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*Review*

# Plant-Derived Bioactive Compounds in Cosmetic Products: Opportunities for Sustainable Agricultural Production

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**Abstract:** Plant materials are increasingly considered valuable components in contemporary cosmetic formulations. Different medicinal and aromatic plant species provide biologically active compounds that may support skin maintenance. These compounds are increasingly incorporated into cosmetic formulations due to their potential antioxidant, anti-inflammatory and protective effects. Such cosmetic formulations may contribute to maintaining skin condition through the presence of plant-derived compounds. In examining cosmetic products, the paper highlights plant-derived bioactive compounds and considers their potential role within sustainable agricultural production. The paper considers selected medicinal plants commonly used as sources of cosmetic ingredients and outlines the connection between plant cultivation, raw material availability and cosmetic product development. Stronger interaction between farmers and cosmetic producers may improve the use of plant resources and encourage wider use of plant materials in cosmetic products.

**Keywords:** *Medicinal and aromatic plants; plant extracts; cosmetic ingredients; sustainable cosmetics; natural cosmetic products; bioactive substances.*

## 1. Introduction

In recent decades, cosmetic formulations have increasingly incorporated ingredients obtained from natural sources. This development is closely associated with changes in consumer attitudes, particularly greater awareness of environmental concerns and stronger interest in products based on natural components, which has stimulated the growth of so-called "green" cosmetics [1]. Bioactive compounds present in plants have attracted research attention due to their potential role in maintaining and protecting the skin. Plant extracts, essential oils, and other botanical substances are widely studied for their antioxidant, anti-inflammatory, and protective properties. Recent studies indicate that plant-based ingredients are now incorporated into cosmetic formulations more frequently than before [2]. This trend reflects the broader development of cosmetic products formulated with natural components aimed at improving skin care and protection.

Medicinal and aromatic plants represent an important source of biologically active compounds, including polyphenols, flavonoids, essential oils, and other secondary metabolites. These compounds have attracted considerable scientific interest because of their antioxidant, anti-inflammatory, and

protective properties, which may contribute to maintaining skin structure and function. Studies show that plant extracts and their constituents can exert various biological effects on the skin, including antioxidant, antimicrobial, and regenerative activities [3]. Recent research also highlights the wide range of biological activities of bioactive compounds derived from medicinal plants and their potential applications in different scientific and industrial fields [4]. Consequently, plant-derived substances are increasingly considered in formulations intended for skin care and protection, contributing to the development of cosmetic products that incorporate natural ingredients to enhance their functional and protective properties [5].

The growing use of plant-based ingredients in cosmetic products highlights the importance of medicinal plants as a source of raw materials for the cosmetic industry. Plant extracts, essential oils, and other botanical compounds are incorporated into cosmetic formulations due to their functional characteristics and their potential contribution to skin health. Essential oils and their individual constituents are of particular interest because of their anti-inflammatory, antimicrobial, and antioxidant activities, which explains their frequent use in products intended for skin and hair care [6]. Recent studies also indicate that many plant extracts contain bioactive compounds with antioxidant, anti-inflammatory, and protective effects, suggesting considerable potential for their application in dermocosmetics and skin care products [7]. Medicinal plants therefore represent an important source of natural ingredients for the development of modern cosmetic formulations.

The increasing use of plant-based ingredients in cosmetic products has also intensified interest in medicinal and aromatic plants as potential sources of bioactive compounds for modern cosmetic formulations. At the same time, their cultivation within agricultural production systems may provide an important and stable supply of raw materials for the cosmetic industry while supporting the development of more sustainable production systems [8]. Recent studies indicate that plant extracts and their derivatives have considerable potential in cosmetic products intended for skin and hair care because of their antioxidant, anti-inflammatory, and antimicrobial properties [9]. Moreover, the growing demand for natural and sustainable cosmetic products further encourages the use of medicinal and aromatic plants as sources of cosmetic ingredients [10]. This paper therefore focuses on plant-derived bioactive compounds used in cosmetic products and examines the role of medicinal and aromatic plants as sources of bioactive ingredients in cosmetic formulations, as well as the potential for their production within sustainable agricultural systems capable of providing a stable and environmentally acceptable supply of raw materials for the cosmetic industry.

## 2. Major groups of plant bioactive compounds

Medicinal and aromatic plants represent a rich source of bioactive compounds that play important roles in plant defence and in the development of products intended for skin care and protection. These compounds belong to different groups of secondary metabolites that may exhibit various biological activities, including antioxidant, anti-inflammatory, antimicrobial, and photoprotective effects [11]. Because of these properties, plant-derived bioactive compounds show considerable potential for use in cosmetic formulations aimed at protecting the skin from oxidative stress and other external factors. The most important groups include phenolic compounds, terpenoids, essential oils, and other secondary metabolites that contribute to the functional properties of cosmetic formulations.

### *2.1. Phenolic Compounds*

Phenolic compounds are among the most widespread and important groups of secondary metabolites in medicinal and aromatic plants. They are characterised by the presence of one or more phenolic rings and include several subgroups such as phenolic acids, flavonoids, stilbenes, and lignans [12,13]. These compounds occur in various plant organs, including leaves, fruits, seeds, and bark, where they contribute to plant protection against stress factors such as ultraviolet radiation, oxidative stress, and pathogenic microorganisms. In addition, phenolic compounds participate in several physiological processes, including growth regulation, defence responses, and interactions with the environment.

From the perspective of biological activity, phenolic compounds are particularly important because of their pronounced antioxidant properties. Their ability to neutralise free radicals contributes to the reduction of oxidative stress and the protection of cellular structures from damage [14]. The antioxidant activity of polyphenols is associated with their capacity to donate electrons or hydrogen atoms, as well as their ability to chelate metal ions that may participate in the formation of reactive oxygen species. Oxidative stress is strongly associated with skin photoaging and the degradation of collagen and elastin. Consequently, phenolic compounds may contribute to protecting the skin from adverse environmental influences, including ultraviolet radiation and environmental pollution and other external stress factors.

In addition to their antioxidant activity, phenolic compounds also exhibit anti-inflammatory, antimicrobial, and photoprotective properties. These biological effects contribute to their importance in cosmetic formulations intended for skin protection and regeneration. Phenolic compounds may modulate inflammatory processes and influence signalling pathways involved in the skin response to stress. Plant extracts rich in phenolic compounds are widely used in skin care products because they may support skin structure, improve elasticity, and slow skin ageing [15,16]. Examples of plants rich in phenolic compounds include *Camellia sinensis*, *Vitis vinifera*, *Punica granatum*, and *Rosmarinus officinalis*, whose extracts are commonly used in cosmetic formulations aimed at protecting the skin from oxidative stress and maintaining skin health.

### *2.2. Terpenoids and essential oils*

Terpenoids represent one of the most diverse and biologically important groups of plant secondary metabolites. They are biosynthesised from isoprenoid units and include several structural classes such as monoterpenes, sesquiterpenes, diterpenes, and triterpenes [17]. Differences in the number of isoprene units and their chemical structure contribute to the remarkable diversity of terpenoids and their functions in plants. In plants, terpenoids play a key role in defence mechanisms, providing protection against herbivores, pathogenic microorganisms, and various abiotic stress factors. Many terpenoids are also responsible for the characteristic aroma of plants and represent an important group of bioactive compounds widely used in the pharmaceutical and cosmetic industries.

Essential oils are complex mixtures of volatile organic compounds mainly composed of monoterpenes, sesquiterpenes, and their oxygenated derivatives [18]. They are obtained from different plant organs, including leaves, flowers, fruits, seeds, and bark, most commonly by steam distillation or extraction. Their chemical composition may vary depending on plant species, geographical origin, cultivation conditions, and extraction method, which can influence their biological properties. Essential oils exhibit a wide range of biological activities relevant to skin care, including antioxidant, antimicrobial, and anti-inflammatory effects [19].

In cosmetic formulations, terpenoids and components of essential oils can inhibit the growth of pathogenic microorganisms on the skin, reduce inflammatory responses, and support the integrity of the skin barrier [20]. Their antioxidant activity is associated with the ability to neutralise reactive oxygen species, thereby limiting oxidative damage to cellular structures and helping to prevent premature skin ageing [21]. Consequently, terpenoids and essential oils are increasingly regarded as valuable natural ingredients in cosmetic products designed to protect and maintain skin health [3].

In addition to their biological properties, essential oils also contribute to the sensory quality of cosmetic products. Their characteristic aromas improve user experience and are widely utilised in skin and hair care formulations such as creams, lotions, shampoos, and fragrances [22]. Plants particularly rich in essential oils include *Lavandula angustifolia*, *Mentha piperita*, *Melaleuca alternifolia*, and *Rosmarinus officinalis*, whose extracts and oils are widely used in the cosmetic industry.

### *2.3. Alkaloids, saponins and other bioactive metabolites*

In addition to phenolic compounds and terpenoids, medicinal and aromatic plants contain numerous other secondary metabolites with potential biological activity and applications in cosmetic formulations. These include alkaloids, saponins, glycosides, plant sterols, and polysaccharides [8]. In plants, these metabolites contribute to defence against pathogens, herbivores, and abiotic stress

factors, while also regulating signalling pathways involved in stress responses [23]. They also participate in various physiological processes, including plant adaptation to environmental changes and interactions with other organisms. Their chemical diversity and broad range of biological activities make them important candidates for the development of natural ingredients used in cosmetic and dermocosmetic products.

Among these metabolites, alkaloids represent a large group of nitrogen-containing organic compounds widely distributed in plants. They are typically derived from amino acids and characterised by diverse chemical structures and broad biological activities [24]. Most alkaloids contain heterocyclic nitrogen rings and may occur in different forms and derivatives. In plant physiology, alkaloids contribute to defence mechanisms by acting as toxic or repellent substances against herbivores and microorganisms. In cosmetic applications, certain alkaloids exhibit antimicrobial, anti-inflammatory, and antioxidant properties, supporting their potential use in formulations intended for skin care and protection.

Saponins are glycosidic compounds composed of a hydrophobic aglycone (sapogenin) linked to one or more sugar residues. Their amphiphilic structure enables interactions with lipid and aqueous phases, giving them pronounced surface-active properties. Consequently, saponins are often used as natural surfactants in products intended for skin and hair cleansing. Studies indicate that saponins exhibit anti-inflammatory, antimicrobial, and regenerative effects that may enhance functional properties of cosmetic formulations [25]. They may support skin regeneration by stimulating fibroblast proliferation, promoting collagen synthesis, and accelerating re-epithelialisation, highlighting their potential in dermocosmetic products aimed at skin repair and protection.

Plants also contain other bioactive metabolites, including glycosides, sterols, and polysaccharides, which may contribute to maintaining skin health. Plant polysaccharides can enhance skin hydration and promote the formation of a protective film on the epidermal surface, thereby improving moisture retention and supporting barrier stability [26]. These compounds may also exhibit anti-inflammatory, antioxidant, and regenerative effects that help protect the skin from oxidative stress and environmental factors associated with ageing [27]. In addition, plant sterols may help stabilise the lipid barrier of the skin and support the maintenance of its structure and function.

Overall, different groups of bioactive compounds present in medicinal and aromatic plants show significant potential for use in cosmetic formulations. Phenolic compounds, terpenoids, essential oils, alkaloids, and saponins exhibit antioxidant, anti-inflammatory, and antimicrobial activities that may help protect and maintain skin function. Owing to their chemical diversity and functional properties, plant extracts containing these metabolites represent an important source of natural ingredients for the development of modern cosmetic products, particularly those aimed at protecting the skin from oxidative stress, maintaining barrier integrity, and supporting skin regeneration.

## 3. Plant-derived bioactive compounds in cosmetics and sustainable production

Plant-derived bioactive compounds represent an important group of natural ingredients widely used in the modern cosmetic industry. Medicinal and aromatic plants contain various secondary metabolites, including phenolic compounds, terpenoids, alkaloids, and saponins, which exhibit antioxidant, anti-inflammatory, and antimicrobial properties. These compounds help protect the skin from oxidative stress, reduce inflammatory processes, and maintain the integrity of the skin barrier, which explains their increasing use as active ingredients in cosmetic formulations intended for skin care and protection [2,3]. Their application includes a wide range of cosmetic products, including preparations for skin and hair care as well as various dermocosmetic formulations.

The increasing use of plant-derived bioactive compounds in cosmetic products has also strengthened interest in medicinal and aromatic plants as an important source of natural raw materials. The development of cosmetic formulations based on plant extracts highlights the need for a stable and sustainable supply of plant material containing desired bioactive compounds. In this context, the organised agricultural cultivation of medicinal and aromatic plants is becoming increasingly important, as it allows controlled production, consistent raw material quality, and reduced pressure on plant species traditionally collected from the wild [7,8]. This approach links the

development of cosmetic products with sustainable systems for producing plant raw materials, supporting environmentally responsible and economically viable agricultural practices.

### *3.1. Application of plant-derived bioactive compounds in cosmetic products*

Plant-derived bioactive compounds are widely used in modern cosmetic formulations due to their diverse biological activities that support skin health. Extracts rich in polyphenols, terpenoids, alkaloids, and other secondary metabolites are frequently incorporated as active ingredients in products designed to protect the skin from oxidative stress, reduce inflammatory processes, and maintain skin barrier integrity. Their antioxidant activity is particularly relevant in formulations aimed at preventing photoageing, as it may help neutralise reactive oxygen species generated by exposure to ultraviolet radiation and other environmental factors [3,5]. Consequently, plant extracts are increasingly included in skin care products intended for epidermal protection and regeneration.

Plant-derived bioactive compounds are widely used in the cosmetic industry in products such as moisturising and anti-ageing creams, serums, lotions, skin cleansing preparations, and hair care formulations. Phenolic compounds are frequently included in formulations designed to protect the skin from oxidative stress and reduce visible signs of ageing, while terpenoids and components of essential oils may provide antimicrobial protection and enhance the sensory properties of cosmetic products. In addition, certain plant-derived bioactive compounds may play an important role in regulating inflammatory processes and maintaining the functional condition of the skin, which is why they are frequently included in dermocosmetic formulations intended for sensitive or problematic skin [7,10]. Similar therapeutic approaches and biological activities have also been reported in dermatological and cosmeceutical studies focused on skin treatments and care [11,28]. Their use therefore supports the development of cosmetic products that combine functional effectiveness with natural sources of active ingredients.

In addition to their biological effects on the skin, plant-derived bioactive compounds also contribute to the functional and sensory properties of cosmetic formulations. Extracts from medicinal and aromatic plants may improve formulation stability, enhance product texture, and provide pleasant aromas that influence the overall consumer experience during product use. For this reason, essential oils and various plant extracts are widely incorporated into skin and hair care formulations, including creams, lotions, shampoos, and fragrances [16, 29]. The use of these ingredients therefore supports the development of cosmetic formulations that combine functional performance with desirable sensory characteristics.

In addition to their biological effects on the skin, plant-derived bioactive compounds also play an important role in improving the functional and sensory characteristics of cosmetic formulations. Extracts from medicinal and aromatic plants may contribute to formulation stability, improved product texture, and pleasant aromas that influence the overall consumer experience during the use of cosmetic products. For this reason, essential oils and various plant extracts are frequently incorporated into skin and hair care formulations, including creams, lotions, shampoos, and fragrances [16,30]. The inclusion of these ingredients enables the development of cosmetic formulations that combine functional performance with desirable aesthetic characteristics and improved overall product quality.

Current trends in the cosmetic industry increasingly focus on the development of formulations based on natural plant-derived ingredients. Growing consumer interest in natural cosmetics has stimulated intensified research into plant bioactive compounds and their potential applications in cosmetic products. As a result, medicinal and aromatic plants are becoming an important source of functional ingredients used in skin and hair care formulations [2]. The development of cosmetic formulations based on plant-derived bioactive compounds therefore supports the concept of natural and sustainable cosmetics.

### *3.2. Sustainable agricultural production of medicinal and aromatic plants*

The increasing use of plant-derived bioactive compounds in cosmetic products has led to growing interest in medicinal and aromatic plants as an important source of natural raw materials.

The cosmetic industry increasingly utilises plant extracts and their bioactive components due to their functional properties and applications in formulations intended for skin care and protection. Recent research has shown that plant-derived extracts can significantly influence the rheological and sensory properties of cosmetic formulations, highlighting their multifunctional role in developing stable and consumer-appealing products [31]. This trend has increased demand for plant raw materials capable of providing a stable and high-quality source of active ingredients for the cosmetic industry. In this context, the organised cultivation of medicinal and aromatic plants is becoming increasingly important for ensuring a sustainable supply of natural raw materials [7,10]. Such production systems support more efficient resource management and help reduce pressure on natural plant populations traditionally harvested from the wild. In addition, medicinal and aromatic plants are recognised as valuable resources for sustainable agriculture because their extracts and bioactive compounds can contribute to environmentally friendly agricultural practices [32], while also enabling integration of cosmetic product development with sustainable agricultural practices.

Modern agricultural approaches increasingly incorporate innovative technologies that support more efficient and sustainable production of medicinal plants. Precision agriculture enables monitoring and optimisation of cultivation conditions through tools such as remote sensing, geographic information systems, and sensor-based monitoring. These technologies improve the efficiency of water, fertiliser, and other input use while enhancing the yield and quality of plant biomass used as raw material in various industries, including the cosmetic sector [33]. In addition, advanced agricultural technologies may support the standardisation of plant material used for obtaining extracts and other bioactive components [34]. Consequently, technological innovations in agriculture play an important role in ensuring a stable and high-quality supply of plant raw materials for the cosmetic industry. Guidelines for Good Agricultural and Collection Practices (GACP) are also important, as they include quality control of planting material, proper soil management, optimisation of cultivation conditions, and standardisation of harvesting and processing procedures [35]. The implementation of these principles helps maintain consistent chemical composition and quality of plant materials used in the pharmaceutical and cosmetic industries.

The link between the agricultural production of medicinal and aromatic plants and the cosmetic industry creates new opportunities for the development of sustainable value chains based on natural resources. Organised cultivation of these plants can provide a stable supply of bioactive compounds used in cosmetic formulations, while also supporting rural development and the diversification of agricultural activities. The integration of medicinal and aromatic plants into modern farming systems may represent an important economic opportunity for producers, as these crops can contribute to higher farm incomes and the strengthening of local economies [36,37]. Sustainable cultivation of medicinal and aromatic plants therefore plays an important role in ensuring a reliable supply of natural raw materials for the cosmetic industry and supports the development of products based on the principles of sustainability and responsible use of natural resources.

## 5. Conclusions

Plant-derived bioactive compounds represent an important group of natural ingredients that play an increasingly significant role in the modern cosmetic industry. Medicinal and aromatic plants are a rich source of secondary metabolites, particularly phenolic compounds, terpenoids, alkaloids, and saponins, which exhibit antioxidant, anti-inflammatory, and antimicrobial activities. Due to these properties, plant extracts and their bioactive constituents are increasingly incorporated into cosmetic formulations intended to protect, maintain, and improve skin condition. At the same time, the growing demand for plant-based cosmetic ingredients highlights the importance of medicinal and aromatic plants as a sustainable source of raw materials and emphasises the need for their cultivation within environmentally responsible agricultural systems.

In addition to their importance in cosmetic formulations, medicinal and aromatic plants also represent a valuable resource for the development of sustainable agricultural systems. Their cultivation can ensure a stable and high-quality supply of plant raw materials for obtaining bioactive compounds

used in the cosmetic industry. Sustainable production of these plants, supported by modern agricultural technologies and the principles of Good Agricultural and Collection Practices, contributes to improving the quality and standardisation of plant material while promoting the responsible and efficient use of natural resources, agricultural inputs, and available environmental resources. In this context, closer integration between the production of medicinal and aromatic plants and the needs of the cosmetic industry may support the development of sustainable value chains and more efficient utilisation of plant resources in the manufacture of cosmetics based on natural ingredients.

**Conflicts of Interest:** The authors declares no conflict of interest.

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