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Review

Geranium robertianum L.: Phytochemical Profile, Biological Activities, and Potential Applications in Skin Health and Cosmetics

Elma Šaćirović [1], Marina Tomović [2], Jovana Dimitrijević [2], Danijela Pecarski [3] and Anica Petrović [2,4,*]

1 Department of Biomedical Sciences, State University of Novi Pazar, 36300 Novi Pazar, Serbia; esacirovic@np.ac.rs
2 Department of Pharmacy, Faculty of Medical Sciences, University of Kragujevac, 34000 Kragujevac, Serbia; marinapop@gmail.com (M.T.); dijovana@gmail.com (J.D.)
3 The College of Health Science, Academy of Applied Studies Belgrade, 11000 Belgrade, Serbia; danipecarski@gmail.com
4 Center of Excellence for Redox Balance Research in Cardiovascular and Metabolic Disorders, University of Kragujevac, 34000 Kragujevac, Serbia
* Correspondence: anica.petrovic@fmn.kg.ac.rs

Abstract

Geranium robertianum L. (Herb Robert), a well-known member of the *Geraniaceae* family distributed widely across Europe, Asia, and North Africa, has a long-standing history in traditional medicine for treating inflammatory skin disorders, wounds, and minor bleeding. In recent years, growing scientific interest has focused on its rich phytochemical profile, particularly its abundance of polyphenolic compounds such as hydrolysable tannins (including ellagitannins and ellagic acid), phenolic acids (gallic and caffeic acids), and diverse flavonoid glycosides derived from quercetin and kaempferol. The available evidence, derived predominantly from phytochemical investigations, chemical antioxidant assays and in vitro experimental studies, suggests antioxidant, anti-inflammatory and antimicrobial potential. However, direct evidence of skin-protective efficacy using standardized *G. robertianum* extracts in skin-specific models or clinical studies remains limited. Furthermore, variations in phytochemical composition due to environmental factors, harvesting conditions, and extraction methods emphasize the necessity for standardized extracts and robust safety and stability evaluations. This review provides a comprehensive synthesis of the traditional uses, phytochemical characteristics, biological activities, and dermocosmetic potential of *G. robertianum*, while highlighting current research gaps and future directions for evidence-based product development.

Keywords: *Geranium robertianum* L.; Herb Robert; phytochemistry; polyphenols; skin health; cosmetics; dermocosmetics; antioxidant activity

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1. Introduction

Medicinal plants represent an important source of structurally diverse bioactive compounds with considerable potential for dermatological and cosmetic applications. Among these compounds, phenolic acids, flavonoids, and tannins have attracted increasing scientific attention owing to their antioxidant, anti-inflammatory, antimicrobial, and wound-healing activities. These properties may contribute to the protection of skin against oxidative stress and persistent inflammation, two interconnected processes involved in skin aging and the pathogenesis of various dermatological disorders [1].

Growing consumer demand for natural and sustainable skincare products has stimulated interest in plant-derived cosmetic ingredients. Botanical extracts may provide multiple biological activities; however, their incorporation into topical formulations presents important challenges. Variations in phytochemical composition related to plant origin, environmental conditions, harvesting, processing, and extraction can affect reproducibility, while the instability of many bioactive constituents and the limited availability of well-designed clinical studies complicate their standardization and validation. Therefore, the development of evidence-based dermocosmetic products requires consideration not only of biological activity but also of safety, stability, compatibility, and performance within the final formulation [2].

Polyphenols are among the most extensively studied plant-derived compounds in skin research because of their ability to scavenge reactive oxygen species (ROS), modulate inflammatory pathways, and protect skin structures from oxidative damage. Their reported effects include modulation of extracellular matrix degradation, attenuation of UV-induced inflammation, and support of skin barrier function. Nevertheless, biological activity does not necessarily translate into cosmetic efficacy after topical application, as formulation characteristics can influence stability, release, skin penetration, and preservation of bioactivity [3].

Within this context, *Geranium robertianum* L. (Herb Robert), a herbaceous species of the *Geraniaceae* family, represents a promising but relatively underexplored source of bioactive phytochemicals relevant to skin health. Widely distributed across Europe, Asia, North Africa, and parts of North America, the species has a long history of traditional use for inflammatory skin conditions, wounds, bruises, minor bleeding, and other ailments [4–8]. These applications are consistent with its reported astringent, antioxidant, anti-inflammatory, antimicrobial, and wound-related properties.

Phytochemical studies have identified *G. robertianum* as a source of tannins, flavonoids, and phenolic acids, including gallic and ellagic acids, together with other potentially bioactive constituents [9–12]. Although experimental studies support several biological activities, the available evidence is heterogeneous and predominantly based on phytochemical characterization and in vitro assays, while skin-relevant models and clinical studies remain limited. Furthermore, although *G. robertianum* extract is listed in the European Commission's CosIng database with cosmetic functions including astringent and tonic effects, this listing does not establish the safety or efficacy of a specific extract or formulation. Data regarding standardized extracts, topical safety, formulation performance, stability, and clinical efficacy remain insufficient.

Several polyphenol-rich botanicals, including *Camellia sinensis*, *Hamamelis virginiana*, and *Geranium thunbergii*, have already been investigated for dermatological and cosmetic applications [13–15]. In comparison, *G. robertianum* remains relatively underexplored in contemporary dermocosmetic development. Addressing these gaps is essential to determine whether its reported biological properties can be translated into reproducible and scientifically substantiated cosmetic applications.

Therefore, this review provides a comprehensive and critical assessment of *G. robertianum*, focusing on its traditional uses, phytochemical composition, biological activities relevant to skin health, topical safety, and potential applications in modern dermocosmetic formulations (Figure 1). Particular attention is given to current evidence gaps and the research priorities required for the development of scientifically substantiated topical products containing *G. robertianum*.

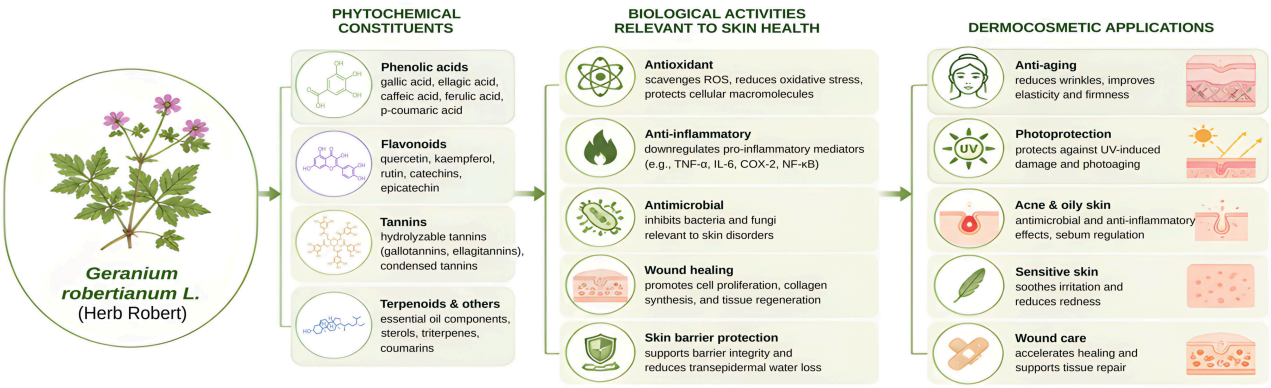


Figure 1. Phytochemical composition, biological activities, and dermocosmetic applications of *Geranium robertianum* L.

2. Traditional Use of *Geranium robertianum* L.

Across Europe, the Balkans, Asia, Africa, and the Americas, *Geranium robertianum* L. (commonly known as Herb Robert) has a long history of traditional medicinal use for a wide range of health conditions. Ethnobotanical and ethnopharmacological records describe its use for gastrointestinal disorders, including ulcers, gastritis, diarrhea, and digestive bleeding, as well as respiratory conditions, hypertension, metabolic disorders, rheumatic complaints, and other ailments [16,17]. However, the available ethnobotanical evidence is heterogeneous, and comprehensive documentation of its traditional applications remains limited.

Of particular relevance to dermatology, *G. robertianum* has traditionally been used externally for wounds, burns, minor cuts, ulcers, bruises, and various inflammatory or irritated skin conditions. Preparations of the aerial parts, including infusions, decoctions, and extracts, were applied topically with the aim of supporting wound-healing, reducing inflammation, and preventing infection. Traditional external applications have also been reported for insect bites, superficial skin irritations, aphthous lesions, and other mucocutaneous inflammatory conditions [17–20]. These uses provide an important ethnopharmacological basis for investigating the potential relevance of *G. robertianum* to skin health.

The reported traditional applications are partly consistent with the biological activities identified in experimental studies. Flavonoids and phenolic acids present in *G. robertianum* may contribute to antioxidant and anti-inflammatory effects, while tannins and other phenolic constituents may be involved in its astringent and antimicrobial properties [11,21,22]. Nevertheless, these mechanisms should not be interpreted as direct evidence of clinical efficacy. Although in vitro studies have demonstrated antimicrobial, antioxidant, and anti-inflammatory activities, direct evidence supporting the traditional use of *G. robertianum* for wound-healing in humans or animal models remains limited [18]. Similarly, evidence for several other traditional applications, including metabolic indications, is largely restricted to experimental and ethnobotanical data.

Thus, the traditional use of *G. robertianum*, particularly for wounds, burns, minor skin injuries, and inflammatory skin conditions, provides a rationale for further investigation of its dermatological and cosmetic potential. However, the transition from traditional use to scientifically substantiated cosmetic applications requires standardized extracts, well-characterized formulations, appropriate safety assessment, and studies using relevant skin models and, ultimately, clinical evaluation (Figure 2)

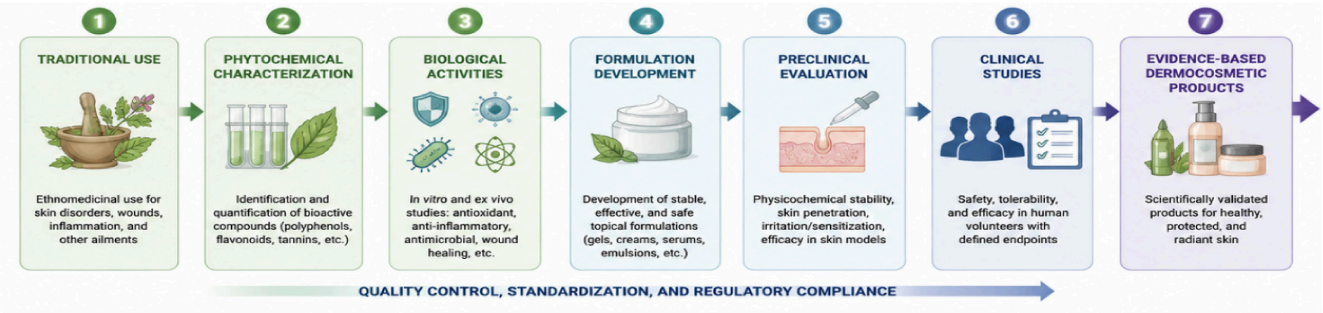


Figure 2. From traditional use to evidence-based dermocosmetic products: research and development roadmap for *Geranium robertianum* L.

3. Phytochemical Composition of *Geranium robertianum* L.

Polyphenols represent the predominant class of bioactive constituents identified in *Geranium robertianum* L. and are considered important contributors to its reported biological activities. Phytochemical investigations have consistently identified phenolic acids, flavonoids, and hydrolysable tannins, although their qualitative and quantitative composition varies according to geographical origin, plant developmental stage, harvesting conditions, extraction procedure, and analytical methodology [1,10]. This variability limits direct comparison among studies and highlights the importance of extract standardization for future pharmacological and dermocosmetic applications (Table 1).

Table 1. Major phytochemical classes of *Geranium robertianum* and their potential relevance to skin health.

Compound Class	Representative Constituents	Reported Biological Activities	Potential Dermatological Relevance
Phenolic acids	Gallic acid, ellagic acid, caffeic acid, caftaric acid	Antioxidant, anti-inflammatory	Protection against oxidative stress and UV-associated damage
Flavonoids	Quercetin and kaempferol derivatives, naringenin glycosides	Antioxidant, anti-inflammatory, photoprotective	Potential protection of extracellular matrix and skin barrier
Hydrolysable tannins	Geraniin, ellagitannins, gallotannins	Astringent, antioxidant, antimicrobial	Potential contribution to tissue repair and control of exudation
Condensed tannins	Proanthocyanidins	Antioxidant, antimicrobial	Potential protection against oxidative damage
Volatile constituents	Linalool, germacrene D, α-terpineol, geraniol, α-caryophyllene	Mainly antimicrobial	Potential contribution to antimicrobial activity
Minerals and vitamins	Mg, Ca, Fe, Mn, Zn; vitamins A, C, E, riboflavin, biotin, niacin	Nutritional and antioxidant functions	Possible contribution to cellular protection and skin homeostasis

The table summarizes representative phytochemical classes reported in the aerial parts of *G. robertianum*. The listed dermatological relevance is based on reported biological activities and mechanistic evidence and should not be interpreted as direct clinical evidence for *G. robertianum* extracts.

Tannins were among the earliest secondary metabolites reported in *G. robertianum*. The species is particularly characterized by hydrolysable tannins containing hexahydroxydiphenoyl (HHDP) groups esterified to a glucose core, with ellagic acid representing an important structural component of ellagitannin-derived products [23]. Subsequent stud-

ies using aqueous and hydroalcoholic extracts have confirmed substantial total phenolic, tannin, and flavonoid contents in plant material collected from different European regions, supporting the classification of *G. robertianum* as a polyphenol-rich medicinal plant [24,25].

Advanced chromatographic techniques, particularly high-performance liquid chromatography (HPLC) and liquid chromatography–mass spectrometry (LC–MS), have enabled more detailed characterization of individual constituents. Frequently reported compounds include phenolic acids such as gallic, ellagic, and chlorogenic acids, as well as flavonoid glycosides derived from quercetin and kaempferol [25,26]. These compounds are of particular interest because many have established antioxidant, anti-inflammatory, and antimicrobial properties, although their contribution to the biological activity of *G. robertianum* extracts depends on their concentration, chemical interactions, and the characteristics of the extract (Table 2).

In addition to polyphenols, *G. robertianum* contains a volatile fraction represented by essential oil constituents, including monoterpenes and sesquiterpenes [27]. Although present in substantially lower amounts than polyphenolic constituents, these compounds may contribute to the biological properties of the plant, particularly its reported antimicrobial and anti-inflammatory activity. However, the composition and biological relevance of the volatile fraction may also vary according to plant material and extraction conditions.

Phytochemical studies have additionally reported the presence of minerals, including magnesium, calcium, iron, manganese, and zinc, as well as several vitamins, including riboflavin, biotin, niacin, and vitamins A, C, and E [23,28,29]. These constituents contribute to the overall nutritional composition of the plant; however, their specific contribution to the biological and dermatological effects of *G. robertianum* extracts remains insufficiently established. Therefore, current evidence suggests that the biological potential of *G. robertianum* is primarily associated with its complex mixture of polyphenolic and other secondary metabolites rather than with individual micronutrients alone.

Table 2. Representative phytochemicals identified in *Geranium robertianum* and biological activities relevant to skin health.

Compound	Chemical Class	Reported Biological Activities	Evidence and Dermatological Relevance	Ref.
Gallic acid	Phenolic acid	Antioxidant, anti-inflammatory	Potential protection against oxidative and UV-associated damage; evidence largely derived from studies of isolated gallic acid	[1,25,30,31]
Ellagic acid	Phenolic acid	Antioxidant, anti-inflammatory, photoprotective	Potential photoprotective and anti-inflammatory relevance; direct evidence for *G. robertianum* remains limited	[1,25]
Caffeic acid	Phenolic acid	Antioxidant, anti-inflammatory	Potential contribution to antioxidant activity	[25]
Caftaric acid	Phenolic acid	Antioxidant	Potential contribution to overall antioxidant activity	[25]
Quercetin derivatives	Flavonoids	Antioxidant, anti-inflammatory, photoprotective	Mechanistic evidence supports potential protection against oxidative and UV-associated damage	[1,26,32–35]

Table 2. *Cont.*

Compound	Chemical Class	Reported Biological Activities	Evidence and Dermatological Relevance	Ref.
Kaempferol derivatives	Flavonoids	Antioxidant, anti-inflammatory	Potential contribution to antioxidant and anti-inflammatory activity	[26]
Naringenin glycosides	Flavonoids	Antioxidant	Potential contribution to overall antioxidant activity	[26]
Geraniin	Hydrolysable tannin	Astringent, antioxidant, antimicrobial	Potential contribution to astringent and protective effects; direct dermatological evidence remains limited	[25,36,37]
Proanthocyanidins	Condensed tannins	Antioxidant, antimicrobial	Potential contribution to antioxidant protection	[23,38]
Linalool	Monoterpene	Antimicrobial, anti-inflammatory	May contribute to antimicrobial activity of the volatile fraction	[27]
α-Terpineol	Monoterpene	Antimicrobial	May contribute to antimicrobial activity	[27]
Geraniol	Monoterpene alcohol	Antimicrobial, antioxidant	May contribute to activity of the volatile fraction	[27]
Germacrene D	Sesquiterpene	Antimicrobial	Possible contribution to antimicrobial activity	[27]
α-Caryophyllene	Sesquiterpene	Antimicrobial, anti-inflammatory	Possible contribution to biological activity of the volatile fraction	[27]

The table summarizes the principal phytochemicals identified in the aerial parts of *Geranium robertianum*, their chemical classification, and the biological activities reported in the literature that are relevant to skin health. The listed activities are based on available phytochemical, pharmacological, and dermatological studies and do not necessarily indicate direct evidence obtained specifically for *G. robertianum* extracts.

3.1. Phenolic Acids

Phenolic acids constitute an important subclass of polyphenols identified in *Geranium robertianum* L. Among the compounds most consistently reported are gallic, ellagic, caffeic, and caftaric acids, although their concentrations vary considerably according to plant origin, extraction procedure, and analytical methodology [24,25]. Quantitative analysis of concentrated aqueous extracts obtained from Romanian plant material revealed particularly high levels of gallic acid (1070.78 mg/kg) and ellagic acid (900.13 mg/kg), indicating their quantitative importance among the phenolic acids detected in the species [25]. Similarly, HPLC analysis of hydrolyzed dried aerial parts identified ellagic acid as a predominant constituent, together with lower amounts of caffeic and caftaric acids [24].

The occurrence of these phenolic acids is relevant to the biological potential of *G. robertianum*, as gallic, ellagic, and related phenolic compounds are widely recognized for their antioxidant and anti-inflammatory properties. However, their concentrations differ substantially between extracts, emphasizing the influence of extraction conditions and the need for standardized phytochemical characterization when evaluating *G. robertianum* for dermocosmetic applications [24,25].

3.2. Flavonoids

Flavonoids represent another major class of polyphenolic constituents in *G. robertianum*. Phytochemical analyses have revealed a diverse profile dominated by quercetin- and kaempferol-derived compounds, together with smaller amounts of naringenin glycosides, predominantly occurring as *O*-glycosides [26]. HPLC-DAD-ESI/MS analysis identified 17 flavonoid glycosides in methanolic, acetone, and ethyl acetate extracts, demonstrating substantial structural diversity within this class [26].

The relative abundance of individual flavonoids was strongly influenced by the extraction solvent. Kaempferol-*O*-deoxyhexosyl-glucuronide was the predominant flavonoid in methanolic extracts (4.78 ± 0.11 mg/g), whereas kaempferol-*O*-deoxyhexosyl-hexoside was predominant in acetone extracts (2.61 ± 0.07 mg/g). Among quercetin derivatives, quercetin-3-*O*-rutinoside was the major compound detected in acetone extracts (3.39 ± 0.06 mg/g), followed by quercetin-*O*-deoxyhexosyl-hexoside and quercetin-*O*-deoxyhexosyl-glucuronide [26]. These findings demonstrate that both solvent polarity and extraction conditions substantially affect the qualitative and quantitative flavonoid profile of *G. robertianum*.

The presence of quercetin- and kaempferol-derived flavonoids is of particular interest because these compounds are associated with antioxidant, anti-inflammatory, and photoprotective activities. Their potential relevance to skin health is discussed in greater detail in the subsequent section addressing the biological activities of *G. robertianum*.

3.3. Tannins

Tannins are among the characteristic secondary metabolites of *G. robertianum* and occur predominantly as hydrolysable tannins, including ellagitannins and gallotannins [23,25]. Ellagitannins contain hexahydroxydiphenoyl (HHDP) groups esterified to a glucose core and can yield ellagic acid upon hydrolysis. Their abundance contributes to the distinctive polyphenolic profile of the species [23,25].

Geraniin, an ellagitannin extensively studied within the *Geranium* genus, has also been reported in *G. robertianum*, although much of the detailed pharmacological literature concerning this compound originates from studies of other *Geranium* species, particularly *G. thunbergii* [35,36]. This distinction is important when interpreting the biological relevance of geraniin specifically in *G. robertianum*. In addition to hydrolysable tannins, condensed tannins (proanthocyanidins) have been detected in methanolic extracts, with their content commonly expressed as catechin equivalents [23,37].

The high tannin content of *G. robertianum* is consistent with several of its traditional applications, particularly those involving astringent and wound-related preparations. Nevertheless, direct evidence linking individual tannins to specific dermatological effects of *G. robertianum* remains limited and should be distinguished from evidence obtained with isolated compounds or other plant species.

3.4. Volatile Constituents

Although present in substantially lower amounts than polyphenols, volatile compounds contribute to the overall phytochemical profile of *G. robertianum*. Analysis of the essential oil obtained from aerial parts identified monoterpenes and sesquiterpenes as the predominant groups, with linalool (13.4%), germacrene D (8.6%), α-caryophyllene (3.4%), α-terpineol (2.7%), and geraniol (2.6%) among the principal constituents [27].

The presence of oxygenated monoterpenes such as linalool, geraniol, and α-terpineol is of interest because these compounds have documented antimicrobial and anti-inflammatory properties in the broader literature. However, the biological activity of the essential oil cannot be inferred solely from the activity of its individual constituents, as the composition

and relative abundance of volatile compounds may influence the observed effects. In *G. robertianum*, the available evidence suggests that the volatile fraction may contribute to the antimicrobial profile of the plant, although it remains considerably less characterized than its polyphenolic fraction [27].

Overall, the phytochemical profile of *G. robertianum* is characterized by a predominance of polyphenolic compounds, particularly tannins, phenolic acids, and flavonoids, accompanied by a smaller volatile fraction. The substantial variability in the composition of different extracts represents an important consideration for future dermocosmetic applications and highlights the need for standardized botanical preparations.

3.5. Summary of the Phytochemical Profile

Geranium robertianum L. is characterized by a polyphenol-rich phytochemical profile, with phenolic acids, flavonoids, and hydrolysable tannins representing the predominant secondary metabolites. The plant also contains a minor volatile fraction composed mainly of monoterpenes and sesquiterpenes, together with several minerals and vitamins. The qualitative and quantitative composition varies according to geographical origin, plant developmental stage, harvesting conditions, extraction procedure, and analytical methodology, emphasizing the need for extract standardization when evaluating its biological and dermocosmetic potential [1,10,23–29]. Among the most consistently identified compounds are gallic and ellagic acids, quercetin- and kaempferol-derived flavonoids, hydrolysable tannins including geraniin, and volatile constituents such as linalool, germacrene D, α-terpineol, geraniol, and α-caryophyllene. Their reported biological activities provide a plausible basis for the antioxidant, anti-inflammatory, antimicrobial, and astringent properties associated with *G. robertianum*. However, the strength of evidence differs substantially among individual compounds and biological effects, and many dermatological activities have been demonstrated for isolated constituents or related *Geranium* species rather than for standardized *G. robertianum* extracts. The principal phytochemical classes, representative constituents, and their reported biological activities and potential relevance to skin health are summarized in Table 1, while Table 2 provides a more detailed overview of individual compounds for which biological activities relevant to dermatology have been reported.

4. Biological Activities Relevant to Skin Health

Geranium robertianum has attracted considerable scientific interest because its phytochemical composition is closely associated with a broad spectrum of biological activities relevant to skin health. Current evidence indicates that the biological effects of the species are primarily mediated by its high content of polyphenols, particularly phenolic acids, flavonoids, and hydrolysable tannins, which collectively exhibit antioxidant, anti-inflammatory, antimicrobial, and wound-healing properties. These findings largely support the plant's long-standing traditional use in the management of wounds and inflammatory skin disorders. However, although numerous *in vitro* studies have demonstrated promising biological activity, the available evidence remains largely limited to phytochemical investigations and experimental assays, while studies employing skin-specific models and well-designed clinical trials are still scarce [1,35]. Experimental evidence supporting the antioxidant activity of *Geranium robertianum* relevant to skin health is presented in Table 3.

Table 3. Experimental evidence supporting the antioxidant activity of *Geranium robertianum* relevant to skin health.

Extract/Fraction	Experimental Model	Principal Findings	Proposed Mechanism	Dermatological Relevance	Ref.
Methanolic extract	DPPH radical scavenging assay	Strong radical scavenging activity (97% inhibition)	Hydrogen atom donation and ROS scavenging	Protection against oxidative stress and prevention of oxidative skin damage	[39]
Aqueous crude extract	DPPH radical scavenging assay	Good antioxidant activity	Polyphenol-mediated free radical scavenging	Reduction in oxidative damage in skin cells	[39]
Dichloromethane extract	DPPH radical scavenging assay	Lower antioxidant activity than methanolic and aqueous extracts	Limited free radical scavenging capacity	Minor contribution to antioxidant protection	[39]
Aqueous extract (6%)	DPPH and ABTS assays	Moderate antioxidant activity (77.6% DPPH inhibition)	Electron and hydrogen donation by polyphenols and flavonoids	Reduction in ROS generation and oxidative stress	[40]
Aqueous extract (10%)	DPPH and ABTS assays	Higher antioxidant activity than the 6% extract	Increased polyphenol concentration enhances radical scavenging	Improved protection against photooxidative damage	[40]
Hydroalcoholic extract (50%)	DPPH, ABTS and Folin–Ciocalteu assays	High antioxidant activity (86% DPPH inhibition)	High phenolic and flavonoid content	Prevention of oxidative damage associated with skin aging	[40]
Hydroalcoholic extract (70%)	DPPH, ABTS and Folin–Ciocalteu assays	Highest antioxidant activity (90.37% DPPH inhibition)	Strong ROS scavenging associated with elevated polyphenol content	Protection against UV-induced oxidative stress and photoaging	[40]
Methanolic and aqueous extracts	FRAP and β-carotene/linoleic acid bleaching assays	High reducing power and inhibition of lipid peroxidation	Prevention of oxidative damage to membrane lipids	Preservation of skin cell integrity and photoprotection	[8]

4.1. Antioxidant Activity

Oxidative stress plays a major role in skin aging and in the development of several inflammatory and degenerative skin conditions. Excessive production of reactive oxygen species (ROS) promotes lipid and protein oxidation, DNA damage, inflammatory signaling, and degradation of extracellular matrix components. Consequently, plant-derived antioxidants have attracted considerable interest as potential ingredients for skin-protective and anti-aging formulations.

Several studies have demonstrated antioxidant activity of *G. robertianum* extracts using complementary in vitro assays, including DPPH and ABTS radical-scavenging assays, ferric reducing antioxidant power (FRAP), and inhibition of lipid peroxidation [8,39,40]. Methanolic, aqueous, and hydroalcoholic extracts generally exhibited stronger antioxidant activity than less polar extracts, while higher activity was frequently associated with increased total phenolic and flavonoid contents [8,39,40]. These findings support the contribution of polyphenols to the antioxidant capacity of the plant, although differences in extraction procedures and assay conditions limit direct comparison between studies.

Several constituents identified in *G. robertianum*, including gallic acid, caffeic acid, quercetin, and rutin, possess established antioxidant and photoprotective properties in experimental models. Quercetin, for example, has been shown to modulate UV-associated

oxidative and inflammatory pathways, including AP-1 and NF-κB signaling, while gallic acid has demonstrated effects on ROS generation, MMP-1 expression, and type I procollagen production in experimental skin models [32–36]. However, these findings primarily concern isolated compounds rather than standardized *G. robertianum* extracts and therefore should be interpreted as mechanistic support rather than direct evidence of clinical efficacy.

Overall, the antioxidant activity of *G. robertianum* represents one of the better-supported aspects of its biological profile. Nevertheless, further studies using standardized extracts, skin-relevant cellular and tissue models, and topical formulations are required to determine whether the antioxidant effects observed in chemical assays translate into meaningful skin protection following topical application.

4.2. Anti-Inflammatory Activity

Inflammation is a fundamental component of numerous acute and chronic skin disorders, including dermatitis, psoriasis, acne, impaired wound-healing, and UV-induced skin damage. Persistent activation of inflammatory pathways promotes excessive production of reactive oxygen species (ROS), pro-inflammatory cytokines, and proteolytic enzymes that contribute to extracellular matrix degradation and disruption of skin homeostasis. Consequently, natural compounds capable of modulating these processes have attracted considerable attention as potential dermatological and dermocosmetic ingredients.

The anti-inflammatory activity of *Geranium robertianum* is largely attributed to its high content of phenolic acids, flavonoids, and hydrolysable tannins, which collectively modulate oxidative stress and inflammatory signaling pathways [1]. Experimental studies have demonstrated that aqueous and hydroalcoholic extracts possess the ability to attenuate several mechanisms associated with cutaneous inflammation. Rather than acting through a single molecular target, the anti-inflammatory effects appear to result from the combined antioxidant and enzyme-modulating properties of the plant's polyphenolic constituents.

One of the proposed mechanisms involves the neutralization of hypochlorous acid (HOCl), a highly reactive oxidant produced by activated neutrophils during inflammatory responses. Hydroalcoholic extracts of *G. robertianum* exhibited measurable HOCl scavenging activity, although with lower efficacy than quercetin used as the reference antioxidant [1]. In addition, aqueous extracts demonstrated weak inhibition of hyaluronidase and moderate inhibition of elastase, two enzymes involved in degradation of extracellular matrix components during chronic inflammation and skin aging. Although the inhibitory effects were relatively modest, these findings suggest that *G. robertianum* may contribute to the preservation of skin structural integrity under inflammatory conditions [1].

The influence of *G. robertianum* on arachidonic acid metabolism appears to be more limited. Available studies demonstrated no significant inhibition of 5-lipoxygenase (5-LOX) activity and no modulation of inducible nitric oxide synthase (iNOS) expression within the investigated concentration range [1]. Nevertheless, aqueous extracts exhibited pronounced nitric oxide (NO) scavenging activity, with IC_{50} values lower than those reported for ascorbic acid, indicating efficient neutralization of reactive nitrogen species generated during inflammatory processes [4]. These observations suggest that the anti-inflammatory effects of *G. robertianum* are mediated predominantly through antioxidant and free radical scavenging mechanisms rather than by direct inhibition of key inflammatory enzymes.

Taken together, the available findings indicate that *G. robertianum* exhibits measurable antioxidant and enzyme-modulating effects that may contribute to its traditional use in inflammatory conditions. However, the relatively weak inhibition of hyaluronidase and the absence of significant effects on 5-LOX and iNOS indicate that its anti-inflammatory profile should be interpreted cautiously. Direct evidence from keratinocytes, fibroblasts, reconstructed skin models, and clinical studies remains insufficient (Table 4).

Table 4. Experimental evidence supporting the anti-inflammatory activity of *Geranium robertianum* relevant to skin health.

Extract Fraction	Experimental Model	Principal Findings	Proposed Mechanism	Ref.
Hydroalcoholic extract	HOCl scavenging assay	Moderate scavenging (lower than quercetin)	Neutralization of reactive oxidants generated during inflammation	[1]
Aqueous extract	Hyaluronidase inhibition assay	Weak hyaluronidase inhibition (7.2%)	Limited protection against hyaluronic acid degradation	[1]
Aqueous extract	Elastase inhibition assay	Moderate elastase inhibition (34.7%)	Reduced degradation of elastin and extracellular matrix	[1]
Aqueous extract	5-LOX inhibition assay	No significant inhibition	No direct modulation of arachidonic acid metabolism	[1]
Aqueous extract	iNOS expression	No significant modulation	No effect on inducible nitric oxide synthase	[1]
Aqueous extract	Nitric oxide scavenging assay	Strong NO scavenging activity (IC50 lower than ascorbic acid)	Neutralization of reactive nitrogen species	[4]

4.3. Antimicrobial Activity

Microbial infections represent a major challenge in dermatology, particularly in chronic wounds, burns, acne, and inflammatory skin disorders, where bacterial colonization can delay tissue repair and aggravate inflammatory responses. Consequently, considerable attention has been directed toward plant-derived compounds with antimicrobial properties that may serve as complementary or alternative agents in topical formulations.

Available studies indicate that *Geranium robertianum* exhibits selective antimicrobial activity against a broad range of Gram-positive bacteria and several opportunistic fungal species, particularly those belonging to the *Candida* genus [18]. Although early investigations suggested that the volatile oil possessed only limited antibacterial activity, subsequent studies demonstrated that extracts prepared using hexane, ethyl acetate, methanol, ethanol, and hydroalcoholic solvents exhibit substantially greater antimicrobial efficacy. The strongest antibacterial activity has been reported against *Staphylococcus*, *Bacillus*, *Enterococcus*, and oral streptococci associated with dental caries, suggesting that the extraction procedure markedly influences the antimicrobial potential of the plant [18].

Fractionation of hexane and ethyl acetate extracts further enhanced antimicrobial activity, with several fractions demonstrating bactericidal effects against *Bacillus* spp. and *Micrococcus luteus*. Antifungal activity has also been reported against several clinically relevant *Candida* species, including *Candida auris*, *Candida krusei*, *Candida lusitaniae*, *Candida glabrata*, *Candida tropicalis*, and *Candida parapsilosis*, indicating that *G. robertianum* possesses a relatively broad antifungal spectrum [18].

The antimicrobial activity of *G. robertianum* is primarily attributed to the combined action of polyphenolic compounds and volatile terpenoids. Phenolic acids, flavonoids, and tannins are known to interfere with microbial cell walls and membranes, inhibit essential microbial enzymes, and reduce microbial adhesion, whereas monoterpenes and sesquiterpenes present in the essential oil increase membrane permeability and contribute to membrane disruption. The coexistence of these chemically diverse constituents suggests that the antimicrobial activity of *G. robertianum* results from synergistic interactions rather than from the action of a single bioactive compound [18,41].

Although clinical evidence remains limited, preliminary translational studies have demonstrated promising therapeutic potential. Ear drops containing *G. robertianum* in combi-

nation with clove and lavender extracts showed clinical efficacy comparable to ciprofloxacin in the treatment of acute otitis externa, suggesting that plant-derived antimicrobial formulations may represent a valuable complementary therapeutic approach [18]. However, because this formulation contained multiple botanical ingredients, the specific contribution of *G. robertianum* cannot be determined with certainty.

These findings indicate that *G. robertianum* may be of interest for the development of topical formulations in which antimicrobial activity is desirable. However, the available evidence does not currently establish efficacy against specific dermatological infections, and the relevance of the observed antimicrobial effects under topical conditions remains to be determined (Table 5).

Table 5. Experimental evidence supporting the antimicrobial activity of *Geranium robertianum* relevant to skin health.

Extract/Fraction	Target Microorganism(s)	Principal Findings	Proposed Mechanism	Ref.
Volatile oil	Gram-positive bacteria	Limited antibacterial activity	Low content of volatile antimicrobial constituents	[18]
Hexane and ethyl acetate extracts	*Staphylococcus* spp., *Bacillus* spp., *Enterococcus* spp., oral streptococci	Significant antibacterial activity	Membrane disruption by lipophilic compounds and phenolics	[18]
Fractionated hexane and ethyl acetate extracts	*Bacillus* spp., *Micrococcus luteus*	Enhanced antimicrobial potency with bactericidal activity	Increased concentration of active antimicrobial constituents	[18]
Fractionated hexane and ethyl acetate extracts	*Candida auris*, *Candida krusei*, *Candida lusitaniae*	Pronounced antifungal activity	Disruption of fungal cell membrane integrity	[18]
Methanolic and ethanolic extracts	*Candida glabrata*, *Candida tropicalis*, *Candida parapsilosis*	Strong antifungal activity	Alteration of fungal membrane permeability and intracellular targets	[18]
Essential oil	Gram-positive and selected Gram-negative bacteria	Antibacterial activity demonstrated	Synergistic action of monoterpenes and sesquiterpenes	[18]

5. Wound-Healing and Tissue Regeneration

Wound-healing is a complex biological process involving coordinated inflammatory, proliferative, and remodeling phases that require tight regulation of oxidative stress, extracellular matrix deposition, angiogenesis, and microbial control. Natural products possessing antioxidant, anti-inflammatory, and antimicrobial activities are therefore increasingly investigated as potential agents for improving skin repair and tissue regeneration.

Although direct experimental studies evaluating the wound-healing activity of *Geranium robertianum* in skin models remain scarce, its phytochemical composition provides a strong rationale for this traditional application. The plant is particularly rich in hydrolysable tannins, flavonoids, and phenolic acids, all of which have been associated with biological processes involved in tissue repair [42,43]. Among these compounds, tannins are considered the principal contributors to wound-healing because of their astringent, antioxidant, anti-inflammatory, and antimicrobial properties.

Tannins may contribute to the wound-healing properties traditionally attributed to *G. robertianum*, based on their reported astringent, antioxidant, antimicrobial and tissue-protective activities. Experimental studies conducted with purified tannic acid demonstrated accelerated wound closure, enhanced re-epithelialization, increased fibroblast prolif-

eration, modulation of IL-1 and IL-6 levels and activation of ERK1/2 signaling pathways [42]. Separately, tannin-rich extracts from the immature fruits of *Terminalia chebula* promoted wound contraction, granulation tissue formation, collagen organization, and VEGF expression in a rat wound model [43]. However, neither study investigated *G. robertianum* extracts and these findings should therefore be considered indirect evidence rather than direct confirmation of the wound-healing efficacy of this species.

Although these mechanisms provide a plausible explanation for the traditional use of *G. robertianum*, direct experimental evidence remains limited. A small clinical study evaluating a topical tannin-containing preparation in burn wounds reported similar bacterial colonization between treatment groups, while more favorable observations concerned eschar quality and hypertrophic scarring [44]. However, this study did not investigate *G. robertianum* extracts and therefore cannot be considered direct evidence of wound-healing efficacy for this species. Nevertheless, the long-standing ethnomedicinal use of *G. robertianum* for the treatment of wounds and minor skin injuries in several Balkan regions further supports its traditional application [45].

Taken together, the currently available evidence suggests that the wound-healing potential of *G. robertianum* is primarily inferred from its phytochemical composition and the well-established biological activities of its major constituents rather than from direct pharmacological or clinical studies. Consequently, future investigations employing standardized extracts, skin-specific experimental models, and controlled clinical trials are required to validate its efficacy and clarify the molecular mechanisms underlying its regenerative properties (Table 6).

Table 6. Experimental evidence supporting the wound-healing potential of *Geranium robertianum* relevant to skin health.

Evidence	Principal Findings	Biological Relevance	Ref.
Phytochemical composition	High content of hydrolysable tannins, flavonoids, and phenolic acids	Provides a mechanistic basis for wound-healing activity	[23,25]
Ethnomedicinal use	Traditional topical application for wounds and minor skin injuries	Supports empirical use but requires pharmacological validation	[45]

6. Anti-Aging Potential and Enzyme Inhibition

Skin aging is a multifactorial process characterized by progressive degradation of the extracellular matrix, loss of skin elasticity, and alterations in pigmentation. Several enzymes, including human neutrophil elastase (HNE), hyaluronidase (Hyal), collagenase, and tyrosinase, play key roles in these processes by promoting degradation of elastin, collagen, and hyaluronic acid or by regulating melanin synthesis. Consequently, inhibition of these enzymes represents one of the principal molecular strategies in the development of modern anti-aging dermocosmetics (Table 7).

Given its high content of polyphenols, flavonoids, and hydrolysable tannins, *Geranium robertianum* could be expected to exhibit inhibitory activity against enzymes involved in skin aging. Numerous phenolic compounds identified in the species, particularly quercetin and ellagic acid derivatives, are structurally related to molecules that have demonstrated inhibitory effects against elastase, hyaluronidase, collagenase, and tyrosinase in other botanical species [46]. Nevertheless, direct experimental evidence supporting these activities in *G. robertianum* remains very limited.

Table 7. Evidence relevant to the wound-healing potential of *Geranium robertianum* L.

Evidence Source	Main Finding	Applicability to *G. robertianum*	Evidence Strength	Ref.
Traditional use of *G. robertianum*	Topical application to wounds and minor skin injuries	Direct—ethnomedicinal use	Low	[45]
Purified tannic acid and tannin-rich extracts from other materials	Effects on wound closure, fibroblast activity and collagen-related processes	Indirect—not tested with *G. robertianum*	Limited	[42,43]
Tannin-containing burn-wound preparation	Similar bacterial colonization between groups; more favorable observations concerning eschar quality and hypertrophic scarring	Indirect—not tested with *G. robertianum*	Low—small pilot study	[44]
G. robertianum extracts	Insufficient direct evidence from wound-healing models	Direct evidence lacking	Insufficient	—

Currently available studies report only weak hyaluronidase inhibition (approximately 7.2%) and moderate elastase inhibition (approximately 34.7%) by aqueous extracts at the tested concentration (10 µg/mL), suggesting only limited modulation of extracellular matrix degradation pathways [47]. Furthermore, no significant studies have demonstrated inhibition of collagenase or tyrosinase by *G. robertianum* extracts using either in vitro or in silico approaches. Consequently, the available data are insufficient to support specific anti-aging claims based on direct enzymatic inhibition.

Interestingly, investigations conducted on other species within the *Geranium* genus indicate that phenolic constituents such as ellagic acid and quercetin possess significant inhibitory activity against tyrosinase and other enzymes associated with skin aging [48]. These observations suggest that *G. robertianum* may possess similar biological potential; however, this hypothesis remains to be experimentally verified.

Overall, direct evidence for the inhibition of skin-aging-related enzymes by *G. robertianum* extracts remains limited. Further investigations using standardized extracts and skin-relevant experimental models are needed to establish the significance of these preliminary findings.

7. Photoprotective and Anti-Aging Potential

Skin aging is a multifactorial process influenced by intrinsic factors and environmental stressors, particularly chronic exposure to ultraviolet (UV) radiation. UV radiation promotes the generation of reactive oxygen species (ROS), oxidative stress, inflammatory responses, and degradation of extracellular matrix components, contributing to collagen loss, reduced elasticity and the development of photoaging [35,38–40]. The antioxidant- and polyphenol-rich profile of *Geranium robertianum* therefore provides a rationale for investigating its potential relevance in photoprotective and anti-aging skincare.

Several studies have demonstrated antioxidant activity of *G. robertianum* extracts using chemical assays such as DPPH, ABTS, and FRAP, as well as models of lipid peroxidation [8,33,34]. The observed activity has frequently been associated with the presence of phenolic acids and flavonoids, although differences in extraction procedures, extract composition, and experimental conditions limit direct comparison between studies. These findings suggest that the antioxidant capacity of *G. robertianum* extracts may contribute to protection against oxidative processes involved in photoaging. However, chemical antioxidant activity alone does not establish photoprotective efficacy in human skin.

The individual phenolic constituents identified in *G. robertianum* provide additional mechanistic support. Gallic acid, one of the phenolic acids reported in the plant, has demonstrated protective effects in experimental models of UVB-induced skin damage. In fibroblast

and in vivo skin models, gallic acid reduced ROS generation and inflammatory responses, attenuated matrix metalloproteinase-1 (MMP-1) expression, and supported type I procollagen production [38–40]. These effects are relevant to mechanisms underlying extracellular matrix degradation and photoaging. Nevertheless, the available evidence primarily concerns isolated gallic acid and should therefore be interpreted as mechanistic support rather than direct evidence that *G. robertianum* extracts exert comparable anti-aging effects.

Flavonoids detected in *G. robertianum*, including quercetin and related glycosides, provide a further basis for investigating its potential skin-protective activity. Experimental studies with isolated flavonoids have demonstrated antioxidant and anti-inflammatory effects, including modulation of ROS, pro-inflammatory mediators such as TNF-α, IL-1β, and IL-6, and endogenous antioxidant defense pathways such as nuclear factor erythroid 2-related factor 2 (Nrf2) signaling [49,50]. Studies in keratinocyte and melanocyte models have additionally reported effects on UVB- or H_2O_2-induced oxidative stress, COX-2 and TNF-α expression, and melanogenesis [49]. Such findings may be relevant to photoaging and pigmentation-related processes, but they should not be directly extrapolated to whole *G. robertianum* extracts because the activity, bioavailability, and concentration of individual constituents within the plant matrix may differ substantially.

The limited evidence concerning the inhibition of skin-aging-related enzymes by *G. robertianum* extracts is discussed in Section 6.

Overall, the photoprotective and anti-aging potential of *G. robertianum* is supported by its antioxidant-rich phytochemical profile and by experimental evidence concerning several of its individual constituents. However, the strength of evidence is substantially greater for isolated phenolic compounds than for standardized *G. robertianum* extracts. Further studies should therefore evaluate chemically characterized extracts in UV-exposed keratinocyte and fibroblast models, reconstructed human skin, and ex vivo skin systems, with endpoints including oxidative stress, inflammatory mediators, MMP activity, collagen and elastin homeostasis, and pigmentation-related pathways. Topical formulation studies and, ultimately, controlled clinical investigations will be necessary to determine whether the observed biological properties can be translated into substantiated cosmetic photoprotective or anti-aging applications.

8. Other Dermatological Activities

Beyond its antioxidant, anti-inflammatory, antimicrobial, and potential wound-healing properties, *Geranium robertianum* may have additional dermatological relevance due to the presence of tannins, flavonoids, and phenolic acids. In particular, the high content of hydrolysable tannins may be associated with the astringent properties traditionally attributed to the plant. Astringent activity may be of interest in topical preparations intended to support skin conditioning and reduce excessive surface exudation; however, direct experimental evaluation of the astringent effect of standardized *G. robertianum* extracts remains limited.

The polyphenolic constituents of *G. robertianum* may also be relevant to skin barrier maintenance through their antioxidant and protective effects. Oxidative stress can adversely affect cellular homeostasis and barrier-associated processes, while phenolic compounds may modulate oxidative and inflammatory responses in skin cells [1]. Nevertheless, direct evidence demonstrating improved epidermal barrier function following topical application of *G. robertianum* extracts is currently lacking. Studies assessing transepidermal water loss (TEWL), lipid organization, filaggrin expression, involucrin, loricrin, and other barrier-associated markers would therefore be valuable.

Some constituents identified in *G. robertianum*, particularly ellagic acid and flavonoids such as quercetin, have also been investigated for their effects on melanogenesis and

pigmentation-related pathways in experimental models [1,25,49]. These observations provide a possible rationale for investigating the plant in cosmetic products targeting uneven skin tone. However, evidence obtained for isolated compounds cannot be directly extrapolated to whole-plant extracts, and direct studies of the depigmenting activity of standardized *G. robertianum* preparations are insufficient.

From a cosmetic perspective, these properties suggest that *G. robertianum* could be investigated as a multifunctional botanical ingredient, particularly in formulations designed for skin conditioning and antioxidant protection. At present, however, the evidence for barrier-supporting, soothing, astringent, or pigmentation-modulating effects remains substantially less developed than the evidence for its antioxidant activity. Further research using validated skin models and well-characterized topical formulations is required to establish the relevance of these additional activities to cosmetic applications.

9. Skin Safety, Irritation, and Cytotoxicity

The increasing interest in *Geranium robertianum* as a potential botanical ingredient for topical and dermocosmetic applications emphasizes the need for an adequate safety assessment. Although the plant exhibits antioxidant, anti-inflammatory, antimicrobial, and other biologically relevant activities, these effects should not be considered independently of concentration, extract composition, and route of exposure. As with other polyphenol-rich botanical extracts, biological activity may be accompanied by concentration-dependent cytotoxicity, highlighting the importance of extract characterization, standardization, and dose selection.

Available in vitro evidence indicates that the cytotoxicity of *G. robertianum* extracts is influenced by both extraction solvent and concentration. In studies using human keratinocytes, optimized ethanol and acetone extracts showed half maximal cytotoxic concentrations (CC_{50}) of 1771.24 ± 5.78 μg/mL and 958.01 ± 6.14 μg/mL, respectively [51]. The higher CC_{50} value observed for the ethanol extract indicates lower cytotoxicity under the experimental conditions used, whereas the acetone extract exhibited greater cytotoxic potential. These findings illustrate that extraction methodology can substantially influence the biological and safety profile of *G. robertianum* preparations.

Importantly, cytotoxicity data obtained in cultured keratinocytes cannot be directly translated into the safety of a finished cosmetic product. The actual safety profile of a topical formulation depends on extract concentration, composition, dermal bioavailability, vehicle characteristics, exposure duration, frequency of application, and the presence of other formulation components. Therefore, CC_{50} values should be interpreted as preliminary indicators of cellular tolerance rather than as evidence of a defined safe concentration for topical use.

Evidence concerning irritation and sensitization is considerably more limited. No comprehensive set of studies specifically evaluating the irritation or sensitization potential of standardized *G. robertianum* extracts intended for topical application has been identified. Human evidence is restricted to isolated reports of allergic contact dermatitis or contact sensitization associated with exposure to the plant [52]. Although such reports indicate that hypersensitivity reactions may occur in susceptible individuals, they do not provide sufficient information to determine their frequency, dose relationship, or relevance to standardized cosmetic formulations.

Overall, the available data provide preliminary evidence that some *G. robertianum* extracts can exhibit relatively low cytotoxicity under defined in vitro conditions; however, the dermal safety of the plant as a cosmetic ingredient cannot yet be considered fully established. Further research should include standardized cytotoxicity testing in relevant human skin models, reconstructed human epidermis or skin irritation models, sensitization

assessment, evaluation of phototoxicity where applicable, and appropriate human compatibility studies. Importantly, such investigations should be performed using chemically characterized and formulation-relevant extracts. Establishing a clear relationship between extract composition, concentration, biological activity, and safety will be essential for the development of evidence-based topical products containing *G. robertianum*.

10. Modern Applications in Skin Health and Cosmetics

The increasing demand for natural, multifunctional, and scientifically substantiated cosmetic ingredients has stimulated interest in medicinal plants as potential sources of bioactive compounds for topical applications. Botanical extracts containing phenolic acids, flavonoids, tannins, and other secondary metabolites may provide multiple biological activities within a single preparation. In this context, the phytochemical profile of *Geranium robertianum* makes it a potential candidate for further investigation as a botanical ingredient for skincare formulations.

The biological properties described for *G. robertianum* suggest several possible areas of dermocosmetic interest. Its antioxidant activity is the most consistently supported property and may be relevant to formulations aimed at protecting the skin against oxidative stress. The anti-inflammatory and antimicrobial activities demonstrated in experimental models may provide additional rationale for investigating the plant in products intended for skin conditioning and maintenance. The astringent properties associated with its tannin content may also be of interest in formulations designed to provide astringent or skin-conditioning effects. However, these potential applications should be distinguished from clinically established efficacy, as most available evidence has been obtained using in vitro assays or isolated constituents.

From a formulation perspective, *G. robertianum* extracts could potentially be incorporated into topical dosage forms such as creams, gels, lotions, emulsions, serums, and hydrogel-based systems. The choice of extract should be based on its chemical composition and intended biological activity, since extraction solvent, plant origin, harvesting conditions, and processing may substantially affect the concentrations of phenolic acids, flavonoids, tannins, and volatile constituents. In addition, formulation development should consider extract–excipient compatibility, preservative efficacy, physicochemical stability, and maintenance of biological activity during manufacturing and storage. Polyphenol-rich extracts may be particularly susceptible to oxidation and degradation under unfavorable conditions, making appropriate packaging and control of pH, temperature, light, and oxygen important considerations.

Although *Geranium robertianum L.* has traditionally been investigated primarily in the context of its oral use, its potential for topical application has also attracted attention. A preliminary clinical study published in 2025 evaluated a multicomponent cosmetic cream containing *G. robertianum* extract for its anti-wrinkle potential, reporting improvements in periorbital wrinkle scores following four weeks of topical application. However, the contribution of the individual plant extract could not be distinguished from the effects of the other formulation ingredients [53]. Despite these results, the systematic investigation of advanced dermal delivery systems for *G. robertianum* extracts, particularly liposomal and other vesicular formulations, remains limited, highlighting an opportunity for further research into their stability, skin delivery, and cosmetic efficacy.

Advanced delivery systems, including liposomes, nanoemulsions, nanostructured lipid carriers, polymeric nanoparticles, and hydrogel-based systems, may offer opportunities to improve the stability, dispersibility, or topical delivery of plant-derived bioactive compounds. However, such approaches have not yet been sufficiently investigated for *G. robertianum*. Evidence obtained from other polyphenol-rich botanical compounds may provide useful

technological precedents, but these findings cannot be directly extrapolated to *G. robertianum* extracts without formulation-specific evaluation.

Despite its interesting phytochemical and biological profile, the translation of *G. robertianum* into evidence-based cosmetic products remains at an early stage. Most available studies focus on phytochemical characterization, chemical antioxidant assays, antimicrobial screening, or mechanistic investigations of individual constituents. In contrast, data on standardized topical extracts, skin penetration and bioavailability, formulation stability, skin-specific biological activity, and controlled clinical evaluation are limited. Therefore, *G. robertianum* should currently be regarded as a promising research candidate for multifunctional topical formulations rather than as an established cosmetic active ingredient (Table 8). Further work integrating extract standardization, formulation development, skin-delivery studies, safety assessment, and clinical validation will be required to determine its practical value in cosmetic applications.

Table 8. Potential dermocosmetic applications of *Geranium robertianum* based on currently available evidence.

Potential Application	Supporting Evidence	Applicability to *G. robertianum*	Evidence Strength	Ref.
Antioxidant skincare	Antioxidant activity demonstrated mainly in chemical assays	Direct—extract assays; skin efficacy unconfirmed	Limited	[8,39,40]
Skin protection/photoaging	Extract antioxidant activity and experimental studies on isolated phenolic compounds	Mixed—direct chemical assays and indirect skin-related evidence	Limited	[8,30–32,39,40]
Skin conditioning/astringent products	Tannin-rich phytochemical profile and traditional use	Indirect—proposed application based on composition	Limited	[23–29,45]
Anti-inflammatory skincare	Experimental anti-inflammatory findings and mechanistic rationale	Preliminary—limited skin-specific evidence	Limited	[18]
Antimicrobial formulations	In vitro antibacterial and antifungal activity	Direct—extract assays; topical efficacy unconfirmed	Limited	[18]
Wound-care-related applications	Traditional use and indirect evidence from tannins	Mixed—direct traditional use and indirect experimental evidence	Limited	[43–45]
Barrier-supporting products	Indirect mechanistic rationale based on polyphenolic constituents	Indirect—no direct barrier-function evidence	Insufficient	[1,23–29]

11. Potential for Cosmetic Formulation Development

The translation of *Geranium robertianum* into topical cosmetic products depends not only on its biological properties but also on the development of formulations capable of maintaining the stability and activity of its phytochemical constituents. Polyphenol-rich botanical extracts may present several formulation challenges, including susceptibility to oxidation, light, temperature, and pH-dependent degradation. Consequently, formulation design, extract characterization, and appropriate storage conditions are important considerations for maintaining product quality and biological activity [54,55].

The formulation of *G. robertianum* extracts requires particular attention to the chemical characteristics of their major constituents. Phenolic acids, flavonoids, and hydrolysable tannins may undergo degradation under unfavorable environmental conditions, potentially affecting both biological activity and the physicochemical characteristics of the final formulation [3]. In addition, extraction solvent and processing conditions can substantially

influence the qualitative and quantitative composition of the resulting extract. Therefore, optimization and standardization of the extraction process should precede formulation development, particularly when biological activity is intended to be associated with specific phytochemical markers.

Several formulation strategies may be considered to improve the stability of polyphenol-rich botanical extracts, including optimization of pH, protection from light and oxygen, appropriate packaging, and the use of compatible stabilizing systems. Encapsulation and advanced delivery systems, such as liposomes, nanostructured lipid carriers (NLCs), nanoemulsions, polymeric nanoparticles, and hydrogel-based systems, have also been investigated for plant-derived polyphenols and may provide opportunities to improve their physicochemical stability and control their release [56,57]. However, the suitability of these systems for *G. robertianum* extracts remains to be established experimentally.

Evidence from other botanical polyphenols illustrates the potential value of such approaches. For example, incorporation of resveratrol into lipid-based delivery systems has been reported to improve its stability and retention of antioxidant activity compared with conventional formulations [58,59]. These findings provide a useful technological precedent for the formulation of polyphenol-rich botanical extracts, but they should not be considered direct evidence of improved dermal delivery or efficacy of *G. robertianum* preparations.

An additional challenge is the standardization and batch-to-batch reproducibility of *G. robertianum* extracts. Geographical origin, plant developmental stage, harvesting conditions, extraction solvent, and processing procedures may influence the concentration of phenolic acids, flavonoids, tannins, and volatile constituents. Accordingly, future formulation studies should include chemically characterized extracts, defined phytochemical markers, quantitative quality control, and assessment of physicochemical and biological stability throughout storage.

At present, formulation-specific research on *G. robertianum* remains limited. In particular, data regarding compatibility with cosmetic excipients, formulation stability, skin deposition or permeation, preservation, and maintenance of biological activity following incorporation into finished products are scarce. These parameters should be systematically evaluated before the biological properties observed in experimental studies can be translated into substantiated cosmetic applications. In addition to improving extract stability and controlling the release of bioactive constituents, the effectiveness of these formulation strategies should be evaluated in terms of dermal availability and safety. In vitro skin permeation and retention studies, preferably using reconstructed human skin models or ex vivo human skin, would help determine the extent of skin penetration and local retention of the extract constituents. These investigations should be complemented by formulation-specific cytotoxicity, skin irritation, and sensitization assessments, since the safety profile of the finished product cannot be inferred solely from the cytotoxicity data obtained for the unformulated extract.

Overall, *G. robertianum* represents a potential source of multifunctional botanical compounds for topical cosmetic formulations, but its practical application requires substantially more formulation and stability research. Future studies should establish standardized extract specifications and evaluate appropriate delivery systems using formulation-relevant concentrations and skin models. Such an approach would provide the technological basis for determining whether the biological properties of *G. robertianum* can be translated into stable, safe, and scientifically substantiated cosmetic products.

12. Future Perspectives

Although the available literature indicates that *Geranium robertianum* contains a range of bioactive compounds potentially relevant to skin health, substantial knowledge gaps re-

main before its broader application in evidence-based cosmetic products can be considered. Future research should therefore adopt an integrated approach combining phytochemical characterization, biological evaluation, formulation science, safety assessment, and clinical investigation.

A major priority is the standardization of plant material and extraction procedures. Variability associated with geographical origin, plant developmental stage, harvesting conditions, extraction methodology, and solvent selection may substantially affect the phytochemical composition and biological activity of *G. robertianum* extracts. Establishing standardized extraction protocols and quantitative specifications for selected phytochemical markers will be essential for ensuring reproducibility, batch to batch consistency, and meaningful comparison among future studies.

Mechanistic investigations should increasingly employ skin-relevant experimental models, including human keratinocytes and dermal fibroblasts, three-dimensional reconstructed skin, and ex vivo human skin. Such models could clarify whether the biological activities observed in chemical assays and non-specific in vitro systems translate into effects relevant to skin physiology. Particular attention should be directed toward oxidative stress, inflammatory signaling, extracellular matrix preservation, collagen homeostasis, skin barrier function, pigmentation-related pathways, and antimicrobial activity under conditions relevant to topical application.

From a formulation perspective, future studies should focus on developing stable topical systems capable of preserving the chemical and biological properties of *G. robertianum* extracts. Liposomes, nanostructured lipid carriers, nanoemulsions, polymeric nanoparticles, and hydrogel-based systems may provide useful approaches for improving extract stability and controlling the delivery of selected constituents. However, these technologies should be evaluated specifically with chemically characterized *G. robertianum* extracts rather than extrapolated from studies of unrelated botanical compounds. Formulation studies should additionally address excipient compatibility, preservative efficacy, physicochemical stability, skin permeation or deposition, and maintenance of biological activity during storage.

Comprehensive safety assessment represents another important research priority. Future studies should include standardized cytotoxicity testing in relevant human skin models, irritation and sensitization assessment, and other safety evaluations appropriate to the intended topical application. Well-designed controlled clinical studies will ultimately be required to determine the tolerability and efficacy of standardized *G. robertianum*-containing formulations and to support scientifically substantiated cosmetic claims.

Sustainability and quality control should also be considered during further development. Good Agricultural and Collection Practices (GACP), appropriate authentication of plant material, traceability of raw materials, and defined phytochemical specifications may contribute to the reproducible production of high-quality botanical extracts. These aspects are particularly important when variability in plant material can directly influence both biological activity and formulation performance.

Overall, *G. robertianum* represents a promising but insufficiently explored botanical source of compounds relevant to skin health and cosmetic formulation. Addressing the current gaps in extract standardization, skin-specific biological evaluation, formulation technology, safety, and clinical validation will be essential for determining its true potential as a scientifically substantiated topical cosmetic ingredient.

13. Conclusions

Geranium robertianum L. is a phytochemically rich medicinal plant containing phenolic acids, flavonoids, hydrolysable tannins, and volatile terpenoids that may contribute to its diverse biological activities. The available evidence provides a scientific rationale for several

traditional dermatological uses and indicates antioxidant, antimicrobial, anti-inflammatory, and astringent properties of the plant and its constituents. Gallic acid, ellagic acid, quercetin derivatives, and geraniin are among the constituents of particular interest because of their reported biological activities relevant to skin protection and topical applications.

However, the strength of evidence varies considerably among the reported activities. Most studies have focused on phytochemical characterization, chemical antioxidant assays, antimicrobial screening, or biological effects of isolated compounds, while direct evidence obtained from standardized *G. robertianum* extracts in skin-specific models remains limited. Evidence for wound-healing, photoprotection, anti-aging effects, skin barrier modulation, and other specific cosmetic benefits is therefore still preliminary. Similarly, dermal safety, skin permeation or deposition, formulation stability, and clinical tolerability have not been sufficiently characterized.

Future research should prioritize standardized plant material and extraction procedures, chemically characterized extracts, skin-relevant experimental models, formulation and stability studies, comprehensive safety assessment, and controlled clinical evaluation. Such an integrated approach will be necessary to determine whether the biological properties identified in experimental studies can be translated into reproducible and scientifically substantiated cosmetic applications.

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Abbreviations

The following abbreviations are used in this manuscript:

UV	Ultraviolet
ROS	Reactive Oxygen Species
EU	European Union
HPLC	High-Performance Liquid Chromatography
LC-MS	Liquid Chromatography–Mass Spectrometry
HHDP	Hexahydroxydiphenoyl
Mg	Magnesium
Ca	Calcium
Fe	Iron
Mn	Manganese
Zn	Zinc
MMPs	Matrix Metalloproteinases
MMP-1	Matrix Metalloproteinase-1

DPPH	2,2-diphenyl-1-picrylhydrazyl
ABTS	2,2-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)
FRAP	Ferric Reducing Antioxidant Power
HOCL	Hypochlorous acid
COX-2	Cyclooxygenase-2
AP-1	Activator Protein 1
NF-Kb	Nuclear Factor kappa B
IL-6	Interleukin-6
ERK	Extracellular Signal-Regulated Kinase
JNK	c-Jun N-terminal Kinase
AKT	Protein Kinase B
STAT3	Signal Transducer and Activator of Transcription 3
PI3K	Phosphoinositide 3-Kinase
IL-1β	Interleukin-1 beta
IL-8	Interleukin-8
TNFα	Tumor Necrosis Factor alpha
5-LOX	5-Lipoxygenase
iNOS	Inducible Nitric Oxide Synthase
NO	Nitric Oxide
IC_{50}	Half-Maximal Inhibitory Concentration
MIC	Minimum Inhibitory Concentration
MBC	Minimum Bactericidal Concentration
SPME	Solid-Phase Microextraction
CC_{50}	Cytotoxic Concentration 50
Nrf2	Nuclear factor erythroid 2-related factor 2
NLCs	Nanostructured Lipid Carriers
GACP	Good Agricultural and Collection Practices
TEWL	Transepidermal Water Loss

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