlighted that the anti-melanogenic effects of the genus are rarely isolated; rather, they occur alongside significant photoprotective and telomere-preserving activities. Notably, the limited clinical data suggests that *A. membranaceus* extracts improve overall skin tone and hydration while simultaneously reducing rhytids (wrinkles) through the inhibition of inflammatory signalling and the promotion of collagen synthesis. For the cosmetic industry, this suggests that *Astragalus* should not be marketed solely as a skin-whitener but as a comprehensive rejuvenating agent that addresses the signs of photoaging, where hyperpigmentation and structural aging intersect. The ability of astragaloside IV to preserve mitochondrial function and elongate telomeres under oxidative stress adds a layer of longevity science to its profile, positioning it as an ingredient for high-quality restorative skincare products.

4.3. Photoprotective Activity

The deleterious effects of exposure to ultraviolet (UV) radiation on the skin have become increasingly apparent. Consequently, sunscreen and skincare products have been developed to help to reduce the occurrence of sunburn, photoaging, and skin carcinogenesis. Phenolic compounds are characterized by their ability to absorb ultraviolet radiation in the ranges of 240–285 nm and 300–550 nm, which is related to the presence of an aromatic ring [68]. According to the literature, the sun protection factors (SPFs) of flavonoids, stilbenes and hydroxycinnamic acid derivatives range from 7 to 29 SPF, corresponding to minimal (SPFs from 2 to 12) and moderate (SPFs from 12 to 30) sun protection [69,70]. However, it should be remembered that, due to the low concentrations of polyphenols in cosmetics, they cannot provide sufficient protection against UV radiation; they can only support this effect. This is particularly important in the context of the prevention of neoplastic diseases, including skin cancers such as melanoma [71,72].

Lekmine et al. [73] analyzed a hydroethanolic extract of *A. gombiformis* Pomel from semi-arid regions of southern Algeria to explore its photoprotection activity. The photoprotective activity of *A. gombiformis* extract against UV damage was assessed through in vitro determination of its SPF. Based on the results, *A. gombiformis* extract demonstrated an excellent capacity to absorb UV radiation, with an SPF of 37.78. This effect may be attributed

to the presence of rosmarinic acid, which is recognized as a photoprotective agent against UV and other ionizing radiations [74]. Therefore, *A. gombiformis* could be employed as a natural sun protection product in sunscreen formulations, as skincare products with SPF values higher than 30 are considered effective UV filters [75]. However, future randomized trials are needed to confirm these findings. In another study, Curnow and Owen [76] investigated whether root extracts of *A. membranaceus* and *Althea officinalis* L. could protect the DNA of cultured human cells from UV-induced damage. The results indicated that these phytochemically rich root extracts have the potential to serve as useful natural components in dermatological formulations, where a reduction in oxidative stress-induced damage is desired.

Phytochemical screening indicates that the high concentrations of total phenolics and flavonoids in various *Astragalus* species correlate directly with their 1,1-diphenyl-2-picrylhydrazyl (DPPH) and ABTS radical scavenging activities. This antioxidant capacity is vital for cosmetic applications aimed at neutralizing ROS produced by environmental pollutants and blue light, thereby protecting skin cells from oxidative stress-induced lipid peroxidation and DNA damage [54]. Among the diverse flavonoids in the *Astragalus* genus, formononetin, found in *A. mongholicus*, has emerged as a potent bioactive agent for maintaining skin homeostasis and combating environmentally induced damage [77]. Recent molecular reviews of both in vitro and in vivo (rodent or non-cutaneous models) studies highlight its ability to activate the Nrf2/HO-1 signalling pathway, which acts as the skin's primary defence mechanism against oxidative stress and heavy metal toxicity. By upregulating endogenous antioxidant enzymes like superoxide dismutase (SOD) and glutathione (GSH), formononetin effectively neutralizes ROS. Furthermore, formononetin demonstrates a strong anti-inflammatory profile by inhibiting the nuclear factor kappa-light-chain-enhancer of activated B cells (NF-κB) and MAPK/JNK pathways, thereby reducing the production of pro-inflammatory mediators such as nitric oxide (NO) and prostaglandin E2 (PGE2). In a cosmetic context, this translates to a dual-action ingredient that not only prevents the visual signs of "inflammaging"—the chronic, low-grade inflammation that accelerates wrinkles—but also strengthens the skin barrier against daily pollutants and irritants.

Beyond its pigment-regulating capabilities, *A. membranaceus* root extract serves as a potent photoprotective agent by preserving the structural integrity of the dermal extracellular matrix (ECM) under ultraviolet B (UVB) stress. Hong et al. [78] have investigated the photoprotective effect of *A. membranaceus* on UVB radiation-induced activation of NF-κB activity in human dermal fibroblasts. The obtained results showed that *A. membranaceus* significantly inhibits the expression of MMP-1, the primary collagenase responsible for the degradation of type I procollagen in human dermal fibroblasts [78]. This protective effect is mediated through the suppression of NF-κB activity that is upregulated upon UV exposure. Consequently, *A. membranaceus* may also be considered as a candidate for use in sun-care formulations.

While much of the anti-melanogenic activity of the *Astragalus* genus is attributed to its phenolic and saponin content, APS also plays a vital role in comprehensive photoprotection. Research on the effects of APS in UVA-irradiated HaCaT cells demonstrates that these macromolecules significantly mitigate photo-damage by reducing the accumulation of ROS and preventing the loss of mitochondrial membrane potential [79]. From a cosmetic formulation perspective, this positions *Astragalus* polysaccharides as an essential biological shield against UVA radiation, which is a primary driver of extrinsic skin aging. By preserving cellular viability and maintaining the redox balance within keratinocytes, APS-rich extracts provide a foundational layer of protection that complements the brightening effects of

other *Astragalus* metabolites, making the genus a highly versatile candidate for daytime urban-protection skincare ranges.

4.4. Atopic Dermatitis

Atopic dermatitis is the most common chronic inflammatory skin disease, with a multifactorial etiology involving both genetic and environmental factors. This chronic disorder is commonly treated with steroids, antihistamines, immunosuppressive agents, and other medications. However, their long-term use or even their abuse may lead to various adverse side effects. Consequently, recent studies have increasingly focused on complementary therapies.

The therapeutic utility of the *Astragalus* genus is further extended by its profound immunomodulatory effects on chronic inflammatory skin conditions such as atopic dermatitis. Calycosin is likely responsible for these biological effects. Ma et al. [32] evaluated the efficacy and safety of calycosin in the treatment of atopic dermatitis. The cell viability and anti-inflammatory impacts of calycosin in vitro were gauged using CCK-8 and RT-qPCR, while in vivo therapeutic efficacy of topical calycosin application was assessed using a calcipotriol (MC903)-induced atopic dermatitis mouse model. The results indicated that calycosin exerts anti-inflammatory activity, particularly by promoting the differentiation of immunosuppressive regulatory T cells and inhibiting T helper cell differentiation, suggesting its potential as an alternative or adjunctive treatment strategy for managing atopic dermatitis. Both in vivo and in vitro models indicated that calycosin promotes the expression of Foxp3, a critical transcription factor for Treg function, while simultaneously suppressing the infiltration of inflammatory cells and reducing the levels of pro-inflammatory cytokines such as IL-4, IL-5, and IL-13. Mechanistically, this effect is mediated through the AhR-STAT5 signalling pathway. From a cosmetic and dermatological perspective, this evidence supports the use of calycosin-rich *A. membranaceus* extracts in specialized "barrier-repair" and "calming" formulations. By addressing underlying immune dysregulation rather than merely masking surface redness, *Astragalus* offers a targeted approach for managing the itch–scratch cycle and restoring skin homeostasis in individuals with sensitive or hyper-reactive skin profiles.

Further expanding the dermatological repertoire of the *Astragalus* genus, the isoflavone formononetin has been identified as a potent modulator of skin inflammation through the activation of the G protein-coupled estrogen receptor (GPER) [34]. The aim of the study was to investigate the potential mechanism of formononetin in alleviating the initial responses of atopic dermatitis and to elucidate its possible therapeutic targets in vivo and in vitro. This study demonstrated that formononetin attenuates atopic dermatitis by upregulating the expression of A20 (TNFAIP3), a key zinc finger protein that acts as a negative regulator of the NF-κB signalling pathway. By enhancing A20 levels, formononetin effectively suppresses the production of pro-inflammatory cytokines and chemokines, which are central to the pathogenesis of atopic dermatitis. From a cosmetic view, this research highlights formononetin as a specialized ingredient for barrier-strengthening formulations. Its ability to provide estrogen-like anti-inflammatory benefits—without the systemic risks associated with traditional hormone therapies—makes it a promising candidate for managing hormone-sensitive or menopausal skin thinning and inflammation. This mechanism complements the immunomodulatory role of calycosin, suggesting that whole-root *A. membranaceus* extracts provide a multi-layered defence against the chronic inflammation and barrier dysfunction characteristic of hyper-reactive skin.

An ethanol extract of *A. membranaceus* was investigated for its protective effects on atopic skin lesions in mice treated topically with 1-chloro-2,4-dinitrobenzene (DNCB). The evaluation included histopathological examination and assessment of the activation of NF-

κB, as well as measurements of serum immunoglobulin E (IgE) and cytokine levels [80]. The results demonstrated that *A. membranaceus* reduced inflammation by suppressing DNCB-induced NF-κB activation in a murine model of atopic dermatitis. Lu et al. [81] also confirmed the potential factor of *A. membranaceus* as an adjunctive therapy for mitigating side effects and improving clinical symptoms, offering a safer alternative to existing treatments.

4.5. Alopecia

Alopecia is a chronic dermatological disorder characterized by hair loss from the scalp and, in some cases, from the body [82]. Pathophysiologically, this disorder is characterized by the shrinking of hair follicles and impairment of their cyclical growth. Due to the high prevalence of alopecia, numerous products aimed at enhancing hair growth and preventing hair loss have been developed. Synthetic drugs used in the treatment of hair loss affect the hair growth cycle and increase the length and diameter of existing hair shafts. However, conventional dosage forms such as oral tablets and topical solutions present several limitations in the management of alopecia. In particular, in transdermal drug delivery, topical solutions often provide poor drug permeation through the skin and are unsuitable for hydrophobic drugs [83]. Recent research on alopecia treatments has increasingly highlighted the role of bioactive compounds derived from plants in promoting hair regrowth. These phytochemicals exhibit multi-targeted actions with fewer side effects compared to synthetic drugs. They demonstrate antioxidant, anti-inflammatory, anti-androgenic, and regenerative effects on hair follicles, positioning them as promising alternatives or complements to conventional therapies.

In the study by Kim et al. [84], the beneficial effects of astragaloside IV on hair loss were demonstrated through the inhibition of apoptosis-related signalling pathways in mice. The authors treated the dorsal skin of depilated C57BL/6 mice with 1 and 100 μM astragaloside IV for 14 days. The results showed that astragaloside IV markedly decreased the expression of caspases, NF-κB, x protein (Bax), p53, and Fas/Fas-ligand [a type-II transmembrane protein in the TNF superfamily] signalling while upregulating the anti-apoptotic proteins B-cell leukemia 2 (Bcl-2) and B-cell lymphoma-extra-large (Bcl-xL). In addition, activation of NF-κB and phosphorylation of IκB-α were inhibited by astragaloside IV, along with reductions in MAPK pathway components, including: ERK, SAPK/JNK and p38. The expression of KGF, p21, TNF-α and IL-1β, which are keratinocyte terminal differentiation markers associated with catagen, was modulated by astragaloside IV. Consequently, astragaloside IV obtained from *A. membranaceus* may be considered a potential natural agent for treatment of hair diseases such as alopecia, effluvium, and hirsutism. In addition, *A. membranaceus* and *A. sinicus* L. can also be used to improve hair loss. Jeon et al. [85] assessed the potential of *A. sinicus* to alleviate dihydrotestosterone-induced damage in human follicle dermal papilla cells caused by dihydrotestosterone. Based on their findings, *A. sinicus* extracts facilitated wound healing, elevated alkaline phosphatase expression in dihydrotestosterone-damaged human follicle dermal papilla cells and substantially enhanced phosphorylation of acutely transforming retrovirus thymoma (AKT)/ERK pathway and activated the Wnt signalling pathway. This study suggests that *A. sinicus* extracts may represent a promising natural ingredient for hair loss treatment.

4.6. Wound Healing

Plants have been employed as therapeutic agents for wound healing for centuries, reflecting their long-standing use in traditional medicine. Their pharmacological effects are largely attributed to the biological activities of their secondary metabolites. Boiling water extracts of *A. membranaceus* roots were used to evaluate wound-healing effects [86]. In this study, experimental open wounds were created on the dorsal side of rats under anesthesia,

and the extract of *A. membranaceus*, incorporated into a hydrophilic foam dressing, was topically applied to the wounds once a day for 11 days. The healing process was evaluated by scoring macroscopic appearance and measuring the area of the open wounds. The results indicated that *A. membranaceus* promoted basal cell proliferation and angiogenesis and significantly reduced the duration of the wound-healing process. In another study using a mouse model of diabetes-associated wounds, astragaloside IV was investigated for its potential efficacy in impaired wound healing in streptozotocin-induced diabetic mice [87]. The results showed that astragaloside IV promoted diabetic wound repair and improved neovascularization in wound tissue, suggesting that it may play an important role in maintaining cutaneous homeostasis and accelerating diabetic wound healing. The authors proposed that this effect may be associated with the induction of alternatively activated macrophages in the wound tissues, together with the upregulation of extracellular matrix deposition and promotion of neovascularisation.

Additionally, the wound-healing properties of tragacanth gel 5% (*w*/*v*), prepared by dissolving powdered tragacanth gum extracted from Iranian *A. gummifer* Labill. in deionized water, were evaluated using a rat model of a full-thickness excisional skin wound [88]. In another study, 10 albino rats weighing about 250 g were used, and two similar (15 mm) parasagittal full-thickness elliptical skin wounds were created, 3 cm apart, on the dorsum of each rat using a scalpel, so each animal served as its own control. Approximately 250 µL of tragacanth gel was applied daily onto the right-side wound of each animal (test samples) for 10 days, while the left-side control wounds received equivalent amounts of sterile deionized water. The results revealed that approximately 90% wound closure occurred within one week in the tragacanth-treated group, and after 10 days, all of the tragacanth-treated wounds were completely or almost completely closed. These findings suggest that the gum tragacanth may be an effective, easy-to-prepare, safe, biocompatible, cheap, and readily available agent for wound dressings. Moreover, a recent study of *A. membranaceus* polysaccharides reported that *Astragalus*-based treatments have been clinically used to promote angiogenesis and are commonly employed in the management of chronic skin ulcers and slow-healing wounds [89,90].

4.7. Antimicrobial Activity

Cosmetics contain organic and inorganic compounds as well as water, which can promote the growth of pathogenic microorganisms and pose a risk to consumers. Therefore, current cosmetic regulations require microbiological purity testing of products to exclude the presence of the most common pathogens, including *Staphylococcus aureus*, *Citrobacter freundii*, *Pseudomonas aeruginosa*, and *Candida albicans*. *S. aureus* causes various skin infections and is partially responsible for the symptoms of atopic dermatitis. A significant correlation has been observed between the degree of *S. aureus* colonization and disease severity [91]. In addition, *S. aureus* induces superficial infection of the epidermis (impetigo), deep ulcerative skin infections, and infection of hair follicles, abscesses, wounds, and ulcers. Infections caused by *P. aeruginosa* are commonly associated with burns, surgical wounds, and vascular diseases [92], whereas *Candida* species cause chronic mucocutaneous candidiasis characterized by persistent mucocutaneous lesions.

Plant extracts exhibiting antimicrobial or antifungal activity are valuable, as they can reduce skin infections and additionally inhibit the growth of microorganisms inside cosmetic products. Phenolic compounds have beneficial effects on the skin, protecting it from pathogenic bacteria, fungi, yeasts and viruses [93]. The mechanism of this activity is mainly related to the inhibition of proteolytic enzymes by disrupting the synthesis of nucleic acids and increasing the permeability of the cell wall to exogenous substances. Antimicrobial properties of these compounds help maintain cosmetic purity by protecting

the product against contamination. However, they do not replace preservatives but may support their action.

Among *Astragalus* species, alcohol extracts of whole plants most commonly possess antibacterial and antifungal activity. To date, however, the antibacterial and antifungal activities of only a few *Astragalus* species have been studied. Ercan et al. [94] evaluated the effect of ethanolic *A. elatus* (Hook. & Arn.) Reiche extract on seven microorganisms, namely, *K. pneumoniae*, *E. coli*, *K. aerogenes*, *B. spizizenii*, *B. megaterium*, *S. aureus*, and *C. albicans*. *A. elatus* extract exhibited antimicrobial efficacy at various levels against all tested microorganisms. It was observed that antimicrobial activity of the extract increased with rising concentration, and a concentration of 50 µg/mL exhibited antimicrobial activity of 57.28% against *K. pneumoniae*, 57.86% against *E. coli*, 73.30% against *K. aerogenes*, 93.75% against *B. spizizenii*, 68.43% against *B. megaterium*, 74.05% against *S. aureus*, and 54.38% against *C. albicans* compared with the reference antibiotic amikacin.

In another study, Aydemir et al. [95] analyzed the methanolic extracts of *A. gymnolobus* Fisch. obtained from different plant organs (leaves, roots, stems, flowers, and whole plant) against 16 clinically important Gram-positive and Gram-negative ATCC standard bacteria strains. Antibacterial activity was assessed using disc diffusion and broth microdilution methods. The results showed that all extracts exhibited antibacterial activity against only *S. pyogenes*, with an inhibition zone diameter of 9–11 mm and a minimum inhibitory concentration (MIC) value of 8192 µg/mL. Additionally, three *S. aureus* strains (ATCC25923, ATCC29213, and ATCC43300) were sensitive to the methanolic extracts of leaves and whole plants, showing inhibition zone diameters of 8–9 mm. Moreover, among all the tested extracts, the whole-plant extract exhibited the highest antibacterial activity against these bacteria. Similar results were obtained by Türker and Koyluoglu [96], who evaluated the biological activities of water, methanol, and ethanol extracts prepared from eight Turkish endemic plants and found that the methanolic extract of *A. gymnolobus* was effective only against *S. pyogenes*, causing a 7 mm inhibition zone.

Yildirim et al. [97] also analyzed the antibacterial activities of methanolic leaf extracts of *A. gymnolobus* and found that the plant exhibited antibacterial potential against only *S. pyogenes*, *S. aureus*, and *S. epidermidis*. These findings indicate the potential application of *A. gymnolobus* as an active antibacterial ingredient against *S. pyogenes*-induced skin and soft tissue infections and *S. aureus* infections, as well as a natural preservative in cosmetic formulations. Furthermore, Türker and Yıldırım [98] analyzed the antibacterial activity of aqueous, methanolic and ethanolic extracts prepared from *A. brachypterus* Fisch. According to their results, all extracts of this species had activity against only *S. pyogenes*. Keskin et al. [99] similarly reported that the methanolic extract of *Astragalus gymnalopecias* Rech. was effective only on *S. pyogenes*, producing a 12 mm inhibition zone. In the study by Jaradat et al. [100], *A. pelecinus* (L.) Barneby was collected from the Jerusalem mountains of Palestine, and its aqueous and methanolic extracts were subsequently analyzed. Antimicrobial activity and MIC were determined using the broth microdilution method. The extracts were tested against *Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa*, methicillin-resistant *S. aureus* (MRSA) and *C. albicans*. Based on the results, the methanolic extract of *A. pelecinus* exhibited antimicrobial activity against *S. aureus*, MRSA and *E. coli* with an MIC of 51.5 mg/mL. Both MRSA and *E. coli* are known contaminants of cosmetic products, posing a risk of infections, including facial skin infection. Moreover, Szabo et al. [101] analyzed the antimicrobial effects of *A. exscapus* ssp. *transsilvanicus* (Schur) Nyár. collected from Transylvania against four bacterial strains (*S. aureus*, *E. coli*, *P. aeruginosa*, and *S. typhimurium*) and two yeast species (*C. albicans* and *C. parapsylosis*) by determining the MIC values. The results showed that the *A. exscapus* aqueous extract exhibited antimicrobial activity against *S. aureus* (MIC = 33 mg/mL), MRSA (MIC = 33 mg/mL), *E. coli* (MIC = 33 mg/mL),

P. aeruginosa (MIC = 66 mg/mL), and *C. albicans* (MIC = 33 mg/mL). In contrast, the methanolic extract showed antimicrobial effect against *S. aureus*, MRSA and *E. coli*, with an MIC value of 51.5 mg/mL in all cases. In contrast, the methanolic extract of the Turkish *A. argaeus* Boiss. & Balansa. was shown to be active against *P. aeruginosa* with 7.0 mm inhibition zones at concentrations of 10 and 5.0% [102].

5. Toxicity and Clinical Trials

The poisonous *Astragalus* species can be divided into three groups, according to the toxins and their effects on animals. In the first group are species that synthesize aliphatic nitro compounds, including *A. miser*, *A. falcatus*, *A. glycyphyllos*, and *A. hamosus* [103]. These species can synthesize aliphatic nitro compounds, which are transformed in the rumen to the toxic principles 3-nitro-1-propanol and 3-nitropropionic acid. In the second group are species such as *A. lentiginosus*, *A. pubentissimus*, *A. mollissimus*, *A. wootoni*, *A. thuseri*, and *A. nothrosys*. They are responsible for locoweed poisoning in grazing animals, including horses, cattle, sheep, and goats [104,105]. Consumption of these plants leads to weight loss, altered behaviour, ataxia, and death [106]. These species contain swainsonine, an indolizidine alkaloid identified as the main toxin. This alkaloid inhibits acidic amannosidases at different concentrations in various tissues. This effect disturbs glycoprotein synthesis, while the accumulation of mannose-rich oligosaccharides in the testis and epididymis induces biochemical abnormalities in reproductive tissues and impacts male reproduction [107]. Finally, the third group includes species that accumulate selenium. Among the known seleniferous *Astragalus* species are *A. bisulcatus*, *A. saurinus*, *A. praelongus*, *A. flavus*, and *A. tenellus* [108]. Chronic poisoning is characterized by a rough hair coat, loss of hair, lameness, hoof lesions, decreased vitality, loss of appetite, and a decrease in reproductive efficiency.

Moreover, to verify the clinical safety of *A. membranaceus*, several studies on the preclinical toxicity of its bioactive compounds have been carried out. The results showed fetal toxicity of AS-IV at a dose above 0.5 mg/kg and maternal toxicity after intravenous administration at 1.0 mg/kg [109]. However, in the case of rats and rabbits, this compound showed no teratogenic effects [109]. Moreover, the AS-IV below 1.0 mg/kg caused a delay in fur development, the righting reflex, and eye opening after birth during a reproductive toxicity test in Sprague-Dawley rats [110]. In addition, it is necessary to evaluate the therapeutic effects of *A. membranaceus* in humans through clinical trials. Some studies have shown its positive effect in patients with myocardial infarction and children with growth retardation syndrome [111,112].

6. Formulation Studies

Despite the relative scarcity of dedicated clinical formulation studies, the genus *Astragalus* is firmly established in the cosmeceutical industry, with several species recognized under the International Nomenclature of Cosmetic Ingredients (INCI). As mentioned above, the most prominent is *Astragalus membranaceus* root extract (CAS No. 94166-93-5; EC No. 303-391-9), which is categorized by the European Commission's CosIng database and the U.S. Personal Care Products Council as a skin-conditioning, emollient, and antioxidant agent [67]. Regulatory assessments and Safety Data Sheets (SDSs) for commercial preparations, often supplied in glycerine or aqueous–glycolic bases, indicate a favourable safety profile with negligible risk of sensitization at typical inclusion levels (0.1–5%). From a formulation standpoint, the primary challenge involves the dermal delivery of large-molecule polysaccharides and lipophilic saponins. Recent research has sought to overcome these barriers through advanced delivery systems, including polysaccharide-hybridized hydrogel microneedles and liposomal encapsulations, which improve the stability and penetration of key markers like astragaloside IV [113]. In more detail, *Astragalus* polysac-

charide liposomes (APSLs) were reported to significantly improve the phagocytic capability of macrophages [114]. They also led to a marked increase in the production of pro-inflammatory cytokines, specifically IL-6 and IL-12, and elevated the secretion of NO and the expression of inducible nitric oxide synthase (iNOS). A critical conclusion of the study is that the immunomodulatory activities of APS are remarkably more potent when encapsulated in liposomes. The lipid bilayer serves as an effective delivery vehicle that likely protects the polysaccharides and facilitates better cellular uptake. On the other hand, while *Astragalus* species are known to contain over 100 bioactive constituents, including flavonoids and polysaccharides, their traditional use is often limited by poor bioavailability and systemic toxicity. By integrating *Astragalus* into 3D-printed hydrogel scaffolds, these compounds can be protected from physicochemical degradation and ensure localized, sustained release [115]. This advanced formulation approach allows for the creation of personalized, biomimetic architects that enhance tissue regeneration while minimizing the side effects associated with conventional TCM dosage forms.

Recent breakthroughs in bioactive scaffolds have significantly advanced the topical application of *Astragalus* derivatives. Specifically, Zhao et al. [44] developed an innovative injectable, photo-cross-linkable composite hydrogel (OCS) designed to modulate the immune microenvironment of wound sites. This formulation utilizes oxidized *Astragalus* polysaccharides (OAPSs) alongside carboxymethyl chitosan and sodium methacrylated alginate as a bioactive matrix for curcumin-encapsulated supramolecular self-assemblies. By leveraging the intrinsic anti-inflammatory and antioxidant properties of the polysaccharides, this specialized delivery system effectively promotes angiogenesis, collagen deposition, and granulation tissue formation. In vivo models demonstrated accelerated re-epithelialization, positioning these *Astragalus*-dominated smart hydrogels as potent therapeutic candidates for the treatment of significant skin defects.

It was also revealed that the primary scientific advantage of nano-complexes formed between APS and amphiphilic chitosan derivatives lies in their ability to overcome the biological barriers that typically limit the bioavailability of large, negatively charged molecules like APS. Chitosan derivatives have the unique ability to open tight junctions between cells by altering intracellular pH through the activation of chloride–bicarbonate exchangers. In skin formulations, this mechanism could potentially enhance the paracellular transport of active ingredients through the epidermal layers. The nano-complexes possess a positive zeta potential. Because skin surfaces and many biological membranes are negatively charged, this positive charge facilitates a strong electrostatic interaction, which can lead to better adhesion and longer residence time on the skin. The derivatives show a high affinity for negatively charged mucin, a property that translates to bioadhesiveness in topical applications, effectively increasing the concentration of the molecules at the absorption site. The complexes self-assemble into a stable size of 100–150 nm. This small particle size is advantageous for topical delivery, as it can improve the penetration depth into skin pores and follicles. The study confirmed that these nano-complexes are not toxic to human cells (specifically the Caco-2 cell line), which is a critical requirement for any ingredient intended for repeated topical use in skincare. Hence, from this study, it might be concluded that the use of these nano-complexes provides a stable, positively charged, and permeation-enhancing delivery system that could significantly improve the dermal absorption and efficacy of APS in cosmetic products.

The scientific utility of APSs in skin formulations is significantly enhanced by their capacity to function as natural, self-assembling nano-carriers. Research indicates that APSs can spontaneously form porous nano-aggregates in aqueous solutions, providing a stable matrix for the encapsulation of hydrophobic molecules, such as flavonoids, thereby markedly improving their solubility, dispersion stability, and dermal permeation [116].

Additionally, the development of nano-complexes between APSs and amphiphilic chitosan derivatives offers a strategic advantage by utilizing positive surface charges for improved bioadhesion and the modulation of tight junctions to facilitate paracellular transport across the epidermal barrier. These delivery systems, typically ranging from 100 to 150 nm, demonstrate high biocompatibility and overcome the inherent bioavailability limitations of large-molecule polysaccharides, making them highly favourable for the development of high-performance, green cosmeceutical products aimed at stabilized, deep-skin delivery.

On the other hand, one must underline that the translation of *Astragalus* from experimental models to commercial cosmeceuticals is governed by the dose gap between laboratory and industrial applications. While many in vitro studies utilize concentrations in the mg/mL or high-micromolar range to elucidate molecular signalling (e.g., the 2.6 mM oxalate model for Nrf2-Keap1 activation), these levels are often unfeasible for standard topical formulations. In the cosmetic industry, *Astragalus membranaceus* root extract (INCI: CAS No. 94166-93-5) is typically incorporated at inclusion levels ranging from 0.1% to 5.0% for leave-on products like serums and creams. These levels ensure both regulatory compliance, as indicated in the European Commission's CosIng database, and the esthetic acceptability of the formulation. Furthermore, to bridge this dose gap, modern smart delivery systems, such as self-implanting microneedles [49] and photo-cross-linkable hydrogels, are used to enhance the bioavailability of bioactive markers like astragaloside IV, allowing for potent clinical efficacy even at lower, regulatory-compliant concentrations.

It should be highlighted that while *Astragalus* extracts are increasingly utilized in anti-aging and pigment-correcting formulations, the industry is moving toward stricter standardization of bioactive fractions to ensure regulatory compliance and consistent clinical efficacy across diverse *Astragalus* species.

7. Future Perspectives

Currently, only *A. membranaceus* is used as an active ingredient in cosmetic products. However, the *Astragalus* genus comprises numerous species with high potential application value in medicinal/pharmaceutical and cosmetic products aimed at improving a broad range of skin conditions (Table 1). While the genus *Astragalus* represents a vast reservoir of bioactive secondary metabolites with significant potential for dermatology and cosmetics, several challenges must be addressed to transition from laboratory findings to commercial success.

Table 1. Biological effects of *Astragalus* species for dermatological medicine and cosmetic products.

Activity	*Astragalus* Species	Type of Extract/Sample	Study Design	Ref.
Skin rejuvenating activity	*Astragalus membranaceus*	Hydroethanol extract	Human study	[48]
Photoprotective activity	*Astragalus gombiformis*	Hydroethanol extract	In vitro	[73]
	Astragalus membranaceus	Aqueous extract	Ex vivo	[76]
Atopic dermatitis treatment	*Astragalus membranaceus*	Hydroethanolic extract	In vivo	[80]
Alopecia treatment	*Astragalus membranaceus*	Astragaloside IV	In vivo	[84]
	Astragalus sinicus	Hydroethanol extract	In vitro	[85]
Wound healing	*Astragalus membranaceus*	Aqueous extract	In vivo	[86]
	Astragalus gummifer	Tragacanth Gel	In vivo	[88]
Antimicrobial activity	*Astragalus elatus*	Ethanol extract	In vitro	[94]
	Astragalus gymnolobus	Methanol extract	In vitro	[95]
	Astragalus brachypterus	Aqueous, methanol, and ethanol extracts	In vitro	[98]
	Astragalus gymnalopecias	Methanol, acetone and ethyl acetate extracts	In vitro	[99]
	Astragalus excapus	Methanol extract	In vitro	[101]

The dermatological benefits of *A* Current research is heavily biased toward *A. membranaceus*. Given that the genus contains nearly 3000 species, future studies should employ high-throughput phytochemical screening and bioprospecting to identify lesser-known species with high concentrations of cycloastragenol and unique flavonoids. Comparative

studies between different species could reveal more potent alternatives for specific skin concerns, such as hyperpigmentation or barrier repair. On the other hand, a significant portion of existing evidence relies on in vitro or animal models. To gain mainstream dermatological acceptance, large-scale, double-blind, placebo-controlled human clinical trials are essential. These trials should focus on standardized extracts to ensure reproducibility, specifically measuring parameters such as transepidermal water loss (TEWL), elasticity index, and melanin index using non-invasive bioengineering methods. Many of the potent compounds in *Astragalus*, such as high-molecular-weight polysaccharides and polar saponins, face challenges in penetrating the stratum corneum.

Astragalus extracts, particularly regarding skin tone, hydration, and the reduction in rhytids, were recently synthesized in a 2015–2025 systematic review [67]. However, it is essential to highlight that the remaining evidence is largely composed of small-scale pilot studies and heterogeneous datasets. Significant variations exist across these trials in terms of the standardized markers used (e.g., astragalosides vs. polysaccharides), the delivery systems employed, and the cohort sizes. Consequently, while the preliminary data suggest a favourable trend in skin rejuvenation, the evidence remains far from definitive. Future research must prioritize large-scale, multi-centre randomized controlled trials (RCTs) with standardized formulations to establish a statistically robust consensus on the efficacy of the *Astragalus* genus in clinical dermatology.

Furthermore, a critical consideration for translating the genus's potential into practical cosmeceutical applications is the apparent duality of its effects on melanogenesis. The opposing activities of the isoflavonoid (anti-melanogenic) and saponin (pro-melanogenic) fractions do not present a contradiction but rather define a roadmap for targeted formulation. Future development should move beyond crude extracts towards bioactivity-guided standardization. For instance, the development of brightening agents should focus on extracts standardized for calycosin and formononetin, utilizing selective polar solvent extraction to enrich these isoflavones. Conversely, for therapeutic applications aimed at repigmentation, such as in vitiligo, formulations should be standardized for astragaloside IV. This strategic approach to isolating specific bioactive fractions, rather than using the whole plant indiscriminately, will be key to unlocking the full, and seemingly diverse, dermatological potential of the genus *Astragalus*.

Future research also should explore smart delivery systems, including nanoemulsions, liposomes, and microneedles, to enhance the bioavailability and targeted delivery of these bioactives into deeper dermal layers. Emerging evidence suggests that *Astragalus* may benefit the skin indirectly *via* the gut–skin axis by modulating systemic inflammation and the microbiome. Investigating oral supplements containing *Astragalus* extracts and their synergistic effects, when combined with topical applications, represents a promising frontier for holistic skincare. Another perspective of this review is the sustainable sourcing of the genus *Astragalus*, which is critical to preventing over-harvesting of wild species. Research into biotechnological production methods, such as hairy root cultures or plant cell fermentation, could provide a sustainable and standardized supply of bioactive metabolites while adhering to the principles of green chemistry. It should also be added that toxicological studies are needed for these lesser-known *Astragalus* species to confirm their safety for topical application. Consequently, this review underscores the necessity for precise phytochemical standardization to unlock the full regulatory potential of the genus in modern dermocosmetic applications.

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